The Refined Consensus Model of Pedagogical Content Knowledge as a Basis for Evaluating and Increasing Pre-Service Biology Teachers' Competence in the Field of Academic and Science Language

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Abstract

Every member of the society needs scientific literacy to be able to follow and participate in the current social discourse. Biology lessons aim to develop students' scientific literacy, and students' outcomes depend on their biology teachers' professional competence, especially their pedagogical content knowledge (PCK). Within this dissertation, teachers' PCK will be described on the basis of the Refined Consensus Model of PCK (RCM) which integrates several models of teachers' competence. It differentiates between three realms of PCK: collective PCK (cPCK), personal PCK (pPCK) and enacted PCK (ePCK), which occurs in action while a teacher plans (ePCK$_P$), teaches (ePCK$_T$) and reflects (ePCK$_R$) a lesson. These three components of ePCK are described as the Plan-Teach-Reflect Cycle of ePCK. For the transformation processes between the realms of PCK, two filters are assumed: teachers' professional values and motivational orientations, thus affective components of teachers' competence, as a filter moderating the transformation between cPCK and pPCK; and teachers' noticing and knowledge-based reasoning as a filter moderating the transformation between pPCK and ePCK. The effect of teachers' PCK on their students' outcomes is mediated by biology-specific lesson quality features such as cognitive activation or elaborate model use. Since it is impossible to learn any biological content without the required academic and biology-specific science language, biology teachers need PCK in the field of academic and biology-specific science language: this forms the basis they need to consider appropriate language use and scaffolding in order to realise biology-specific lesson quality features in biology instruction.

This dissertation aimed to (1) evaluate the RCM with regard to its proposed filters between the three realms of PCK and to the Plan-Teach-Reflect Cycle of ePCK, (2) include the language in biology instruction into existing models of teachers' competence, and (3) develop materials to assess biology lesson plans and biology instruction on the basis of the research findings.

To achieve those aims, three studies were conducted within the framework of a BMBF-funded nationwide initiative to improve teacher education in Germany (Qualitätsoffensive Lehrerbildung). All studies took place in obligatory seminars for pre-service teachers and followed a pre-/post-test design; different aspects of participants' professional competences were tested. Results showed that knowledge-based reasoning moderates the transformation between pPCK and ePCK and therefore, can be defined as a filter within the RCM. Motivational orientations, professional values and noticing were hypothesised as filters, too, but research findings did not support this assumption. Training the Plan-Teach-Reflect Cycle of ePCK as a whole or in parts enhances pre-service biology teachers' pPCK, motivational orientations and ePCK. Including the Teach-component to the cycle strengthens the effect in contrast to replacing the Teach-component by presentations of lesson plans. The same effects were hypothesised for professional values as well, but research findings did not support this assumption.

Therefore, pre-service teachers' knowledge-based reasoning could be identified as one filter between pPCK and ePCK. It is possible to assess and to foster some aspects of pre-service teachers' professional competence in the field of academic and science language, and to include the language in biology instruction into existing models of teachers' competence in order to enable the realisation of biology-specific lesson quality features. Deriving from the research findings, there are implications for future research as well as for science teacher education: it is recommended to detect further filters between the realms of PCK, and strategies to map and increase science teachers' professional values, and to investigate the impact of science teachers' PCK in the field of academic and science language on their students' outcomes. Since the research within this dissertation provides high ecological validity, the findings are recommended to be implemented into science teacher education programmes: to include an additional focus on language in science instruction, to train pre-service teachers' knowledge-based reasoning together with their PCK, and to include the Teach-component.

Zusammenfassung

Jedes Mitglied der Gesellschaft benötigt Scientific Literacy, um dem aktuellen gesellschaftlichen Diskurs folgen und daran teilhaben zu können. Ziel des Biologieunterrichts ist es, die Scientific Literacy der Schüler*innen zu entwickeln, und die Leistungen der Schüler*innen hängen von der Professionellen Kompetenz, insbesondere dem Fachdidaktischen Wissen (PCK) ihrer Lehrkräfte ab. In dieser Dissertation wird das PCK der Lehrkräfte auf Basis des Refined Consensus Model of PCK (RCM) beschrieben. Es unterscheidet zwischen drei PCK-Bereichen: collective PCK (cPCK), personal PCK (pPCK) und enacted PCK (ePCK), das nur auftritt, während eine Lehrkraft eine Unterrichtsstunde plant ($ePCK_P$), unterrichtet ($ePCK_T$) und reflektiert ($ePCK_R$). Diese drei Komponenten des ePCK werden als Plan-Teach-Reflect Cycle of ePCK beschrieben. Für den Transformationsprozess zwischen den PCK-Bereichen werden zwei Filter angenommen: die professionellen Werthaltungen und die motivationalen Orientierungen von Lehrkräften, also affektive Komponenten der Kompetenzen von Lehrkräften, als ein Filter, der die Transformation zwischen cPCK und pPCK moderiert; sowie das Noticing und Knowledge-Based Reasoning der Lehrkräfte als ein Filter, der die Transformation zwischen pPCK und ePCK moderiert. Der Effekt des PCK der Lehrkräfte auf die Lernergebnisse ihrer Schüler*innen wird durch biologiespezifische Unterrichtsqualitätsmerkmale wie Kognitive Aktivierung oder Einbettung Naturwissenschaftlichen Arbeitens mediiert. Da es unmöglich ist, jeglichen biologischen Inhalt ohne die dafür notwendigen bildungs- und fachsprachlichen Kenntnisse zu erlernen, benötigen Biologielehrkräfte PCK im Bereich Bildungs- und Fachsprache: dieses bildet die erforderliche Basis um biologiespezifische Unterrichtsqualitätsmerkmale im Biologieunterricht umzusetzen.

Ziel dieser Dissertation war es, (1) das RCM im Hinblick auf die vorgeschlagenen Filter und den Plan-Teach-Reflect Cycle of ePCK zu evaluieren, (2) in bestehende Modelle zu Kompetenzen von Lehrkräften die Sprache im Biologieunterricht zu integrieren, und (3) Materialien zur Bewertung von Artikulationsschemata und Biologieunterricht auf der Basis der Forschungsergebnisse zu entwickeln.

Um diese Ziele zu erreichen, wurden drei Studien im Rahmen einer vom BMBF geförderten bundesweiten Initiative zur Verbesserung der Lehrkräfteausbildung in Deutschland (Qualitätsoffensive Lehrerbildung) durchgeführt. Alle Studien fanden in Pflichtseminaren für Biologielehramtsstudierenden statt und folgten einem Prä-/Posttest-Design; getestet wurden verschiedene Aspekte der professionellen Kompetenz der Teilnehmenden. Die Ergebnisse zeigten, dass Knowledge-Based Reasoning die Transformation zwischen pPCK und ePCK moderiert und daher als Filter innerhalb des RCM definiert werden kann. Motivationale Orientierungen, Professionelle Werthaltungen und Noticing wurden ebenfalls als Filter angenommen, aber die Forschungsergebnisse haben diese Annahme nicht bestätigt. Ein Training des Plan-Teach-Reflect Cycle of ePCK als Ganzes oder in Teilen verbessert das pPCK, die Motivationalen Orientierungen und das ePCK von Biologielehramtsstudierenden. Der Einbezug der Teach-Komponente in den Zyklus verstärkt den Effekt im Gegensatz zum Ersetzen der Teach-Komponente durch Präsentationen von Artikulationsschemata. Die gleichen Effekte wurden

auch für die professionellen Werthaltungen angenommen, aber die Forschungsergebnisse haben diese Annahme nicht bestätigt.

Damit konnte das Knowledge-Based Reasoning von Lehramtsstudierenden als ein Filter zwischen pPCK und ePCK identifiziert werden. Es ist möglich, einige Aspekte der professionellen Kompetenz von Biologielehramtsstudierenden im Bereich Bildungs- und Fachsprache zu bewerten und zu fördern, und die Sprache im Biologieunterricht in bestehende Modelle der Kompetenz von Lehrkräften zu integrieren. Aus den Forschungsergebnissen ergeben sich Implikationen für die zukünftige Forschung sowie für die Ausbildung von Lehrkräften naturwissenschaftlicher Fächer: Es wird empfohlen, weitere Filter zwischen den PCK-Bereichen, sowie Strategien zur Abbildung und Steigerung der professionellen Werthaltungen von Lehrkräften zu ermitteln und die Auswirkungen des PCK der Lehrkräfte im Bereich Bildungs- und Fachsprache auf die Lernergebnisse ihrer Schüler*innen zu untersuchen. Da die Forschung im Rahmen dieser Dissertation eine hohe ökologische Validität aufweist, wird empfohlen, die Ergebnisse in die Lehramtsausbildung für naturwissenschaftliche Fächer zu implementieren: einen Fokus auf Sprache im naturwissenschaftlichen Unterricht zu legen, das Knowledge-Based Reasoning von Lehramtsstudierenden zusammen mit ihrem PCK zu trainieren und die Teach-Komponente einzubeziehen.

"Die Grenzen meiner Sprache bedeuten die Grenzen meiner Welt."

Wittgenstein (1921, p. 246)

Content

1. Introduction

For the last two years, there was no topic more present in the media than the Covid-19 pandemic. Every single day, we were confronted with technical terms like Sars-CoV-2, mRNA, vector vaccine, spike protein, reproduction number, aerosol. We were supposed to be able to interpret diagrams showing infection numbers, incidence values, hospital admissions, deaths related to Covid-19. We had to decide not only whether to get vaccinated or not, but about the type of vaccine, too. We underwent and undergo varying recommendations and legal regulations, depending on the latest research findings. If one does not have the required biological knowledge and deep understanding of how scientific research works, one will not be able to follow the current social discourse, and one will not be able to make informed decisions for oneself and one's family. In other words: each member of society absolutely needs scientific literacy.

In the framework of the PISA studies, scientific literacy is defined as "the ability to engage with science-related issues, and with the ideas of science, as a reflective citizen" (OECD, 2019a, p. 100). The PISA studies measure students' competences to explain phenomena scientifically, to evaluate and design scientific enquiry, and to interpret data and evidence scientifically (OECD, 2019a, p. 99), and they define appropriate competence levels.

Scientific literacy is the highest aim of biology education at school (Kattmann, 2016; Nitz, 2016), and should be a part of general education (Eilks et al., 2004). Bybee (1997) demanded scientific literacy not to be a nice slogan, but to be a serious and important aim of science education. Therefore, he defined four competence levels: From recognising scientific terms, using scientific terms, understanding scientific concepts to a deep understanding of science in its historical and social context, the highest multidimensional level (Bybee, 1997, 2002). With a precise description of competence levels, standards for science education aiming scientific literacy have been (further) developed (e.g., Bybee, 1997; KMK, 2005a, 2020a; National Research Council, 1996). The PISA studies uncovered that German students' performance in science is not the best (OECD, 2003, p. 109), and worse, currently follows an increasingly negative trend (OECD, 2019b, p. 134), whereby especially the number of low achieving students increases (Reiss et al., 2019).

Germany implemented National Standards for science education (KMK, 2005a, 2005b, 2005c, 2020a, 2020b, 2020c) as well as curricula taking up these standards (e.g., ISB, 2021). Nevertheless, German students' scientific literacy is not sufficient. Gogolin (2013) assumes that students do not have the necessary science language proficiency, which fits the recommendation of Holbrook and Rannikmae (2009) to recognise that interaction skills and communication are needed to improve scientific literacy. Where is the connection? Let us take a look at the "literacy" in scientific literacy: it is implicated that one has to be able to read, understand and write scientific texts since our culture is based on written language (Norris & Phillips, 2003; Rost et al., 2004, p. 25). Furthermore, nearly every member of society is expected to be literate (Bybee, 1997), thus not only to be able to communicate face to face, but also to have the so-called functional literacy which enables people to participate in social and political discourse (Castell et al., 1986; Gräber & Nentwig, 2002; Nitz, 2016). This enlightens the fact that language is essential for learning and teaching in every single subject (Becker-Mrotzek et al., 2013; Osborne, 2002; Prediger, 2017).

The challenges of the Covid-19 pandemic revealed and underlined the importance of biology education as a part of scientific education in particular: the structure of a virus, its way of reproduction, its transmission paths, the function of the human immune system, the process of a polymerase chain reaction, the mechanism of a mRNA-vaccine in comparison to an inactivated vaccine – these are biological topics in particular, which require profound biological knowledge. Thus, especially the contribution of biology education to scientific literacy is demanded. It has never been more important to provide solid scientific literacy, thus the ability to join public science debate (Eilks et al., 2004; KMK, 2005a; Sharon & Baram-Tsabari, 2020; Trefil & Hazen, 1995), which is aim, purpose and challenge of education, biology education in particular.

Science education researchers agree that science teachers' professional competence is the decisive factor for good science lessons and high-achieving students (Baumert & Kunter, 2006, 2011; Blömeke et al., 2015; Carlson & Daehler, 2019; Hattie, 2012; Helmke, 2009; Shulman, 1986), since good biology lessons are characterised by biology-specific lesson quality features which depend on teachers' professional competence (Förtsch et al., 2016; Förtsch et al., 2018; Schmelzing et al., 2008; Wüsten et al., 2008, 2010). Therefore, this dissertation will give a brief overview over teachers' professional competence, lesson quality features in biology instruction, the language which is necessary to implement them in class, and the professional competence in the field of academic and biology-specific science language biology teachers need to enable their students to join public science discourse. Empirically tested solution approaches for biology teacher education will be provided, followed by a discussion of their benefits and limitations, which will lead to implications for further research and for science teacher education.

1.1. A Model of Teachers' Competence: The Refined Consensus Model of Pedagogical Content Knowledge (RCM)

Teaching is a very complex and challenging process. Myriads of science education researchers try to identify and map the classroom processes decisive for students' performance in science, especially science teachers' competences required for these processes. Shulman (1986) defined two subject-specific knowledge bases science teachers need: *content knowledge (CK)*, the profound knowledge of a biology teacher understanding biological facts and concepts as well as the reasons why facts and concepts are how they are, and *pedagogical content knowledge (PCK)*, a particular form of CK comprising the knowledge of students' (pre-)conceptions and how to deal with them, as well as of useful forms of representation to make content comprehensible for learners. Current research in science education's focus is especially on teachers' PCK as it is considered to be most relevant for teaching, and therefore, for students' educational success (Alonzo et al., 2019; Alonzo & Kim, 2016; Carlson & Daehler, 2019). Teachers' PCK predicts students' performance: the higher teachers' PCK, the more cognitively activating are their lessons, the higher is their students' performance (Baumert et al., 2010; Förtsch et al., 2016; Krauss et al., 2008). Video studies provided evidence of the assumed effect of teachers' PCK on students' outcomes, mediated by cognitive activation (Förtsch et al., 2017), elaborate model use (Förtsch et al., 2018), and dealing with students' errors (Kotzebue et al., 2021).

Currently, the *Refined Consensus Model of PCK* (RCM; Carlson & Daehler, 2019) is very much discussed among the science education community around the world, since it is an approach to bring together several models of teachers' competence. Since research results indicate teacher's PCK to be the decisive factor for high lesson quality and students' high performance (Förtsch et al., 2016; Förtsch et al., 2018), Carlson and Daehler (2019) concentrate explicitly on PCK following Shulman's (1986) definition, and try to describe its nature more precisely. Thereby, they take up the idea of Blömeke et al. (2015) in some ways, who describe teachers' competence as a continuum, after having determined that the dichotomy assumed until then between teachers' dispositions, therefore cognitive and affective-motivational factors, on the one hand, and their visible performance in class on the other hand was unsatisfactory, as it does not explain in which way the two are related to each other. That is why they suggest them to be connected via so called situation-specific skills, which include the perception and interpretation of relevant incidents in class and the following decision making, which creates a fluent transition, thus a continuum between dispositions over situation-specific skills and performance. The named continuum is multi-dimensional: horizontally, it describes the process teachers undergo activating their cognition and volition-affect-motivation, integrating them to situation-specific skills, and appearing in visible behaviour. The vertical dimension of the continuum describes different performance levels and developmental stages of a teacher's competence: for example, a pre-service teacher's dispositions, situation-specific skills and performance, thus those of a novice in teaching, will be usually located on a lower level than those of an expert teacher (Blömeke et al., 2015). Carlson and Daehler (2019) present their visualisation of three realms of PCK influencing each other in form of three concentric circles (Figure 1).

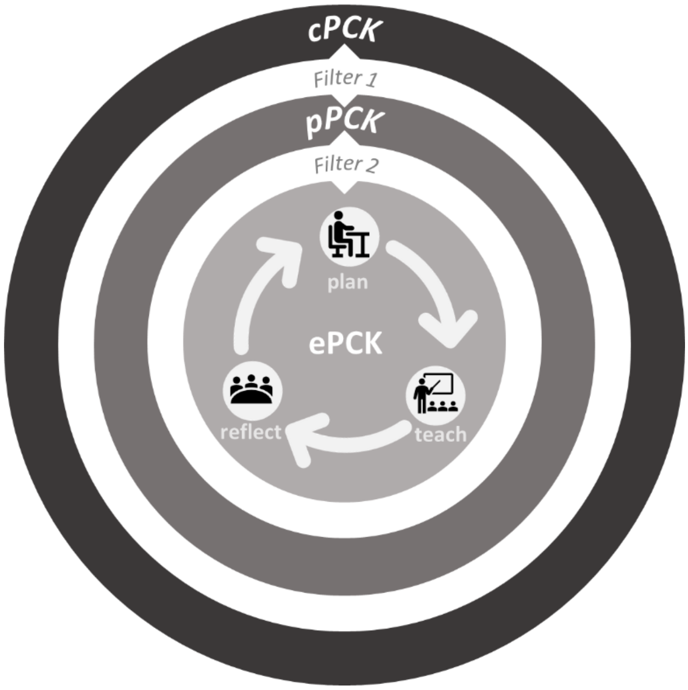

Figure 1. The Refined Consensus Model of PCK (Alonzo et al., 2019; Carlson & Daehler, 2019), supplemented by two assumed filters (white circles).

Collective PCK (cPCK) is represented by the outer circle, and relates to the realm of PCK which is commonly known and shared among the science education community, and published for example in journals or books (Carlson & Daehler, 2019). Carlson and Daehler (2019) describe cPCK as a horizontal continuum between discipline-specific PCK, topic-specific PCK, and concept-specific PCK, thus from broader to narrower ideas, and a vertical continuum from basic to expert level. This continuum does not only apply to cPCK, but also to the other realms of PCK.

Teachers' *personal PCK (pPCK)* describes the PCK each teacher has constructed on their own, based on consulted literature, exchange with colleagues, teacher training sessions, and their own teaching experiences, and is represented by the middle circle (Carlson & Daehler, 2019). When teachers document and share their teaching experiences, they contribute to cPCK.

Carlson and Daehler (2019) assume the so-called learning context to be a *filter* in the transformation process between cPCK and ePCK: this means for example individual characteristics of the students or the national educational policy, which influence learning processes. Furthermore, they suggest teachers' attitudes and beliefs to play a decisive role in the transformation process between cPCK and pPCK. Thereby, they take up Blömeke et al.'s (2015) affect-motivation, respectively Baumert and Kunter's (2011) professional values and motivational orientations: teachers' *professional values* address moral aspects such as care for students, fairness and integrity (Flynn & Bruce, 2019; Oser, 1996) more strongly. It is assumed that these professional values influence teachers' professional performance, but it has not yet been clarified in which way they do that (Baumert & Kunter, 2006; Palermo & Thomson, 2019). Other authors assume that a person’s values can be changed by external influences (Bardi & Goodwin, 2011; Gollan, 2012; Ryndak & Saldaeva, 2019). Teachers’ *motivational orientations* are characterised by their ability beliefs and their enthusiasm for their profession and their teaching subject (Baumert & Kunter, 2011; Kunter et al., 2008; Kunter, 2011). They determine inter alia the intensity, quality and duration of teachers’ behaviour (Han & Yin, 2016; Kunter, 2011; Mitchell, 1997). Teachers with strong ability beliefs are considered to be more resilient in their professional life, and to use more effective and innovative methods within their lessons (Brouwers & Tomic, 2000; Kunter, 2011). Teachers’ enthusiasm, their enthusiasm for their profession and the subject they teach, is considered to be an important characteristic of effective teaching (Helmke, 2003, 2009; Woolfolk Hoy et al., 2006). It is assumed that motivational orientations are not stable personality traits, but vary depending on for example the learning group or the professional context (Kunter, 2011; Ryan & Deci, 2000).

The inner circle of the RCM describes the PCK a teacher generates during the teaching situation which is called *enacted PCK* (*ePCK*; Alonzo et al., 2019; Carlson & Daehler, 2019). Since it is assumed to occur in action only, it is unique and not repeatable, and therefore difficult to catch. That is why Alonzo et al. (2019) differentiate between the three steps of teaching to describe the nature of ePCK: in the first step, teachers **plan** the lesson, whereby they generate $ePCK_P$. In the second step, they **teach** the lesson, generating $ePCK_T$. After the lesson, teachers **reflect** the lesson, and generate $ePCK_R$. The reflection feeds into the next planning situation, and the *Plan-Teach-Reflect Cycle of ePCK* is completed (Alonzo et al., 2019). To generate ePCK, teachers use their pPCK to choose appropriate teaching strategies. The other way round, each teaching experience contributes to their pPCK (Carlson & Daehler, 2019). Thereby, Alonzo et al. (2019) differentiate between a macro cycle of ePCK as described above, and a micro cycle which occurs within the teaching situation when teachers need their situation-specific skills to make decisions within seconds (Blömeke et al., 2015).

For the transformation process between teacher’s pPCK and ePCK, Carlson and Daehler (2019) suggest a further *filter*, the pedagogical reasoning, which can also be described as Blömeke et al.'s (2015) situation-specific skills, or the model of professional vision (Meschede et al., 2017; Seidel & Stürmer, 2014; Sherin, 2001, 2007; Stürmer & Seidel, 2015; van Es & Sherin, 2002), which is characterised by the skills noticing and knowledge-based reasoning (Sherin, 2007): teaching situations are extremely complex, innumerable things happen to occur during a lesson. That is why a teacher has to be able to assess each incident within seconds, and to act in an appropriate way. Being able to direct one’s attention to situations in class relevant for teaching and learning only is called *noticing* (Seidel & Stürmer, 2014; Stürmer & Seidel, 2015). After having noticed a relevant incident, it has to be rated: teachers need to use their professional knowledge to reason about the incident (Borko, 2004; Seidel & Stürmer, 2014). The so-called *knowledge-based reasoning* is usually classified to three distinct but highly interrelated aspects: description, explanation and prediction (Seidel & Stürmer, 2014; van Es & Sherin, 2002). The first step to reason about a classroom event is *description*, thus to present the event precisely without grading it. Next, the described situation has to be related to teacher's professional knowledge to give an *explanation*, in which way the event is important for students' learning, and to make a *prediction* how it may influence students' behaviour in class (Seidel & Stürmer, 2014). Decision-making in the sense of the ability to propose *alternative instructional strategies* in class can be described as further aspect of knowledge-based reasoning (Blömeke et al., 2015; Santagata & Yeh, 2016).

1.2. Lesson Quality Features in Biology Instruction

Students attend biology lessons to be able to participate in social discourse regarding scientific subjects (e.g., ISB, 2021), in other words: biology instruction aims to foster students' scientific literacy (Kattmann, 2016; Sadler & Zeidler, 2009). Good biology lessons that produce high-achieving students are characterised by general and biology-specific lesson quality features (Wüsten et al., 2008; Wüsten, 2010). Video studies explored several biology-specific lesson quality features which depend on teachers' PCK, such as cognitive activation, elaborate model use, embedding of scientific work, and dealing with students' preconceptions (Förtsch et al., 2016; Förtsch et al., 2017; Klieme et al., 2006; Kotzebue et al., 2021; Lipowsky et al., 2009; Neuhaus, 2007, 2021; Wüsten, 2010; Wüsten et al., 2010; Figure 2).

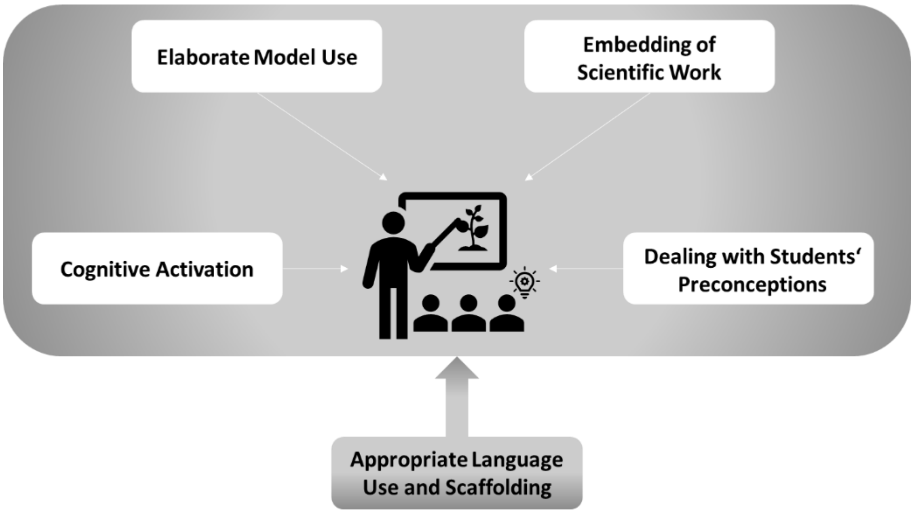

Figure 2. Biology-specific lesson quality features (Behling et al., 2022; Förtsch et al., 2016; Förtsch et al., 2017; Kotzebue et al., 2021; Neuhaus, 2007; Wüsten, 2010).

Since learning is an active process, students have to be cognitively engaged to construct and integrate knowledge (Chi & Wylie, 2014). Teachers should foster their students' mental activity, thus provide *cognitive activation* during the lesson (Fauth & Leuders, 2018; Förtsch et al., 2017; Kunter et al., 2007). This can be achieved by working out competence-oriented learning objectives for the lesson (Bloom et al., 1972; Weitzel, 2018), by creating an interesting introduction to the lesson content (Krapp, 1998), which relates to students' everyday life, activates their previous knowledge (Förtsch et al., 2016), contains a cognitive conflict (Dorfner et al., 2019; Nachreiner et al., 2015), and leads to a focus question (Nawani et al., 2018). To be able to answer the focus question at the end of the lesson, challenging and complex tasks should be used (Dorfner et al., 2019; Nachreiner et al., 2015), as well as conceptual instruction (Förtsch et al., 2017; Lipowsky et al., 2009). Cognitive activation was identified one of the most important impact factors on students' performance (Förtsch et al., 2017; Klieme et al., 2006; Lipowsky et al., 2009).

The nature of science (NOS) is an important part of scientific literacy (Bybee, 1997), whereby students should gain insights into the development of scientific theories (Zoller,

2001) and scientific work (Tytler, 2001). Holbrook and Rannikmae (2007) suggest to do education through science instead of teaching science through education to enable students to get a deeper understanding of NOS: biology lessons can follow the research cycle or the historical path of scientific perceptions, they can relate to examples from students' everyday life, take up current issues from scientific research and social discourse, or encourage students to discuss ethical aspects of scientific issues. To work on the lesson content as close to science as possible, research questions can be answered by *embedding of scientific work*: students need to generate hypotheses, to plan and conduct an inquiry, to analyse and interpret the resulting data, and to verify or falsify the hypotheses (Mayer, 2007, 2016). Scientific models are often used in biology lessons, but mostly in order to illustrate learning content instead of using them in the sense of scientific inquiry (Upmeier zu Belzen & Krüger, 2010). Therefore, science teachers are recommended to focus on and to train students' model competence (Upmeier zu Belzen & Krüger, 2019). Research findings indicate that teachers' *elaborate model use* in biology lessons affects students' outcomes in a positive way (Förtsch et al., 2018). The German National Standards in Biology demand students to be able to do scientific work as well as to use and construct scientific models in a well-founded way (KMK, 2005a, 2020a).

Students never attend biology lessons without any associations about the lesson content, which are called *students' preconceptions* (Krüger, 2007). Those preconceptions are often tried and tested in students' everyday life: if teachers do not deal with them in an appropriate way, students do not integrate the new scientific conceptions taught in the lesson into their knowledge, but stick to the old idea (Duit, 1999). One approach to deal with students' preconceptions is the conceptual change-theory, which postulates that it is necessary to provoke a dissatisfaction with existing conceptions before it is possible to introduce a new conception which needs to be intelligible, plausible and fruitful (Strike & Posner, 1982, 1992). Students' errors becoming visible during a lesson provide indications about their preconceptions as well, whereby research findings indicate that teachers' effective dealing with students' errors has a positive effect on their achievement in biology (Kotzebue et al., 2021).

To realise the named lesson quality features in biology instruction, teachers and students need to use language: to communicate, and to construct knowledge as well (Maier & Schweiger, 1999; Prediger, 2013, 2017). The term "scientific literacy" used in the PISA studies (OECD, 2003, 2019a) makes clear that one needs to have an appropriate language proficiency to solve scientific tasks (Nitz, 2016; Norris & Phillips, 2003), in opposition to the German term "Naturwissenschaftliche Grundbildung" [scientific basic education] (Gogolin, 2013), from which this aspect does not emerge. Therefore, biology teachers need to consider *appropriate language use and scaffolding* to realise biology-specific lesson quality features, which will be described in the following chapter.

1.3. Required PCK in the Field of Language to Realise Lesson Quality Features in Biology Instruction

Learning any lesson content without language is impossible (Schmölzer-Eibinger, 2013; Wellington & Osborne, 2001), and requires academic and science language proficiency (Childs et al., 2015; Gogolin, 2013; Prediger et al., 2015). Since teachers' PCK influences students' performance in science indirectly (Baumert et al., 2010; Förtsch et al., 2016; Krauss et al., 2008), it seems to be obvious that science teachers need *PCK in the field of academic and science language* which forms the knowledge base for *appropriate language use and scaffolding* in biology instruction. Following Shulman's (1986) definition of teachers' PCK, Markic (2018) defined the PCK a science teacher needs to teach language-sensitive science lessons as the "knowledge of scientific language related to teaching and learning [science]" (Markic, 2018, p. 181).

On the basis of a literature review, Mönch and Markic (2022) describe the current *cPCK in the field of academic and science language*: teachers as well as students are role models regarding science language; conceptual understanding has to be developed before the related language; academic and science language have to be made explicit; teachers need to implement discursive classrooms; various resources and representations should be provided as well as appropriate scaffolds; teachers should make clear their expectations regarding academic and science language use.

What is this "academic and science language"? The use of language is highly related to the context in which it is used: depending on the context, language is characterised by specific style, vocabulary and grammar, which is called *language registers* (Halliday, 1975, 1978). Riebling (2013a) indicates three language registers to be relevant for education at school: the everyday register, the academic register and the science register (Figure 3).

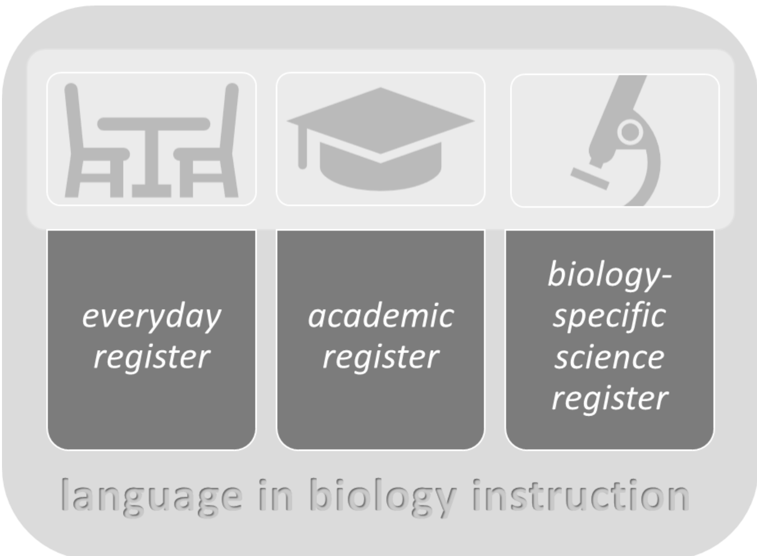

Figure 3. Language registers relevant for biology instruction (based on Halliday, 1975; Prediger, 2017; Riebling, 2013a).

The *everyday register* is characterised by a person's everyday life, thus communication situations within the family, with friends or neighbours, when shopping or at sports. Usually, the communicating persons are physically present and talk about concrete objects or situations, they use mimics and gestures, and do not have to be especially precise in their language (Gogolin, 2011).

The *academic register* is relevant for expressing and understanding complex issues (Gantefort, 2013), for example schoolbooks' texts or tasks to work out biological content. It requires the use of grammatical structures such as passive constructions or conditional clauses (Riebling, 2013a). The findings of Prediger and Wessel (2018) indicate that linguistic scaffolding in mathematics increases each students' performance, no matter if they are mono- or multilingual, linguistically strong or weak. This is a very thrilling finding, since terms like scaffolding, supporting, fostering are often associated with low-performing learners only.

The *science register* serves to generate and share subject-specific knowledge among a specific community (Nitz, 2016; Riebling, 2013a). Biology-specific science language is characterised by biology-specific technical terms such as "photosynthesis" or "semipermeable", and representations such as models, diagrams or schemes; whereby these representations are rarely used to support biology-specific language development (Nitz et al., 2012). German biology teachers tend to use a lot of technical terms in their lessons, and to use different synonyms in addition (Dorfner et al., 2020), such as "Citrate Cycle/Citric Acid Cycle/Krebs Cycle". An investigation of German biology textbooks explored the same findings (Graf & Berck, 1993). Using synonyms for the same abstract content makes the learning process even more difficult. In addition, many biology-specific technical terms also occur in everyday language, but have a different meaning there (Drumm, 2016; Wellington & Osborne, 2001, p. 41; Figure 4).

term/phrase	meaning in everyday register	meaning in biology-specific science register
delivery	distribution of goods	childbirth
(to) experiment	(to) test something	method of scientific inquiry
anvil	a blacksmith's tool	part of the ossicles
division	one piece is divided into two halves	one cell divides into two (whole) cells
niche	a small space	habitat adaption

Figure 4. Examples of terms with different meanings in everyday and biology-specific science register.

Linguistically strong students stand these differences since they are able to switch language registers, but linguistically weak students struggle with this challenge (Busch & Ralle, 2013; Drumm, 2016). Biological content knowledge and biology-specific science language are mutually dependent (Busch & Ralle, 2013), they go hand in hand – so those who are excluded from biology-specific science language will be handicapped in their content learning, too. This is also supported by the fact that students struggle with the challenge to learn new content at the same time as the related science language (Rincke, 2007, 2010), and that they struggle with tasks containing technical terms (Schmiemann, 2011). Furthermore, the linguistic requirements of the subject are neither named nor perceived as such (Schmölzer-Eibinger, 2013; Schmölzer-Eibinger & Egger, 2012; Tajmel, 2011; Vollmer & Thürmann, 2010). The German National Standards in Biology define four realms of competence students should have acquired after ten years at school: biological content knowledge, scientific inquiry, communication of biological issues, and assessment of biological issues (KMK, 2005a). If we take a closer look at the required skills related to the respective competence, we will detect a good deal of linguistic skills, which are not assigned to the realm communication competence, but to the three other ones (Figure 5).

Realm of competence	Selection of required skills
Biological content knowledge	– Describe and explain the interactions between organisms – Compare structures and functions of bacterial, plant and animal cells – Elucidate the importance of cell division for growth, reproduction and multiplication
Scientific inquiry	– Describe and compare the anatomy and morphology of organisms – Identify frequently occurring species with the help of suitable literature – Discuss the scope and limitations of research design, steps and results – Explain dynamic processes in ecosystems with the help of suitable models
Assessment of biological issues	– Discuss options for action for environment- and nature-compatible participation in the sense of sustainability – Describe and evaluate findings and methodes in selected current topics such as medicine, biotechnology and genetic engeneering, taking into account negotiable values

Figure 5. Selected required skills related to three realms of competence except "communication" of the German National Standards in Biology (KMK, 2005a, pp. 13–15).

What do the underlined operators shown in Figure 5 mean? Let us take the operator "describe" as an example: students are requested to formulate observations, structures, facts, methods, procedures or interrelationships in a structured way by using biology-specific science language (IQB, 2020). If the task is to observe a ladybird feeding, and to describe its mouthparts, the student would have to produce something like this: "The ladybird moves to the greenfly, and captures it with its forefeet. The biting-chewing mouthparts are used to consume the prey […]." This example shows that not only the technical terms are essential, but also common vocabulary to connect technical terms (Mammino, 2010), in this case "to move" instead of "to go", "to capture" instead of "to take", "to consume" instead of "to eat". This kind of vocabulary can be assigned to the academic register, as well as the passive construction ("are used"). Science teachers are often aware of science-specific technical terms and carefully introduce them, but they are not aware of the academic language requirements of scientific texts and representations (Snow, 2010).

Tajmel (2011, 2013b) recommends science teachers to draft linguistic learning objectives in addition to cognitive learning objectives within the lesson planning process, which would take into account the request of language in class to be learning requirement as well as learning medium and learning subject (Prediger, 2013). Scientific texts in particular should be used as learning opportunities to develop academic language proficiency by concrete example

(Drumm, 2013), and at the same time with the biological content; the learning content should be illustrated for example by using images or models (Beese et al., 2015; Tajmel & Hägi-Mead, 2017). Doing scientific work in class can influence language development, since students are challenged to read and understand instructions, to generate hypotheses, do discuss observations and to write protocols (Busch & Ralle, 2013).

Following the RCM (Carlson & Daehler, 2019), teachers would construct *pPCK in the field of academic and science language* by for example reading publications such as the one of Mönch and Markic (2022), or joining related teacher training sessions. Research findings indicate that science teachers' pPCK in this field is quite low (Markic, 2018).

Teachers' attitudes and beliefs are assumed to be filters between the transformation process between cPCK and pPCK (Carlson & Daehler, 2019), which are also known as professional values and motivational orientations (Baumert & Kunter, 2011). In the light of language in biology instruction, teachers' *professional values regarding multilingualism and responsibility for students' language development* are considered to be the first decisive factor: (science) teachers tend to dislike multilingualism in their classrooms although it is social reality (Dirim & Khakpour, 2018; Dirim & Springsits, 2022; Mecheril & Quehl, 2006), and they do not feel responsible for language education (Markic, 2014; Mönch & Markic, 2022), although learning science is indispensable without language proficiency (Childs et al., 2015; Osborne, 2002), and teachers are demanded to support students' language proficiency (Moore, 2007; Phillips Galloway et al., 2020; Schleppegrell, 2012). Teachers' *motivational orientations to implement language-sensitive biology instruction* are considered to be the second decisive factor, since teachers' enthusiasm and beliefs influence their professional performance, persistence, effort and achievement choices (Baumert & Kunter, 2011; Lazarides et al., 2018; Wigfield & Eccles, 2000).

Teachers express their *ePCK in the field of academic and science language* when they plan, teach and reflect lessons, on the basis of their pPCK (Alonzo et al., 2019; Carlson & Daehler, 2019). At this point, biology teachers realise biology-specific lesson quality features, therefore, at this point, they need to consider *appropriate language use and scaffolding* in biology instruction: in the planning process, they would for example define linguistic learning objectives (Tajmel, 2011), and think about linguistic tools, thus vocabulary and grammatical structures required for the learning content (Brandt & Gogolin, 2016; Tajmel et al., 2009; Tajmel & Hägi-Mead, 2017), and about scaffolding strategies, thus possibilities to enable equal opportunities for each student (Beese et al., 2015; Kniffka, 2010; Tajmel & Hägi-Mead, 2017). During the teaching situation, the teachers would for example provide many opportunities to speak and write within a safe and respectful atmosphere (Tajmel & Hägi-Mead, 2017). Within the reflection after the lesson, the teachers would think about situations in which the students struggled, or mastered linguistic demanding tasks well. These considerations during the reflection process would feed into the next lesson planning process.

Teachers' pedagogical reasoning is assumed to work as a filter between the transformation process between pPCK and ePCK (Carlson & Daehler, 2019), which is also known as noticing and knowledge-based reasoning (Seidel & Stürmer, 2014). In the light of language in biology instruction, teachers' *noticing of* and *knowledge-based reasoning about relevant events regarding students' language proficiency* are assumed to be filters in this process: science teachers need to notice wrong expressions of their students and to decide whether they should be corrected in the current situation or not (Tajmel & Hägi-Mead, 2017). They need to notice difficulties in understanding and to decide about appropriate scaffolding strategies (Kniffka, 2013), for example they could explain the phenomenon in other words, or use a (further) figure.

1.4. Biology Teacher Education in Germany and the Project "Uniklasse"

Future biology teachers in Germany who aim to teach at secondary schools undergo a structured teacher education programme at university, followed by an 18- to 24-months traineeship (KMK, 2004). Depending on the respective federal province and the school type, pre-service biology teachers have to choose at least one subject in addition to biology, which will be usually chemistry in the federal province of Bavaria. During their studies, pre-service biology teachers acquire content knowledge, pedagogical content knowledge and pedagogical knowledge. To be allowed to teach students up to A-Levels (academic track teachers), 270 ECTS credits have to be acquired (one ECTS credit is equivalent to 25-30 working hours). Of these, at least eight ECTS only have to be acquired in biology education, so there are minimum 200-240 working hours on PCK in biology (e.g., LPO I, 2008/13.03.2008). In this time available, the pre-service biology teachers need to learn to plan biology lessons on the basis of didactic theories, to teach and to reflect biology lessons, to include reasonably digital media in their lessons, to be able to motivate, support and engage their students, to do practical scientific work with students, as well as to diagnose and assess students' performance in biology class (e.g., KMK, 2004; LPO I, 2008/13.03.2008).

A biology teacher's unique selling point in comparison to other subject teachers on the one hand, and to biologists on the other hand, is their biology-specific PCK which makes them experts in teaching and learning biology (Gropengießer, 2016a; Jüttner & Neuhaus, 2013). Since teacher's professional knowledge as a part of their professional competence is prerequisite for successful biology lessons (Förtsch et al., 2016; Förtsch et al., 2018; Kotzebue & Neuhaus, 2016), teacher education programmes aim to impart cPCK (Gess-Newsome et al., 2019). To enable pre-service teachers to do the step from theory to teaching practise, they need to be accompanied by experienced instructors giving elaborated feedback, and relating to the pre-service teacher's theoretical knowledge (OECD, 2018, 48f).

Due to the funding of the German Federal Ministry of Education and Research [Bundesministerium für Bildung und Forschung – BMBF; grant numbers 01JA1510, 01JA1810] in the framework of a nationwide initiative to improve teacher education [Qualitätsoffensive Lehrerbildung (BMBF, 2022)], a so-called "Uniklasse" was implemented at a partner school: the partner school is a secondary school in Munich with approximately 900 students, most of them with another first language than German. At this school, a biology classroom was supplemented with six permanently installed cameras and microphones. A neighboured observation room was equipped with a recording unit, which is connected to the cameras and microphones. This "Uniklasse" combines the benefits of real teaching experience chaperoned by university (Santagata & Yeh, 2014; Stürmer, Seidel, & Schäfer, 2013) and the use of video clubs (Santagata & Guarino, 2011; Stürmer & Seidel, 2015), and is used to train the *Plan-Teach-Reflect Cycle of ePCK* (Alonzo et al., 2019) to the pre-service biology teachers: at home, the pre-service teachers plan biology lessons on the basis of the PCK imparted within biology education seminars, and generate $ePCK_P$. At school, they teach the lessons to a school class in the biology classroom, and generate $ePCK_T$. In the meanwhile, the lecturer and the fellow pre-service teachers are seated in the neighboured observation room and observe the lesson, which is live-broadcast to a big screen. Afterwards, the lesson is reflected during a lecturer-guided joint reflection, and the pre-service teachers generate ePCK$_R$. Since the lessons are recorded in addition, it is possible to re-watch selected situations, and to enable each pre-service teacher to watch their own lessons (Figure 6).

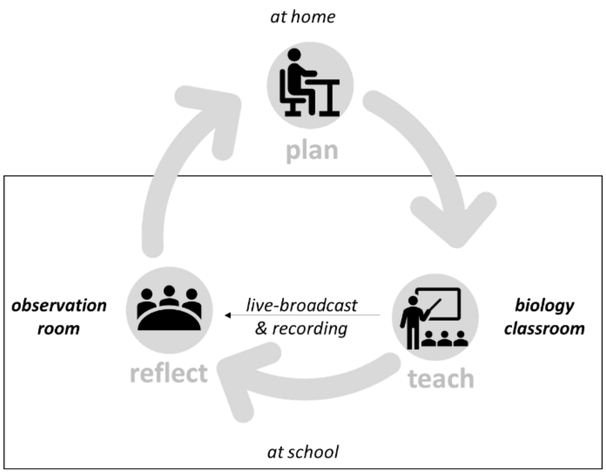

Figure 6. The "Uniklasse" used to train the *Plan-Teach-Reflect Cycle of ePCK* (Alonzo et al., 2019).

2. Research Gap, Aims and Research Questions

2.1. Research Gap

The PISA studies uncovered that German students' performance in science was below OECD average (OECD, 2003, p. 109), and that there is an increasingly negative trend since 2006 (OECD, 2019b, p. 134), accompanied by an increase of low achieving students (Reiss et al., 2019). Thereby, research findings indicate that students struggle with linguistic requirements of the learning content in science instruction (Busch & Ralle, 2013; Rincke, 2007, 2010; Schmiemann, 2011).

Several studies indicate that teachers' professional knowledge, especially their PCK is prerequisite for students' learning success (Baumert et al., 2010; Förtsch et al., 2016; Förtsch et al., 2018; Krauss et al., 2008), and that teachers' motivational orientations and values influence their lessons (Kunter, 2011; Palermo & Thomson, 2019). It is possible to measure teachers' PCK in the field of academic and science language, while research findings indicate that it is very low (Markic, 2018), and that it is influenced by teachers' awareness of the importance of language in science education (Mönch & Markic, 2022).

Good biology lessons are characterised by general and especially biology-specific lesson quality features (Wüsten et al., 2008; Wüsten, 2010), which depend on teachers' PCK: the effect of biology teachers' PCK on students' outcomes is mediated by the lesson quality features cognitive activation (Förtsch et al., 2017), elaborate model use (Förtsch et al., 2018), and dealing with students' errors (Kotzebue et al., 2021).

Research findings indicate that German biology textbooks as well as the biology teachers themselves tend to use innumerable technical terms and synonyms (Dorfner et al., 2020; Graf & Berck, 1993), and representations which could support students' biology-specific language development are rarely used (Nitz, 2012). Biology teachers try to help themselves by developing different strategies to deal with their students' linguistic problems, for example they simplify texts they want to use in class, or tell their students about learning strategies which were helpful for themselves, but they feel that the task of increasing their students' language proficiency is overstraining (Drumm, 2016).

For mathematics instruction, there are research findings which indicate that students' outcomes depend on their academic language proficiency (Prediger et al., 2015), that they benefit from linguistic development (Moschkovich, 2015; Prediger & Wessel, 2018).

Therefore, biology teachers need to consider appropriate language use and scaffolding to realise biology-specific lesson quality features, which depend on their PCK. This results in a need to impart PCK in the field of academic and science language to (future) biology teachers, and to detect useful ways to do that successfully.

Figure 7 shows a summary of research findings from which the research gap for this dissertation can be derived.

Research Field	Authors	Summary of Research Findings
Students' Performance in Science	OECD (2003); OECD (2019b); Reiss et al. (2019)	German students' performance is below OECD average; increasingly negative trend since 2006; increase of low achievers
	Rincke (2007, 2010)	Students struggle with the challenge to learn new physics content at the same time as the related science language
	Busch & Ralle (2013)	Students struggle with technical terms in chemistry lessons having a different meaning in everyday language
	Schmiemann (2011)	Students struggle with biological tasks including technical terms
Teachers' Competence	Baumert et al. (2010); Förtsch et al. (2016); Förtsch et al. (2018); Krauss et al. (2008)	Teachers' professional knowledge is prerequisite for students' learning success: the higher teachers' PCK the higher students' performance
	Markic (2018)	Teachers' PCK in the field of academic and science language can be measured; teachers' PCK in the field of academic and science language is low
	Kunter (2011)	Teachers' motivational orientations are associated with higher lesson quality
	Palermo & Thomson (2019)	Teachers' motivational orientations and values predict instructional changes
	Mönch & Markic (2022)	Teachers' awareness of the role of language influences their PCK in the field of academic and science language
Biology-Specific Lesson Quality Features	Wüsten et al. (2008); Wüsten (2010)	General and biology-specific lesson quality features can be differentiated; biology-specific lesson quality features are e.g., embedding of scientific work, elaborate model use
	Förtsch et al. (2017)/Förtsch et al. (2018)/Kotzebue et al. (2021)	Cognitive activation/Elaborate model use/Dealing with students' errors mediates the effect of biology teachers' PCK on students' outcomes
Dealing with Language in German Biology Instruction	Graf & Berck (1993)	German biology textbooks use innumerable and inconsistent technical terms
	Dorfner et al. (2020)	German biology teachers tend to use a lot of technical terms and synonyms
	Nitz (2012)	Representations supporting biology-specific language development are rarely used in class
	Drumm (2016)	Biology teachers try to develop different strategies to deal with their students' linguistic problems, and are partly overstrained
Findings From Mathematics Instruction	Prediger et al. (2015)	Academic language proficiency is decisive factor for students' mathematical performance
	Moschkovich (2015)	Academic language development enhances students' mathematical understanding
	Prediger & Wessel (2018)	Monolingual students benefit as much as multilingual students from linguistic scaffolding in mathematics; linguistically strong students benefit as well as linguistically weak students

Figure 7. Summary of research findings.

2.2. Aims and Research Questions

In order to better prepare pre-service biology teachers for teaching biology successfully at school in linguistically heterogeneous classes, this dissertation focusses three aims A1 – A3, whereby three research questions Q1 – Q3 in line with A1 are investigated (Figure 8):

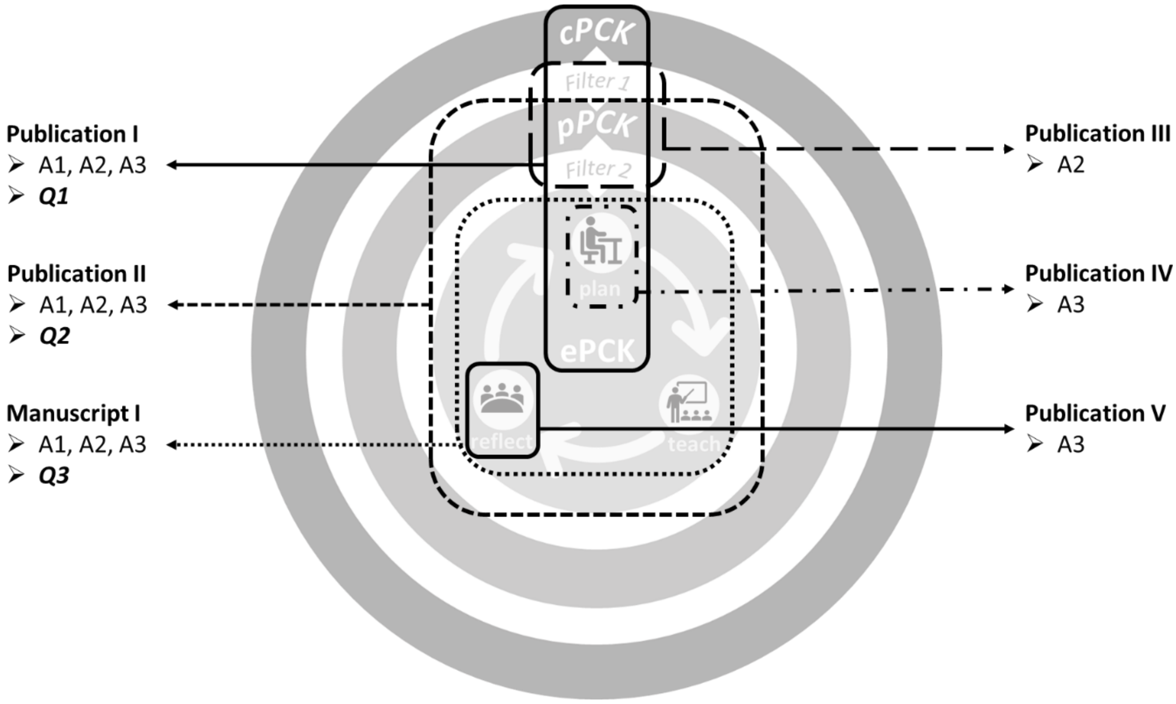

Figure 8. Overview over the Aims A1 – A3, the Research Questions Q1 – Q3 in line with A1, and the affiliated publications in relation to the RCM (Alonzo et al., 2019; Carlson & Daehler, 2019).

A1: Evaluating the RCM with regard to its proposed filters between the three realms of PCK, and to the Plan-Teach-Reflect Cycle of ePCK. To identify supporting or obstructing factors in the transformation between cPCK and pPCK, and between pPCK and ePCK, it was aimed to identify Carlson and Daehler's (2019) proposed filters between the realms of PCK. Furthermore, to identify strategies to increase pre-service biology teachers' PCK, it was aimed to detect the influence of the Plan-Teach-Reflect Cycle of ePCK (Alonzo et al., 2019) on their pPCK, professional values, motivational orientations and ePCK.

Three Research Questions **Q1 – Q3** were formulated in line with **Aim 1:**

Q1: Which filters moderate the transformation between the realms of PCK?

This research question was investigated within Publication I, which describes the research design, procedure and results of Study 1.

Q2: How can pre-service biology teachers' pPCK, professional values and motivational orientations be increased on the basis of the Plan-Teach-Reflect Cycle of ePCK?

This research question was investigated within Publication II, which describes the research design, procedure and results of Study 2.

Q3: How can pre-service biology teachers' ePCK be increased on the basis of the Plan-Teach-Reflect Cycle of ePCK?

This research question was investigated within Manuscript I, which describes the research design, procedure and results of Study 3.

A2: Including the language in biology instruction into existing models of teachers' competence. Therefore, aspects and significance of language for teaching and learning biology were described and applied to existing models of teachers' competence.

This aim was addressed within Publication III, which contains a project description, and provides an overview over the setting which was used for the intervention within Study 2 and Study 3. Furthermore, this aim was addressed in Publication I, Publication II and Manuscript I.

A3: Developing materials to assess biology lesson plans and biology instruction on the basis of the research findings. Therefore, a manual for assessing biology lesson plans and an observation file for biology lessons were developed on the basis of the research findings of Study 1, Study 2 and Study 3.

This aim was addressed within Publication IV and Publication V. Publication IV describes a manual for assessing biology lesson plans. This manual resulted from the coding manual used within Study 1 and Study 3 to rate pre-service biology teachers' lesson plans. Publication V describes a structured observation file which can be used to assess biology lessons. This observation file was used within Study 1, Study 2 and Study 3 as a basis for the joint reflection of biology lessons. Therefore, this aim was addressed in Publication I, Publication II and Manuscript I, too.

To answer the Research Questions Q1 – Q3, three studies were conducted which fed into three publications (Figure 9). All studies took place in obligatory biology education seminars. The participants were pre-service biology teachers participating in a teacher education programme for secondary education. All studies followed a pre-/post-test design with the pre-test in the beginning of the semester and the post-test at the end of the semester.

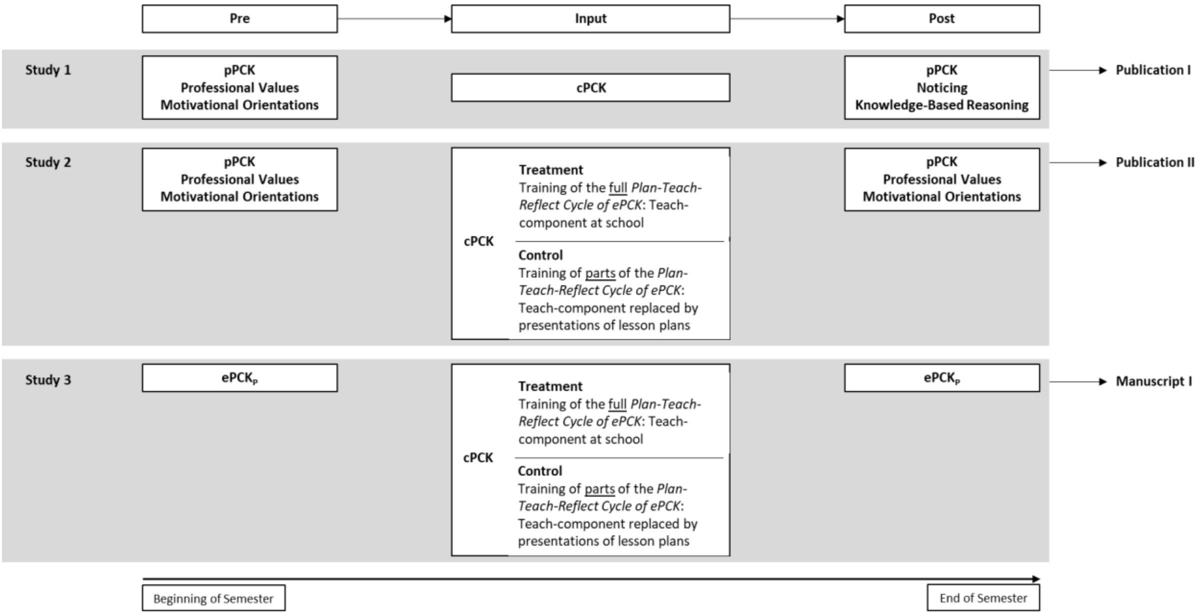

Figure 9. Design of the three studies, and the affiliated publications.

Study 1 took place in an advanced seminar (*N = 58*) for pre-service biology teachers, on average in their 7th semester. In the pre-test, participants' $pPCK_{pre}$, their *motivational orientations to implement language-sensitive biology instruction*, and their *professional values regarding multilingualism and responsibility for students' language development* were measured from paper-/pencil-tests. In the post-test, participants' $pPCK_{post}$ was measured from a paper-/pencil-tests. Their *noticing of* and *knowledge-based reasoning about relevant events regarding students' language proficiency* were measured from questionnaires which included videos of real teaching situations. The results of Study 1 are described in Publication I.

Study 2 and Study 3 included an intervention. Thereby, the training of the *Plan-Teach-Reflect Cycle of ePCK* (Alonzo et al., 2019) was varied: the treatment group planned biology lessons, taught them in a school class, and reflected the lessons. The control group planned biology lessons, presented the lesson plans to the seminar group, and reflected the presented lesson plans.

Study 2 took place in a beginner's seminar (*N = 32*) for pre-service teachers, on average in their 5th semester. In the pre- and in the post-test, participants' *pPCK*, their *motivational orientations to implement language-sensitive biology instruction*, and their *professional values regarding multilingualism and responsibility for students' language development* were measured from paper-/pencil-tests. The group was divided into a treatment group (*N = 15*) and a control group (*N = 17*). As an intervention, the training of the *Plan-Teach-Reflect Cycle of ePCK* (Alonzo et al., 2019) was varied as described above. The results of Study 2 are described in Publication II.

Study 3 took place in an advanced seminar *(N = 56)* for pre-service biology teachers, on average in their 7th semester. In the pre- and in the post-test, participants' $ePCK_P$ was measured from evaluating written lesson plans. The group was divided into three treatment groups ($N_1 = 12$; $N_2 = 14$; $N_3 = 15$) and a control group (*N = 15*). As an intervention, the training of the *Plan-*

Teach-Reflect Cycle of ePCK (Alonzo et al., 2019) was varied as described above. The results of Study 3 are described in Manuscript I.

3. Results

3.1. Publication I

Franziska Behling, Christian Förtsch, and Birgit J. Neuhaus

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

Accepted for publication in

Education Sciences

Behling, F., Förtsch, C. & Neuhaus, B. J. (2022). The Refined Consensus Model of Pedagogical Content Knowledge (PCK): Detecting Filters Between the Realms of PCK. *Education Sciences*, *12*(9), https://doi.org/10.3390/educsci12090592.

3.2. Publication II

Franziska Behling, Christian Förtsch, and Birgit J. Neuhaus

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.

Accepted for publication in

Education Sciences

Behling, F., Förtsch, C. & Neuhaus, B. J. (2022). 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. *Education Sciences*, *12*(10), https://doi.org/10.3390/educsci12100654.

3.3. Manuscript I

Franziska Behling, Christian Förtsch, and Birgit J. Neuhaus

Using the Refined Consensus Model of Pedagogical Content Knowledge to Improve Pre-Service Biology Teachers' Lesson Planning.

Submitted manuscript in

Journal of Science Teacher Education

Abstract

In this article, we analyze how to improve pre-service biology teachers' skills in planning a biology lesson. On the basis of the theory of the *Refined Consensus Model of PCK* (*RCM*) and the *Plan-Teach-Reflect Cycle of ePCK*, we define pre-service teachers' lesson planning skills as $ePCK_P$ (enacted PCK to plan a lesson). We made a two-month quasi-experimental intervention study with 56 pre-service biology teachers. In the treatment group we trained pre-service biology teachers in planning, reflecting and teaching a biology class. In the control group the teaching of the biology class was replaced by presentations of their lesson plans to fellow pre-service teachers. As dependent variable, we analyzed teachers' lesson planning skills ($ePCK_P$). Our results show that training the *Plan-Teach-Reflect Cycle of ePCK* as a whole or in parts increases participants' planning skills. Results showed a strong effect of time on pre-service teachers' lesson planning skills ($F(1,54) = 26.38$, $p < 0.001$, part. $\eta^2 = 0.33$, $d = 1.40$). Including the Teach-component into the *Plan-Teach-Reflect Cycle of ePCK* enhances the effect. We draw the conclusion that the Teach-component of the cycle is especially important to improve pre-service teachers' lesson-planning skills.

Keywords: Refined Consensus Model (RCM); Pedagogical Content Knowledge (PCK); Biology Education; Language-Sensitive Biology Instruction

Introduction

Before people do essential things, they make a plan: before a house is to be built, the architect makes a blueprint; before a loaf of bread is to be baked, the baker creates a recipe; before a car is to be constructed, the engineer makes a construction plan; before the family enters the house at Christmas, the host plans the dinner, consults cookbooks and writes a shopping list. Since science education is much more essential than a Christmas dinner, science teachers plan their lessons much more carefully, and they take much more time, than preparing a dinner.

Education at school aims to impart applicable knowledge (Helmke, 2009, p. 42; Weinert, 2000). Science teachers aim to develop students' scientific literacy (e.g. Holbrook & Rannikmae, 2007), which is a difficult construct that requires abstract thinking as well as appropriate academic and science language proficiency (Gogolin, 2013; Osborne, 2002). It seems obvious that these aims are impossible to reach without sound lesson planning. Alonzo et al. (2019) describe teachers' lesson planning as a part of their pedagogical content knowledge (PCK) in the framework of the Refined Consensus Model of PCK (RCM; Carlson & Daehler, 2019). Therefore, we describe briefly the RCM, and use it as a basis for an intervention study to improve pre-service biology teachers' PCK in the field of academic and science language with a special focus on lesson planning.

The Refined Consensus Model of PCK (RCM)

Teachers' PCK relates to their knowledge of students' (pre-)conceptions, how to deal with them within the learning process, and how to make content comprehensible for students by appropriate forms of representation (Shulman, 1986). On this basis, Carlson and Daehler (2019) bring together several models of teachers' PCK and describe the latter in the RCM in the form of three concentric circles lying within each other (Figure 1): the outer circle *collective PCK*, the middle circle *personal PCK*, and the inner circle *enacted PCK*.

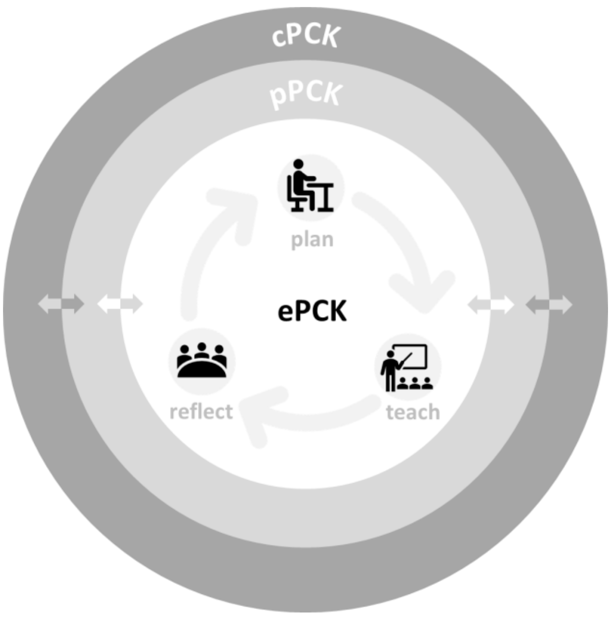

Figure 1. The Refined Consensus Model of PCK based on Carlson and Dahler (2019).

Collective PCK (cPCK)

The collected, shared PCK among the science education community, which is published in e.g., journals or books, is called cPCK. Research findings contribute to cPCK as well as teachers' documented teaching experience (Carlson & Daehler, 2019).

Personal PCK (pPCK)

When teachers join teacher training sessions, consult literature or talk about teaching situations with colleagues, they integrate parts of cPCK into their own knowledge and construct pPCK, an internalized form of PCK. If they share their knowledge and teaching experience, they contribute to cPCK (Carlson & Daehler, 2019).

Enacted PCK (ePCK)

In the teaching process, every teacher generates their own unique applied PCK, the so-called *ePCK*, that only appears in action, and is based on their pPCK (Carlson & Daehler, 2019). Teachers' ePCK can be differentiated according to the three steps of teaching: when **planning** the lesson the teacher's ePCK appears in the form of *$ePCK_P$*; in the concrete **teaching** situation in class it appears in the form of *$ePCK_T$*, and when **reflecting** after the lesson it appears in form of *$ePCK_R$* (Alonzo et al., 2019). According to this model, the three steps of teaching are mutually dependent, since they can be described as a cycle, the *Plan-Teach-Reflect Cycle of ePCK* (Figure 1), which leads to the conclusion that good lesson planning increases the probability of good lessons taught. The transformation process from a teacher's theoretical pPCK into applicable ePCK occurs during their lesson planning (Stender, 2014, p. 39). Lesson plans are also the basis for reflection (Gropengießer, 2016), and teachers' conclusions from their reflection processes feed into future lesson planning (Alonzo et al., 2019).

The transformation from pPCK to ePCK is very difficult for pre-service teachers (Stokking et al., 2003; Stürmer et al., 2013), while they are supposed to be able to do theory-based lesson planning (e.g., LPO I, 2008/13.03.2008). For this, pre-service teachers need specific lesson-planning situations, ideally by experiencing classroom situations, to transform their theoretical pPCK into applied ePCK (Stender, 2014, 214 et seq.). Many teacher education programs include internships at school which allow pre-service teachers to plan and run lessons on their own, an important requirement for the transformation from theoretical PCK into teaching practice (Stender, 2014). This process needs the structured support of the university (Santagata & Yeh, 2014), which is often not the case with internships at school. This is why there are approaches to integrating internships at school into university settings (Gröschner et al., 2013; Kee, 2012; Santagata & Yeh, 2014). In previous studies, we were able to provide indications that knowledge-based reasoning moderates the transformation between pPCK and ePCK (Behling et al., 2022b), and that training the *Plan-Teach-Reflect Cycle of ePCK* (Alonzo et al., 2019) enhances pre-service biology teachers' pPCK and motivational orientations (Behling et al., 2022c).

Since our study focuses on PCK in the field of academic and science language in biology lessons, we describe some characteristics of language in biology lessons, and necessary biology teachers' knowledge.

Language in Biology Lessons

We have already determined scientific literacy to be an important aim of biology education. Scientific literacy relates to a deep understanding of scientific terms and concepts as well as scientific inquiry, the history and the nature of science (Bybee, 1997). The word "literacy" in the term scientific literacy does not only mean the ability to read and write, but also to enable obtaining access to information (Bybee, 1997). Moschkovich (2015) describes a person's academic literacy in science as the ability to participate in science discourse. These perspectives illustrate that in the learning process, academic and science language proficiency is indispensable (Prediger, 2017). The findings of Childs et al. (2015) and Prediger et al. (2015) indicate that students' academic language proficiency is the most important impact factor in their educational success, supporting Wellington and Osborne's (2001) claim that language is the major barrier to students' learning success in science. Therefore, biology teachers need PCK in the field of academic and biology-specific science language.

What does that mean? Language always depends on the context in which it is spoken. That is what Halliday (1975) defined as so-called language registers, specific characteristics of the language with typical vocabulary and grammar. For biology lessons, three language registers are relevant: the everyday register, the academic register and the biology-specific science register (Riebling, 2013).

The *everyday register* is relevant for everyday life and everyday communication, which is usually oral, between physically present persons and about physically present or well-known objects or situations. It is not necessary to be very precise, since one can use gestures or mimic expressions. Since the "everyday life" depends on one's age, their family, social background and many more, the everyday language is not that homogeneous as the word implicates; it is characterized e.g., by youth language, dialects, different first languages (Gogolin, 2011; Riebling, 2013). When students do an observation of an insect during a biology lesson and they have to describe it, they could e.g., tell the teacher "This here is moving there and makes that.", as "this here" is present on the table and they can point to it and the direction where it moves, and they can demonstrate the kind of movement.

The *academic register* is characterized by a high density of information and level of abstraction, by such grammatical structures as nominalizations, conditional clauses or passive constructions; it is conceptually written (Cummins, 2008; Gogolin, 2011; Riebling, 2013). The teacher in the observation situation above would describe the same observation e.g., like this: "The grasshopper's movement is abrupt and very quick. When it jumped from the left side of the box to the right side, it covered a distance of approximately 30 cm." This description makes the situation comprehensible for somebody who is not in the situation. Academic language is considered to be most relevant for students' learning success (Childs et al., 2015; Moore, 2007; Prediger et al., 2015).

The biology-specific *science register* builds on the academic register and is characterized by specific technical terms and forms of representations (Drumm, 2016; Nitz et al., 2012). In our observation example, that could mean that the term "grasshopper" could be replaced by the more precise terms "Great Green Bush-Cricket" or "Tettigonia viridissima". The students could be demanded to make a labeled sketch of the animal (Retzlaff-Fürst, 2016), which is characterized by specific requirements. In addition, they could use a model (Upmeier zu Belzen, 2016; Upmeier zu Belzen & Krüger, 2010) of an insect's leg and be demanded to allocate the single structures of the grasshopper's jumping leg to those of the model, and to proceed a model critique. Or they could be demanded to construct a model themselves. The biggest problem would not be to learn the technical term, but to "translate" and execute teacher's demands: how does a sketch in biology look like? Is it different from a sketch in arts? What is a model in biology? How and why is it used?

Biology teachers have to introduce carefully these terms and their meanings, and what students are supposed to do when the teacher demands them to e.g., make a sketch or describe an observation. Hereby, so-called *linguistic tools* play a decisive role: these are (technical) terms and grammatical structures required for learning content, which sometimes imply linguistic barriers (Brandt & Gogolin, 2016; Tajmel et al., 2009; Tajmel & Hägi-Mead, 2017), and should be considered carefully in the planning process of the lesson. Furthermore, the teachers themselves are important role models, and the didactic materials used (Beese et al., 2015): every (planned) linguistic action has to be *correct* in terms of spelling and grammar and *appropriate* to the students' grade, and *technical terms* have to be introduced explicitly, explained and repeated (Brandt & Gogolin, 2016). With appropriate *linguistic scaffolding strategies*, the teacher and the didactic materials used, systematically support students' development of language proficiency. This happens through, for example, connecting passages during the lesson, illustrating the content by different materials, linguistically differentiating tasks and prompting students to perform their own oral or written language actions or both (Beese et al., 2015; Tajmel & Hägi-Mead, 2017).

Hypotheses

Based on the described theory, we analyzed the following hypotheses, using the example of academic and biology-specific science language (Figure 2):

H1: Training the *Plan-Teach-Reflect Cycle of ePCK* as a whole or in parts to pre-service biology teachers enhances their $ePCK_P$.

H2: Training the whole *Plan-Teach-Reflect Cycle of ePCK* has a higher effect on pre-service biology teachers' $ePCK_P$ than replacing the Teach-component by oral representations of lesson plans.

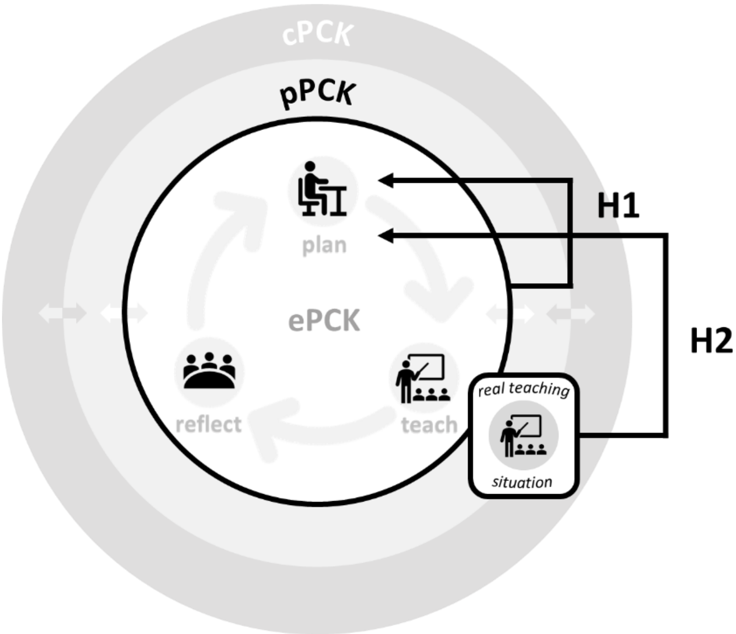

Figure 2. Graphical illustration of hypotheses H1 & H2.

Methods

Design and Procedure

We did a quasi-experimental study in a pre-/post-test design. As independent variable, we varied the *Plan-Teach-Reflect Cycle of ePCK* as described below. As dependent variable, pre-service teachers' ePCK$_P$ was measured before and after the seminar. Therefore, participants' lesson plans were evaluated. pPCK was measured as control variable.

The pre-test took place in the beginning of the semester and the post-test in the end of the semester (Figure 3). At the beginning of the semester, pre-service teachers' pPCK was measured by using a 20-minute paper-and-pencil test, and each participant planned a lesson at home. After the last seminar, each participant again planned a lesson. Between these tests, students participated in a two-month of biology education seminar.

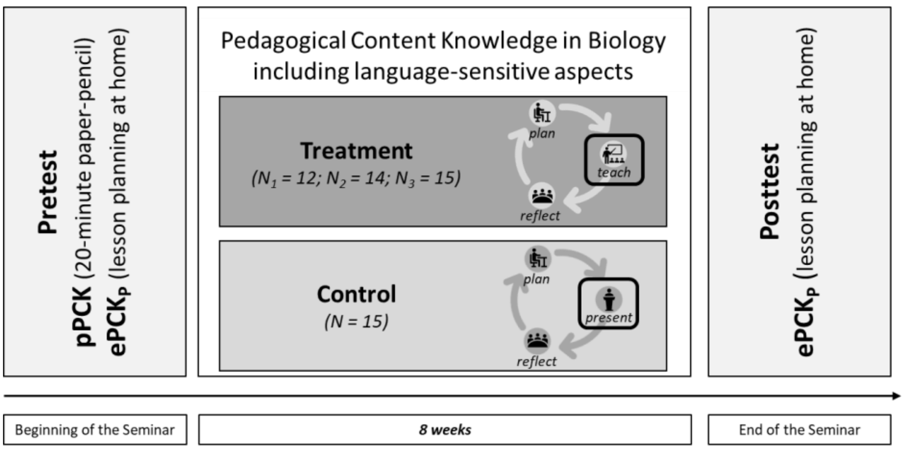

Figure 3. Research Design and Procedure.

Sample

Participants of the study were 56 pre-service biology teachers, on average in their 7th semester (M = 6.98, SD = 0.58). The group was divided into a treatment group consisting of three seminar groups (N_1 = 12; N_2 = 14; N_3 = 15; 27 female, 14 male, all with German as first language, 9 bilingual), and a control group (N = 15; 10 female, 5 male, 14 with German as first language, 3 bilingual, 1 with another first language). As the seminar was obligatorily scheduled for pre-service biology teachers and there were different time slots for organizational reasons, pre-service teachers decided themselves which time slot and thereby which group they joined; the treatment group was divided into three treatment groups due to the group size.

Setting and Content of the Seminar

We tested our hypotheses by using an obligatory advanced seminar in our biology teacher education program for pre-service secondary biology teachers. This program trained biology-specific PCK, such as characteristics of the lesson-quality features of appropriate language use, cognitive activation, elaborate model use, that deal with students' preconceptions and embedding of scientific work. The seminar had a special focus on theory-based lesson planning as described below. Within the seminar, participants have to use their acquired pPCK for theory-based lesson planning as described below. The seminar's duration is two months, 90 minutes each week. Three ECTS-credits (European Credit Transfer and Accumulation system; one ECTS-credit corresponds to 25-30 working hours) can be acquired.

The seminar aimed to impart biology-specific PCK, e.g., elaborate model use, embedding of scientific work, dealing with students' pre-conceptions, including academic and biology-specific science language. The focus was on lesson planning, on the basis of the imparted PCK. The pre-service teachers were taught to plan biology lessons according the models of Kattmann et al. (1997) and Dorfner et al. (2019) and to write a tabular lesson plan (Gropengießer, 2016; John, 2006), which included an exact description of the teacher's and students' actions, including linguistic tools, and named the methods/social form, and materials.

Intervention

In the treatment group, pre-service teachers taught a biology class at school as part of the *Plan-Teach-Reflect Cycle of ePCK* (Alonzo et al., 2019): we demanded our pre-service teachers plan lessons at home to generate $ePCK_P$, whereby the lesson topics were randomly distributed. At a partner school, a secondary school with about 900 students most with another first language than German, we used a biology classroom where each pre-service teacher could teach biology lesson with students, generating $ePCK_T$. We videotaped these lessons and broadcast them live to a neighboring observation room where fellow pre-service teachers and the lecturer observed the lesson. Thereby, they used a structured observation file to focus on academic and biology-specific science language (Behling et al., 2022a), which formed the basis of the subsequent joint reflection, a situation generating $ePCK_R$. During the reflection, the participants were asked to describe observed classroom situations, in particular those which were relevant for academic and science language, to explain their meaning for students' learning success, and to propose alternative instruction strategies. This training of the *Plan-Teach-Reflect Cycle of ePCK* (Alonzo et al., 2019) took place eight times, once a week. Since we recorded the lessons, each pre-service teacher watched their own lesson and we were able to re-watch relevant extracts of the lesson during the reflection process.

In the control group, pre-service teachers only made oral presentations of their lesson plans to the seminar group, instead of teaching them in a school class. All other aspects of the seminar remained the same; participants did lesson plans at home, and there was a joint reflection on the basis of the same observation file: the participants were asked to describe planned classroom situations, in particular those which were relevant for academic and science language, to explain their meaning for students' learning success, and to propose alternative instruction strategies. In this way, the pre-service teachers were trained in only two parts of the *Plan-Teach-Reflect Cycle of ePCK* (Alonzo et al., 2019): the Teach-component was replaced by oral presentations of lesson plans.

Test Instruments

pPCK was measured from a standardized paper-and-pencil test, $ePCK_P$ was measured by rating the lesson plans of the pre-service teachers. All test instruments showed acceptable values for objectivity and homogeneity (Table 1). Rasch theory, which allows conversion of non-linear raw-scores from our measurements to linear person ability scores that can be used for data analysis, was used to compute values for reliability (W. J. Boone et al., 2014) by the program Winsteps (Linacre, 2022c). We converted the person ability scores to a range from 0—100 (Linacre, 2022b); all data met the desired requirements (W. J. Boone & Noltemeyer, 2017; Linacre, 2022c; Wright & Linacre, 1994).

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	< 1.5	< 1.5	0.99	0.75	ICC(159,159) = 0.97, p < 0.001
ePCK_P	N = 8	< 1.5	< 1.5	0.86	0.86	ICC(534,534) = 0.98, p < 0.001

In the following, we describe the test instruments in more detail.

pPCK

We measured pre-service biology teachers' pPCK with a focus on academic and biology-specific science language by an open-ended paper-and-pencil test with nine items, which took the participants 20 minutes. The test instrument was based on a validated PCK-test of Jüttner et al. (2013). We chose and adapted the test instrument for our content area of PCK following the recommendations of Reeves and Marbach-Ad (2016): based on a literature review (e.g., Childs et al., 2015; Drumm, 2016; Halliday, 1975; Markic, 2018; Nitz et al., 2012), we defined the content area of language in biology education and learning objectives for the pre-service teachers (Wiggins & McTighe, 2005), and constructed theory-based items according to those of Jüttner et al. (2013). To strengthen content validity, the items were submitted to a small group of in-service biology teachers and biology education researchers, who were demanded to answer the test items and to give their feedback, e.g., if they knew what they had to do, if they would prefer another wording, or if we missed important content to cover the topic of academic and science language in biology lessons (Behling et al., 2022b). For construct validity, we evaluated the Wright map of the Rasch analysis (Aryadoust, 2009; W. Boone & Rogan, 2005), which showed even distribution of item difficulties. Thereby, items which 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 which 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." (Behling et al., 2022b). The test was based on the Rasch Partial Credit Model (PCM; Linacre, 2022c; Planinic et al., 2019) to be able to consider multiple item levels. The test included requests to notice and name examples for the academic and science register in a schoolbook's text, and to lighten the linguistic load of a biology task in a well-founded way, one item asking to name and explain as many terms as possible having different meanings in everyday and science registers (Behling et al., 2019, 2022b; Drumm, 2016), and questions on the classroom-relevant language registers (Halliday, 1975; Riebling, 2013). For objectivity, 10% of the sample was double-coded by two independent researchers resulting in a high agreement (ICC(159,159) = 0.97, $p < 0.001$). After the Rasch PCM was applied, the scale showed acceptable values for homogeneity (item reliability = 0.99, person reliability = 0.75), and all items showed good fit values (Table 1).

$ePCK_P$

$ePCK_P$ was measured by collecting and evaluating pre-service teachers' lesson plans, which had to include learning objectives, necessary teaching materials and a detailed description of the planned lesson in tabular form. Therefore, we developed a rating manual (Behling et al., 2021) on the basis of a rating manual of Schröder et al. (2019) adapted to our content area academic and science language in biology. For content validity, we followed the recommendations of Reeves and Marbach-Ad (2016): the content area was defined on the basis of a literature review (e.g., Beese et al., 2015; Dorfner et al., 2020; Gogolin & Lange, 2011; Özayli & Ortner, 2015; Sandmann et al., 2013; Tajmel, 2011; Tajmel & Hägi-Mead, 2017), learning objectives were defined (Wiggins & McTighe, 2005), and theory-based items were constructed according to those of Schröder et al. (2019). For construct validity, the Wright map of the Rasch analysis was evaluated (Aryadoust, 2009; W. Boone & Rogan, 2005), which showed even distribution of item difficulties. Thereby, items which 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 which were more difficult to agree with were located at the upper end of the Wright map, e.g., "There are necessary and reasonable linguistic tools for all phases of the lesson." (Behling et al., 2022b). The test instrument consisted of five subdimensions, which represent different aspects biology teachers need to take care of which are described in theory: the subdimension *linguistic tools* includes two items, e.g. "There are meaningful linguistic tools for each teaching phase." The subdimension *technical terms* includes one item: "All new technical terms are explained, repeated and set out in writing." The subdimension *language use appropriate to students' grade* includes one item: "The written and spoken language is appropriate to students' grade." The subdimension *correct linguistic action* includes one item: "All (planned) written and spoken linguistic action as well as the used didactic materials are correct in spelling and grammar." The subdimension *linguistic scaffolding strategies* includes three items, e.g. "Students are challenged to perform their own oral language acts through teaching methods." For objectivity, 10% of the sample was double-coded by two independent researchers, which resulted in a high agreement ($ICC(534,534 = 0.98, p < 0.001$). After the Rasch PCM was applied, the scale showed acceptable values for homogeneity (item reliability = 0.97, person reliability = 0.86), and good item fit values (Table 1).

Data Analysis

Descriptive Analyses

We used the mean values and standard deviations of all resulting person ability scores (Table 2). To make sure that the three treatment groups could be treated as one, an analysis of variance was calculated. To make sure that treatment and control group would not differ from one another in the pre-test, unpaired t-Tests were calculated. We calculated Pearson correlations between $pPCK_{pre}$ and $ePCK_{P\text{-}pre}$.

Mixed ANOVA

We calculated a mixed ANOVA with the described intervention as independent variable, and pre-service teachers' $ePCK_P$ as dependent variable (Table 3). To test Hypothesis 1, we interpreted the effect of time as the effect of training the *Plan-Teach-Reflect Cycle of ePCK* as a whole or in parts to pre-service biology teachers which we did both in the treatment and the control group. To test Hypothesis 2, we interpreted the interaction effect to identify the effect of training the whole *Plan-Teach-Reflect Cycle of ePCK* in comparison with replacing the Teach-component by oral representations of lesson plans.

Results

Descriptive Results

Table 2 shows the descriptive results of the measured variables:

Table 2. Summary of mean scores (pre- and post-test).

variable	mean of person ability score		SD		Min		Max	
	treatment	control	treatment	control	treatment	control	treatment	control
$pPCK_{pre}$	43.74	47.44	7.37	6.68	28.59	32.34	66.31	60.23
$ePCK_{P\text{-}pre}$	44.90	61.84	16.12	7.73	20.07	44.37	68.58	52.22
$ePCK_{P\text{-}post}$	71.14	61.33	5.01	9.08	54.37	36.91	80.84	72.57

Analysis of variance did not detect significant group differences within the three treatment groups for pre-service teachers' pPCK ($F(2,38) = 1.99$, $p = 0.51$) and their $ePCK_P$ ($F(2,38) = 2.51$, $p = 0.10$). Therefore, the three treatment groups were treated as one.
An unpaired t-test explored a significant difference between the treatment and the control group in the pre-test for the variable $ePCK_P$ ($t(49.85) = 5.27$, $p < 0.001$, $d = 1.59$; Cohen, 1988), whereby the person ability scores of the treatment group were lower than those of the control group. There was no difference for the variable pPCK ($t(54) = 1.79$, $p = 0.09$).

We did not find a correlation between pre-service biology teachers' $pPCK_{pre}$ and $ePCK_{P\text{-}pre}$ ($r = 0.24$, $p = 0.08$, $N = 56$; Cohen, 1988).

Mixed ANOVA

To analyze the treatment effect of our intervention described above, a mixed ANOVA was calculated with the described intervention as independent variable, and pre-service teachers' $ePCK_P$ as dependent variable (Table 3).

Table 3. Summary of mixed ANOVA.

hypothesis	dependent variable	F	p	part. η^2	d
		effect of time			
H1	$ePCK_P$	$F(1,54) = 26.38$	< 0.001	0.33	1.40
		interaction effect			
H2	$ePCK_P$	$F(1,54) = 24.49$	< 0.001	0.35	1.47

To test Hypothesis 1, we interpreted the effect of time, which allows a statement about the effect of training the *Plan-Teach-Reflect Cycle of ePCK* as a whole or in parts to pre-service biology teachers, in both the treatment and the control group. Results showed a strong effect of time on pre-service teachers' $ePCK_P$ ($F(1,54) = 26.38$, $p < 0.001$, part. $\eta^2 = 0.33$, $d = 1.40$; Table 3; Figure 4).

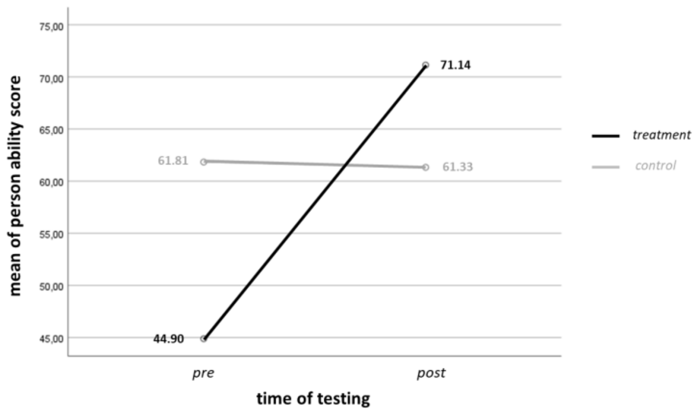

Figure 4. Results of mixed ANOVA: it shows the mean of person ability scores of the treatment group (black) and the control group (grey) depending on the time of testing.

Since the mixed ANOVA showed a strong effect of time and the graphic representation (Figure 5) indicated a slight decrease of the mean person ability scores within the control group, a paired t-test was calculated in addition. Results showed no effect for the control group ($t(14) = 0.29$, $p = 0.78$).

To test Hypothesis 2, we interpreted the interaction effect to identify the effect of training the whole *Plan-Teach-Reflect Cycle of ePCK* in comparison with replacing the Teach-component by oral representations of lesson plans. Results showed a strong interaction effect on pre-service teachers' $ePCK_P$ ($F(1,54) = 24.49$, $p < 0.001$, part. $\eta^2 = 0.35$, $d = 1.47$; Table 3; Figure 4).

Discussion

The results of our study indicate that training the *Plan-Teach-Reflect Cycle of ePCK* as a whole or in parts to pre-service biology teachers enhances their *$ePCK_P$*. Including the Teach-component to the cycle increases the effect (Figure 5).

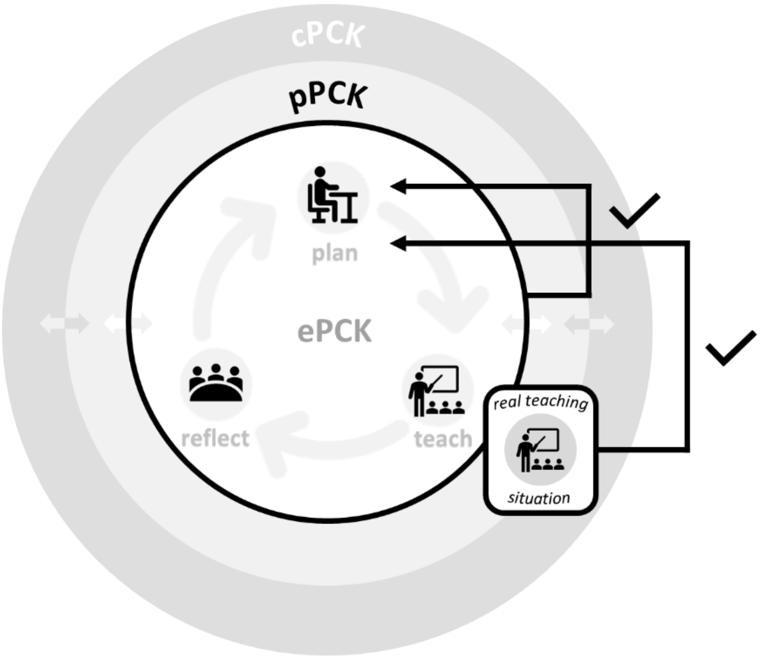

Figure 6. Graphical illustration of research findings.

We intended to find a useful possibility to foster our pre-service biology teachers' ePCK$_P$ in the field of academic and science language, since research results indicate that structured construction of students' academic language skills leads to better performance in mathematics (Prediger et al., 2015) and in science (Childs & Ryan, 2018).
We expected to find a strong correlation between pre-service teachers' and *ePCK$_P$*, since they should be mutually dependent (Carlson & Daehler, 2019), which was not the case in our study. That was why we decided not to use pre-service teachers' pPCK as a covariable for our measurement. Since the person reliability of our pPCK-test was on the edge, it could have been not sensitive enough to distinguish between high and low performers. The item reliability of our ePCK$_P$-test was on the edge, too, which indicates that the sample could have been not large enough (Linacre, 2022a). That could explain why we did not detect the assumed correlation. That is why we recommend re-measuring the impact of pre-service teachers' pPCK on their ePCK$_P$ as well as its assumed increase during a semester.

Our results indicate that training the *Plan-Teach-Reflect Cycle of ePCK* as a whole or in parts increases pre-service biology teachers' ePCK$_P$. Since the mean of person ability scores of the control group were significantly higher than the treatment groups' in the pre-test, and there was no significant change during the semester, we assume that is the intervention effect which is decisive: it is the Teach-component into the *Plan-Teach-Reflect Cycle of ePCK* instead of replacing it by oral presentations of lesson plans which makes the difference, which is strengthened by the strong interaction effect of our treatment. The authentic classroom experience seems to affect pre-service teachers' ePCK$_P$ positively. One could assume that only the knowledge that one will have to stand in front of the class would make a pre-service teacher work out their lesson plans very carefully. But since the treatment group's *ePCK$_P$* was even worse than the control group's, that seems not to be an impact factor. These results suggest that it is the direct interaction with real students in the classroom and the teaching experience that makes the difference: if one sees students struggle with technical terms, with grammatical structures, with questions and tasks given by oneself, one will consider those experienced problems during the next lesson planning, which would fit the finding that the direct interaction with (multilingual) students increases pre-service teachers' motivational orientations (Eccles et al., 1983; Wigfield & Eccles, 2000) to implement language-sensitive biology instruction, too (Behling et al., 2022c). In addition, there was even more room for improvement of the treatment group's *$ePCK_P$* since they performed worse than the control group in the pre-test. Since our control group was much smaller than the treatment group, their "non-performance" could be influenced by coincidence or characteristics of this group we did not capture, and therefore be treated with care. Furthermore, it would be interesting to investigate the question of the interaction effects between the teaching experience itself and the experience of the joint reflection, as well as between the structured lesson observation and the joint reflection, to understand better the relations between $ePCK_P$, $ePCK_T$ and $ePCK_R$.

These findings reinforce Alonzo et al.'s (2019) *Plan-Teach-Reflect Cycle of ePCK*, since teaching and reflecting on biology lessons leads to an increase in pre-service biology teachers' lesson planning skills, especially when the training includes the teaching experience at school and structured video-supported lesson observations.

Implications for Pre-Service Teacher Education

Our results lead us to the conclusion that it is necessary to foster pre-service biology teachers' ePCK in the fields of academic and biology-specific science language by integrating the latter into the imparting of PCK in the framework of teacher education programs: structured guidance of pre-service teachers in the lesson planning process, i.e. PCK-instruction, the demand to write lesson plans, and guided reflection of lessons, increases their $ePCK_P$, especially when the Teach-component is included into the *Plan-Teach-Reflect Cycle of ePCK* (Alonzo et al., 2019). Since language academic and science proficiency influences (Childs & Ryan, 2018; Prediger et al., 2015) students' performance in science positively, and teachers' PCK is relevant for students' performance (Förtsch et al., 2017), we recommend the compulsory inclusion of PCK in the field of academic and science language in biology teacher education programs. Our specific intervention with undergoing the *Plan-Teach-Reflect-Cycle of ePCK* at a school with the possibility to live-broadcast and record the lessons is a kind of luxury, but many countries provide internships at school during teacher education, which are partly accompanied by university. On the basis of our findings, we recommend making this experience possible, with a focus on language in particular, if possible, with videography of the lessons to be used for the reflection process. If internships are not possible, using video clubs focusing on linguistic barriers with concrete instructions for observation, for example in the form of an observation file (e.g., Behling et al., 2022a) could be an alternative. Since a majority of science teachers do not feel well-prepared to foster their students' academic language skills and to provide helpful scaffolding strategies (Childs & Ryan, 2018), in-service biology teachers would benefit from appropriate training, too. Since all natural sciences pursue the target of scientific literacy and have a common mindset, so our results should be transferable to chemistry and physics teacher education, too.

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Disclosure statement

The authors report there are no competing interests to declare.

Ethical statement

The authors report that their study met the ethics/human subject requirements of their institution at the time the data were collected.

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3.4. Publication III

Franziska Behling, Christian Förtsch, and Birgit J. Neuhaus

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3.5. Publication IV

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3.6. Publication V

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4. Discussion

4.1. Preparing Pre-Service Biology Teachers for Teaching Biology in Linguistically Heterogeneous Classes

This dissertation had three aims A1 – A3 in order to detect useful strategies to better prepare pre-service biology teachers for teaching biology successfully at school in linguistically heterogeneous classes, and hereby, develop their students' scientific literacy. Figure 10 gives an overview of the aims that were achieved within this dissertation, and those that were not achieved, and that will be discussed in the following sections:

	Aim	achieved	not achieved
A1	Evaluating the RCM with regard to its proposed filters between the three realms of PCK, and to the Plan-Teach-Reflect Cycle of ePCK.		
	Filters moderating the transformation between the realms of PCK:		
	▪ **Motivational orientations** as a filter between cPCK and pPCK		✗
	▪ **Professional values** as a filter between cPCK and pPCK		✗
	▪ **Noticing** as a filter between pPCK and ePCK		✗
	▪ **Knowledge-based reasoning** as a filter between pPCK and ePCK	✓	
	Using the Plan-Teach-Reflect Cycle of ePCK to increase pre-service teachers'		
	▪ … **pPCK**	✓	
	▪ … **professional values**		✗
	▪ … **motivational orientations**	✓	
	▪ … **ePCK**	✓	
A2	Including the **language in biology instruction** into existing models of teachers' competence.	✓	
A3	Developing materials to **assess biology lesson plans** and **biology instruction** on the basis of the research findings.	✓	

Figure 10. Overview over the aims achieved and not achieved within this dissertation.

4.1.1. Filters Moderating the Transformation Between the Realms of PCK

This dissertation aimed to enable pre-service biology teachers to teach biology lessons of high quality in linguistically heterogeneous learning groups, and therefore, to improve their PCK in the field of academic and science language. If we intend to impart PCK to pre-service teachers, which we do in teacher education programmes (Gess-Newsome et al., 2019), we need a deep understanding for how pre-service teachers take in PCK. That is why it was aimed to evaluate the RCM with regard to its proposed filters between the three realms of PCK, and to the Plan-Teach-Reflect Cycle of ePCK (Carlson & Daehler, 2019).

Therefore, Study 1 aimed to identify filters between the realms of PCK: the results provide indications that pre-service teachers' *knowledge-based reasoning* moderates the transformation between their pPCK and ePCK, which fits Carlson and Daehler's (2019) assumption of pedagogical reasoning as a filter between these two realms of PCK. Other authors agree that pedagogical reasoning is required to enact PCK (Blömeke et al., 2015; Loughran, 2019). Interestingly enough, the level of their knowledge-based reasoning seems to be important: the better their knowledge-based reasoning, the stronger the effect on the transformation from pPCK to ePCK, which seems quite obvious. But this only applies to a certain point: when the level of knowledge-based reasoning is too low, the effect is reversed, and pre-service teachers' ePCK even decreases. This leads to the conclusion that pre-service teachers' knowledge-based reasoning should be definitely trained in parallel with their PCK, which fits the findings of Kramer et al. (2021).

In addition, it was hypothesised that pre-service teachers' noticing would be a filter between pPCK and ePCK, too, which the data of Study 1 did not support. Teachers need to notice relevant events in class before they can start to reason about them (Seidel & Stürmer, 2014). Therefore, it was assumed that the two constructs would correlate strongly, which they did. Due to the test construction, the relevant events to reason about were predefined in the knowledge-based reasoning-test. Maybe pre-service teachers are able to reason about given relevant classroom events as they are trained to use their PCK in similar situations. Being requested to notice relevant classroom events within a complex teaching situation where various events occur in every single minute may overwhelm novices in contrast to experts in teaching (Sherin & van Es, 2009; Star & Strickland, 2008). That is why noticing as a filter between pPCK and ePCK should not be rejected due to the results of Study 1, but should be investigated with in-service teachers.

Furthermore, the affective components of teachers' competence, motivational orientations and professional values (Baumert & Kunter, 2011), were hypothesised to moderate the transformation process between cPCK and pPCK, which the data of Study 1 did not support either. Both are considered influencing factors on teachers' performance in class (Baumert & Kunter, 2011; Kunter, 2011; Palermo & Thomson, 2019; Sunley & Locke, 2010); Mientus et al. (2022) identified teachers' beliefs and attitudes as impact factors on teachers' PCK. Since most research on these constructs was done on in-service teachers, they should not be discarded as filters on the basis of Study 1, but investigated with in-service teachers. Both are not stable personal traits, but develop during teachers' professional life (Kunter, 2011; Oser, 1996; Palermo & Thomson, 2019), so it is possible that their influence on pre-service teachers' performance is much lower than on in-service teachers'. Study 1 did not focus on Carlson and Daehler's (2019) learning context, but argued that the RCM names teachers' enthusiasm and ability beliefs explicitly, and that the learning context as defined in the RCM would have an impact on both teachers' motivational orientations and professional values. This impact has not yet been clarified, so that should be done, as well as hypothesising the learning context itself as a moderator within future research.

4.1.2. Using the Plan-Teach-Reflect Cycle of ePCK to Increase pPCK, Professional Values, Motivational Orientations and ePCK

When pre-service biology teachers leave university and start working at school, they should have a solid knowledge base in form of pPCK, also in the field of academic and biology-specific science language. Furthermore, they should be aware of the role of language (Mönch & Markic, 2022), thus have professional values regarding multilingualism and responsibility for students' language proficiency, and they should have motivational orientations to implement language-sensitive biology instruction. Research findings indicate that practical teaching experience at school which is embedded in university settings supports pre-service teachers' development of PCK (Gröschner & Schmitt, 2012; Loughran, 2019; Mientus et al., 2022; Santagata & Yeh, 2014). That is why Study 2 aimed to investigate the impact of the *Teach-component* of the Plan-Teach-Reflect Cycle of ePCK (Alonzo et al., 2019) on pre-service biology teachers' pPCK, professional values and motivational orientations.

The results of Study 2 indicate that training the Plan-Teach-Reflect Cycle of ePCK as a whole or in parts to pre-service biology teachers increases their *pPCK in the field of academic and science language*, and that this effect is strengthened when the Teach-component is included into the cycle. It was not too surprising that participants' pPCK increased since the setting of Study 2 was an obligatory seminar which aimed to impart cPCK to the participants, and this process was supported by a joint and lecturer-guided reflection which is assumed to augment the integration and development of PCK (Alonzo et al., 2019; Mientus et al., 2022; Nilsson, 2014). The Teach-component seems to be a decisive factor for pre-service teachers' development of pPCK, which fits the assumptions of Alonzo et al. (2019) and Carlson and Daehler (2019): a teacher's pPCK is informed by cPCK and ePCK, and ePCK occurs in the macro- and the micro cycle. First, the Teach-component is integral part of the macro cycle, and second, the micro cycle is present within the Teach-component only. The findings of van Driel et al. (2002), Mulholland and Wallace (2005), and Mientus et al. (2022) indicate that the Teach-component directly informs teachers' PCK, which is supported by the results of Study 2.

Furthermore, the findings of Study 2 indicate that the Teach-component is essential for pre-service teachers' *motivational orientations to implement language-sensitive biology instruction*. Receiving knowledge about the meaning of language in biology, linguistic hurdles and scaffolding strategies on the one hand, and to be put into the shoes of someone who does not have the required linguistic skills to fulfil a seemingly simple task on the other hand, as it happens during the setting of Study 2, should increase participants' motivational orientations (Tajmel & Hägi-Mead, 2017). The Teach-component increases the effect in this case, too. This fits the assumptions of Wigfield and Eccles (2000) that motivational orientations can be changed by external influences and experiences, which could be teaching experiences as well. Pre-service teachers experience directly their students' dealing with the learning content and the related linguistic requests, the appearing difficulties and feelings of success in a classroom teaching situation, which is totally different from an abstract concept they get when discussing these issues theoretically. Research findings indicate that teachers' motivational orientations have an impact on their PCK including their teaching performance, and their students' outcome (Kalyar et al., 2018; Kunter, 2011; Mientus et al., 2022). Since the RCM assumes that the realms of PCK influence each other, and the arrows in the visualisation of the RCM point in both directions, and teachers' motivational orientations as affective component are included into the models of teachers' competence (Baumert & Kunter, 2006; Blömeke et al., 2015; Carlson & Daehler, 2019; Mientus et al., 2022), the results of Study 2 indicate that it could be the other way round, too: that teaching experience influences teachers' motivational orientations.

It was further hypothesised in Study 2 that training the Plan-Teach-Reflect Cycle of ePCK would enhance pre-service teachers' professional values regarding multilingualism and responsibility for students' language development, which the results did not verify. It is assumed that teachers' professional values have an impact on their professional behaviour (Baumert & Kunter, 2011; Blömeke et al., 2015; Sunley & Locke, 2010), and that they are modifiable (Bardi & Goodwin, 2011; Gollan, 2012). The intervention done in Study 2 only took eight weeks, which is probably too short to have an influence on a person's values which are considered more persistent than beliefs (Corrigan & Smith, 2015).

Written lesson plans are prerequisite for biology lessons (Gropengießer, 2016b), and it is assumed that it is possible to learn to write lesson plans without any teaching experience (Mientus et al., 2022). The planning process of a lesson is part of teachers' ePCK (Alonzo et al., 2019), so evaluating lesson plans should allow evidence about their ePCK, at least $ePCK_P$. It is assumed that the experience of teaching and reflecting lessons feeds into future lesson planning (Alonzo et al., 2019). Therefore, Study 3 investigated the effect of the *Teach-component* of the Plan-Teach-Reflect Cycle of ePCK (Alonzo et al., 2019) on pre-service biology teachers' *$ePCK_P$ in the field of academic and science language*.

The results indicate that training the Plan-Teach-Reflect Cycle of ePCK as a whole or in parts increase participants' $ePCK_P$, and that the effect is strengthened when the Teach-component is included into the cycle. Interestingly enough, results showed that there was no change in participants' $ePCK_P$ in the control group who did not teach their planned lessons, but only presented them to their seminar group, but a big change in the treatment group who taught their planned lessons to students at school. Therefore, the Teach-component seems to play an especially decisive role in this case: the Plan-component belongs to teachers' ePCK and occurs in the macro cycle, just as the Teach-component, whereby the micro cycle is present during the teaching situation only (Alonzo et al., 2019). All participants reflected the presented respectively taught lessons, and this pedagogical reasoning should increase their PCK (Kramer et al., 2021; Mientus et al., 2022), which was not the case in Study 3. Maybe this assumption only applies to teachers' pPCK but not to their ePCK: teachers' pedagogical reasoning also depends on their classroom experience (Gess-Newsome, 1999), thus the Teach-component and the related micro cycle, and teachers need pedagogical reasoning to enact PCK (Loughran, 2019). This is some kind of catch-22: you need pedagogical reasoning to enact PCK, but enacting PCK develops pedagogical reasoning. Hence, it can be assumed that it is necessary to teach in order to learn to teach, and that the Teach-component informs teachers' PCK (Mientus et al., 2022; Mulholland & Wallace, 2005; van Driel et al., 2002), their pPCK as well as their ePCK.

4.1.3. Including the Language in Biology Instruction Into Existing Models of Teachers' Competence

Research findings indicate that academic and science language proficiency is a decisive factor for students' educational success (Childs et al., 2015; Gogolin, 2013; Prediger et al., 2015). Education researchers are demanding to include a focus on language into every learning content for many years (Childs & Ryan, 2018; Gogolin, 2016; Lemke, 1990; Moore, 2007; Osborne, 2002; Riebling, 2013b; Snow, 2010). To meet these demands, science teachers need the appropriate competence, and therefore, it is necessary to include a the language in science instruction into existing models of teachers' competence.

An additional focus on language in biology instruction can be included in models of teachers' competence: teachers' PCK, which is in the focus of most models of teachers' competence (Alonzo et al., 2019; Baumert & Kunter, 2011; Blömeke et al., 2015; Carlson & Daehler, 2019; Förtsch et al., 2018; Meschede et al., 2017; Mientus et al., 2022; Seidel & Stürmer, 2014; Shulman, 1986; Stürmer, Könings, & Seidel, 2013), can be described for the field of academic and science language, as shown by Drumm (2016) and Nitz (2016) for biology, by Markic (2018) and Mönch and Markic (2022) for chemistry, and by Tajmel (2013a) and Tajmel and Hägi-Mead (2017) for physics.

Teachers' competence is not only defined by their knowledge, but by affective-motivational factors as well (Baumert & Kunter, 2011; Blömeke et al., 2015; Carlson & Daehler, 2019; Park & Suh, 2019). Teachers' professional values are assumed to influence their professional performance (Baumert & Kunter, 2006; Palermo & Thomson, 2019; Sunley & Locke, 2010). Regarding language in their lessons, many science teachers are not aware that language education could be one of their tasks (Markic, 2014; Mönch & Markic, 2022), they expect their students to already have the necessary academic language proficiency (Dirim & Springsits, 2022; Gogolin, 1994, 2010), and they do not appreciate multilingualism (Mecheril et al., 2010; Mecheril & Quehl, 2006; Schmidt, 2009). Since Mönch and Markic (2022) draw the conclusion that teachers' awareness of the role of language influences their PCK in the field of academic and science language, teachers' professional values regarding multilingualism and responsibility for language education should be taken into account when considering teachers' competence in the light of language in science education. Teachers' motivational orientations influence their achievement choices, and how strong, how well and how long they maintain a certain behaviour (Baumert & Kunter, 2011; Han & Yin, 2016; Kunter, 2011; Mitchell, 1997; Wigfield & Eccles, 2000). That is why teachers' motivational orientations to implement language-sensitive biology instruction cannot be left out when teachers are demanded to do so.

Teachers need their situation-specific skills (Blömeke et al., 2015) to make decisions before and within the teaching situation, which is also known as noticing and knowledge-based reasoning (Seidel & Stürmer, 2014), or as pedagogical reasoning (Carlson & Daehler, 2019). Teachers need to notice relevant events for students' learning, thus to draw their attention to them during the lesson (Seidel & Stürmer, 2014; Stürmer & Seidel, 2015), and to reason about them using their PCK (Santagata & Yeh, 2016; van Es & Sherin, 2002). Several authors described potential linguistic hurdles (Becker-Mrotzek et al., 2013; Beese et al., 2015; Brandt & Gogolin, 2016; Bunch, 2013; Busch & Ralle, 2013; Dirim & Knappig, 2018; Drumm, 2013, 2016; Gogolin, 2011, 2019; Kniffka, 2013; Lange, 2020; Leisen, 2017; Lengyel, 2010, 2016; Mecheril & Quehl, 2015; Moore, 2007; Morek & Heller, 2012; Nitz, 2016; Snow, 2010), therefore relevant events regarding students' language proficiency teachers need to notice and reason about. Teachers' performance in class (Blömeke et al., 2015), the teaching experience itself, is considered a decisive factor for teachers' PCK-development, whereby the pedagogical reasoning moderates the development process (Mientus et al., 2022). Therefore, the experience of students struggling with and overcoming linguistic hurdles in science lessons, the discourse with the students about these experiences and possible solution strategies (Gogolin, 2011; Tajmel & Hägi-Mead, 2017), should contribute to teachers' PCK in the field of academic and science language.

That leads to the conclusion that each model of teachers' competence, and each component within these models can be considered in the light of language in biology instruction, which is prerequisite to develop adequate strategies to foster (pre-service) biology teachers' PCK in the field of academic and science language they need to teach biology lessons of high quality.

4.1.4. Developing Materials to Assess Biology Lesson Plans and Biology Instruction on the Basis of the Research Findings

It is necessary to assess biology lessons to be able to determine their quality and to measure modifications. Carlson and Daehler (2019) describe teachers' performance in class as ePCK, which is considered unique and appearing only in action – what makes it impossible, or at least difficult to assess. Alonzo et al. (2019) suggest to differentiate teachers' ePCK according to the three steps of teaching plan-teach-reflect. Following this suggestion led to the development of a test instrument which enables to assess biology lesson plans.

This assessment file for biology lesson plans was developed on the basis of a model to plan biology lessons (Dorfner et al., 2019), and a rating manual for physics lessons (Schröder et al., 2019; Schröder et al., 2020). First of all, it intended to rate pre-service biology teachers' lesson plans in the framework of Study 1 and Study 3 in order to measure their ePCK, whereby it showed good item fit values, and acceptable values for homogeneity and objectivity. Its development followed recommended criteria for content and construct validity (Reeves & Marbach-Ad, 2016). Its focus is on biology-specific lesson quality features (Wüsten, 2010), particularly on cognitive activation and embedding of scientific work, and includes appropriate language use and scaffolding. Therefore, it can be used to rate any biology lesson plans independent from their content.

There are various reasons and opportunities to assess lesson plans, especially during teacher education (Gropengießer, 2016b): lesson plans are assessed to grade (pre-service) teachers as well as to have a basis for advice and further development during teacher education. Therefore, teacher educators need an objective instrument for their assessment, which can be shared with the assessed persons to provide more transparency. Since the developed assessment file showed good test quality, it was published for the use not only in research, but in teacher education as well (Publication IV).

The settings of Study 1, Study 2 and Study 3 were obligatory biology education seminars, in which pre-service biology teachers planned biology lessons, taught or presented them, and reflected on them. Therefore, it was necessary to have a basis for the reflection, and a structured observation file had to be developed. There are published observation files for lessons, but they usually focus on general lesson quality features (e.g., Barendsen & Henze, 2019; Echevarria et al., 2017; ISB, 2022b). On the basis of the model of professional vision (Seidel & Stürmer, 2014; Stürmer & Seidel, 2015), an observation file which focusses on the same biology-specific criteria as the assessment file for lesson plans was developed and used within the three studies. Since teachers need professional vision to be able to make reasonable decisions during their lessons (Seidel & Prenzel, 2007; van Es & Sherin, 2002), it is possible to train these skills (Santagata & Yeh, 2016; Sherin & van Es, 2009), and the training increases teachers' PCK (Kramer et al., 2021), the observation file was published for the use in teacher education (Publication V).

4.2. Limitations

There are some limitations of Study 1 – 3: first of all, the sample sizes of all studies were quite small, since they were conducted in the framework of the teacher education programme at the chair of Biology Education at the LMU Munich. This procedure affects the representativeness of the results, too: all participants joined the same teacher education programme with its regional specifics. Therefore, the results can be considered representative for pre-service biology teachers at the LMU Munich, but maybe not for other samples without limitations. The design of Study 2 and Study 3 did not provide fully experimental conditions, since participants chose themselves if they joined the treatment or the control group, depended on their timetables. Furthermore, the participants were tested at the beginning and at the end of obligatory seminars, so it cannot be excluded that the results could be influenced by pre-service teachers' aim to collect ECTS credits. Since neither the tests themselves nor participants' performance during the seminars were graded, these possible distortions are considered marginal. However, the procedure of the three studies also brings advantages: the fact that the studies were integrated into the usual biology teacher education programme leads to high ecological validity, and makes possible that the findings can be applied directly to further develop teacher education programmes and trainings. Again and again, teachers complain about the "research-practice-gap" (Korthagen, 2007; Runesson Kempe, 2019), they feel that the research and lectures done at university are not congruent with school reality. Since Study 2 and Study 3 were done in cooperation with a partner school, and the effects of the real classroom situation on pre-service teachers' PCK were investigated, the results of these studies should reduce the research-practice-gap.

Study 1 aimed to detect filters between the three realms of PCK on the basis of the RCM. In contrast to the RCM framework, the study was done with pre-service teachers instead of in-service teachers. The difference between experts and novices (e.g., Großschedl et al., 2019) in teaching may distort the results. Since Study 1 was done with pre-service teachers from a teacher education programme which enables them to teach students up to A-levels (academic track teachers) and quite at the end of their studies, and research results indicate that pre-service teachers' PCK has its highest level at the end of their university education, and that academic track pre-service teachers' PCK level is higher than that of non-academic track pre-service teachers, and very close to in-service teachers' PCK (Kleickmann et al., 2013), the difference regarding PCK itself should be reduced to a minimum. Nevertheless, since the findings revealed significant moderation models for professional values and motivational orientations as filters between cPCK and pPCK, but no significant moderation effects, Study 1 should be repeated with a group of in-service teachers.

Furthermore, all test instruments used were adapted or developed in the framework of the three studies. The adaption as well as the development followed the recommendations of Reeves and Marbach-Ad (2016): for content validity, items were adapted respectively developed on the basis of a literature review. These items were submitted to a group of biology-education researchers and in-service biology teachers who were asked to answer the items, and then to give their feedback, for example if they knew what to do in any case, if they would recommend another wording, or if they missed anything important. For construct validity, the Wright maps of the Rasch analysis (Aryadoust, 2009; Boone & Rogan, 2005) were evaluated: all of them showed even distribution of item difficulties, and items which were easier to agree with were located at the lower end of the Wright maps, whereby items which were more difficult to agree with were located at the upper end of the Wright maps. All test instruments showed acceptable values for item reliability which indicates construct validity of the test instrument (Linacre, 2022a). Therefore, all test instruments can be considered acceptable validity. For all test instruments which requested coding, ten percent of the sample were double coded by two independent researchers, who showed a high agreement in any case. Therefore, all test instruments can be considered acceptable objectivity. The tests were based on the Rasch partial credit model (PCM; Linacre, 2022b; Planinic et al., 2019), and all of them showed good item fit values which indicates that there were no alarming outliers (Wright & Linacre, 1994). Most of the test instruments showed acceptable values for person reliability which allows a statement about the test reliability, such as for example Cronbach's Alpha (Linacre, 2022b). The person reliability scores of the noticing- and the knowledge-based reasoning-test used in Study 1, and the professional values-test used in Study 2 were at the lower end. This indicates that they were not able to distinguish more than two groups of pre-service teachers: those with high and those with low noticing/knowledge-based reasoning/professional values. Therefore, the test instruments measuring pre-service teachers' pPCK, ePCK and motivational orientations can be considered acceptable reliability.

4.3. Implications for Future Research

The focus of science education research is on teachers' PCK for many years, at least since Lee S. Shulman coined the term *pedagogical content knowledge* in 1986. This research has not yet come to an end, and the introduction of the RCM (Carlson & Daehler, 2019) opened up new perspectives (Mientus et al., 2022) to which this dissertation may contribute.

The results of Study 1 indicated that knowledge-based reasoning moderates the transformation between pPCK and ePCK, and therefore could be regarded as a filter. Since the person reliability scores of the test instrument were at the lower end, more items should be included for further research (Linacre, 2022a). In the next step, further filters should be identified: only if we know which factors contribute to teachers' development of PCK and which ones obstruct this process, we are able to create the best possible conditions for teachers' learning processes during university teacher education and in-service teacher trainings. Therefore, the necessary research should be conducted with pre-service as well as in-service teachers in order to detect differences and similarities. Study 1 focused on professional values, motivational orientations, noticing and knowledge-based reasoning as hypothesised filters. Carlson and Daehler (2019) considered the learning context in particular as a filter between cPCK and pPCK. Therefore, this huge construct should be differentiated into single factors to make it measurable, for example political requirements, equipment of school and classroom, parents' engagement for school issues, students' language proficiency. Using regression analyses, potential impact factors could be detected. Study 1 hypothesised the moderation effects in one direction, whereby the RCM describes the transformation processes between the realms of PCK in both directions (Carlson & Daehler, 2019). Therefore, future research should consider and investigate this bidirectionality.

Study 1 and Study 3 dealt with ePCK (Alonzo et al., 2019; Carlson & Daehler, 2019), and assumed that $ePCK_P$ could map a teacher's ePCK approximated. To catch better the core of ePCK as far as possible, future research should focus on $ePCK_T$, for example by videotaping and coding lessons, and on $ePCK_R$, for example by generating think-aloud protocols of reflection processes or by videotaping these as well. This way, correlations between the manifestations of ePCK could be investigated and therefore, possibly support the assumption that measuring $ePCK_P$ allows a valid statement on teachers' ePCK. Alonzo et al. (2019) argue that ePCK is tacit and unarticulated in general, which implies that written lesson plans or think-aloud protocols of a lesson reflection would not allow a statement on teachers' ePCK, but on their pPCK. If one followed this argumentation, only evaluations of videotaped teaching situations would be appropriate to map ePCK.

The research group around Susanne Prediger investigated the effects of different linguistic scaffolding strategies on students' outcomes in mathematics (e.g., Prediger et al., 2022; Prediger & Wessel, 2018; Wessel & Prediger, 2017), which has not been done for biology until today. Silvija Markic and her colleagues integrated the language in science instruction into models of science teachers' PCK (e.g., Childs et al., 2015; Markic, 2018; Mönch & Markic, 2022). Future research should investigate in which way science teachers' PCK in the field of academic and science language has an impact on students' performance in science, as done in the framework of the ProwiN project: 85 biology lessons were videotaped and coded with a focus on the lesson quality feature cognitive activation; the PCK of the participating biology teachers was measured as well as their students' achievement. This way, Förtsch et al. (2016) detected the indirect effect of teachers' PCK on students' outcomes, mediated through cognitive activation. It is conceivable that similar relations could be found for teachers' PCK in the field of academic and science language, appropriate scaffolding strategies as mediator variable, and students' outcomes.

In the framework of this dissertation, an assessment file for biology lesson plans and an observation file for biology lessons were developed. Following the recommendations of Hattie (2012), assessment criteria need to be made transparent for the assessed persons: therefore, it was argued in Publication IV and Publication V that both files would help teacher educators making assessment criteria (more) transparent to pre-service and trainee teachers in order to enhance their performance. On the one hand, it would be interesting to know if the files are used for the suggested purpose, and if this is the case in which way. This could be investigated by a questionnaire distributed to German teacher educators. On the other hand, it could be hypothesised that the consequent use of the files within teacher education programmes increases pre-service and trainee teachers' PCK. Therefore, an intervention study would be appropriate.

Students weak in language and multilingual students speaking the "wrong" language are at risk to be discriminated against at school (Dirim & Springsits, 2022; Mecheril et al., 2010; Mecheril & Quehl, 2006; Schmidt, 2009). Although the findings of this dissertation do not contribute to insights into teachers' professional values regarding multilingualism and responsibility for students' language development, this construct should be kept in focus: several authors with different backgrounds assume that teachers' professional values influence their performance in class (e.g., Baumert & Kunter, 2006; Flynn & Bruce, 2019; Oser, 1996; Palermo & Thomson, 2019; Ryndak & Saldaeva, 2019; Sunley & Locke, 2010). Therefore, teachers' professional values should be differentiated into value types in a first step, for example according to the work of Huch et al. (2012) who focused on students' values regarding sexual orientations. In a second step, the relation between teachers' value type and students' outcomes should be investigated via path analyses. In a third step, strategies to foster the development of those value types having the highest impact on students' outcomes should be developed and tested within intervention studies. Possible interventions could be designed on the basis of for example Derman-Sparks' (1989) Anti-Bias Curriculum, or Bardi and Goodwin's (2011) Dual Route to Value Change.

4.4. Implications for Science Teacher Education

“Change begins when people decide to do things differently. Each change spreads in unpredictable ways, leading to other changes.” (Lemke, 1990, p. 167)

The research findings of this dissertation have already been implemented into the biology teacher education programme at the chair of Biology Education at the LMU Munich: the necessity of appropriate language use and scaffolding as a requirement for biology instruction of high quality was included into obligatory seminars for all pre-service teachers in teacher education programmes for primary as well as for secondary schools. One aspect would be the transfer of PCK in the field of academic and science language: the significance of language for learning processes (Childs et al., 2015; Prediger, 2013), necessary language registers (Riebling, 2013a), specific characteristics of biology-specific science language (Drumm, 2016; Nitz et al., 2011; Nitz et al., 2012), implications for lesson planning such as thinking about linguistic learning objectives in addition to cognitive learning objectives (Tajmel, 2011, 2013b), and scaffolding strategies (Kniffka, 2010; Tajmel & Hägi-Mead, 2017). The other aspect aims at the affective components of teachers’ competence, whereby a suggestion of Tajmel and Hägi-Mead (2017, p. 28) is used: the pre-service biology teachers are demanded to watch a short video showing a simple experiment which can be situated in grade 5 at any secondary school, and to write a scientific protocol in their second-best language, except German. Most of the pre-service teachers choose English as their second-best language, some of them choose the language spoken at home. Nearly all of them struggle with the task: they do not have the necessary vocabulary, the appropriate grammatical structures, they are not able to “think” the really simple experiment in the other language – even those pre-service teachers using their mother tongue different from German. On the one hand, they experience the meaning of the term “language registers” in this situation: academic and biology-specific science language is required to write a biology-specific protocol, registers they (usually) do not use in another language than German. On the other hand, they experience the emotions caused by the situation: they feel helpless, uncomfortable, sometimes even ashamed or stupid, as if they should be able to fulfil their task smoothly. From this experience, they feel the need to develop helpful strategies to make biological content accessible for their future students.

As Study 1 indicates that pre-service teachers’ PCK development is moderated by their knowledge-based reasoning, the developed observation file for biology lessons is used within obligatory seminars and internships at school to observe biology lessons on the basis of the predefined criteria structure of the lesson, cognitive activation, embedding of scientific work, appropriate language use and scaffolding. Therefore, it is intended to train pre-service teachers’ professional vision (Seidel & Stürmer, 2014; Stürmer & Seidel, 2015) parallel to their development of PCK.

The assessment file for biology lesson plans is based on the same criteria as the observation file. These criteria are made transparent to the pre-service teachers (Hattie, 2012), used during obligatory seminars to advise pre-service teachers during their lesson planning, to reflect about lessons, and to grade lesson plans in the case of examinations. The setting

"Uniklasse" in cooperation with a partner school is included into obligatory seminars for all pre-service teachers in teacher education programmes for secondary schools.

This dissertation focused on pre-service biology teachers' professional competence. Since the natural sciences are very close to each other, show overlapping areas and a similar way of thinking, and aim to develop scientific literacy, the results should be applicable to chemistry and physics as well. Therefore, on the basis of the ecological valid findings of this dissertation, the following implications are recommended for science teacher education in general: the language in science instruction should be included into all science teacher education programmes as demanded for all learning subjects by many researchers and institutions (Brandt & Gogolin, 2016; Childs et al., 2015; Childs & Ryan, 2018; Dirim et al., 2018; Dirim & Khakpour, 2018; Drumm, 2016; Gogolin, 2011, 2013; ISB, 2022a; KMK, 2005a; Lange, 2012; Leisen, 2017; Lengyel, 2012; Markic, 2018; Moore, 2007; Nitz, 2016; Osborne, 2002; Riebling, 2013b; Schleppegrell, 2012; Schmölzer-Eibinger, 2013; Snow, 2010; Tajmel et al., 2009; Tajmel & Hägi-Mead, 2017; Thürmann & Vollmer, 2013) to make scientific content accessible for learners. Hereby, pre-service teachers' PCK in the field of academic and science language should be addressed as well as their professional values regarding multilingualism and responsibility for students' language development, and their motivational orientations to implement language-sensitive instruction. Since many in-service science teachers are not aware that language education could be one of their tasks (Markic, 2014; Mönch & Markic, 2022), and if so, do not feel well prepared (Tajmel, 2013b), trainings for in-service teachers are recommended as well. The area of science language needs to be adapted to the specifics of chemistry and physics.

Furthermore, the Teach-component should be included into science teacher programmes: both pre-service teachers' pPCK and ePCK as well as their motivational orientations benefit from the teaching experience. Other researchers recommend university-guided internships at school (e.g., Santagata & Yeh, 2014; Stürmer, Seidel, & Schäfer, 2013) as well, and the research findings of this dissertation support their recommendations. If there is no possibility to implement internships connected to the university or partnerships with a school which allow seminars in the classroom, at least simulations of science lessons instead of presentations of lesson plans could be an alternative. In any case, pre-service teachers' knowledge-based reasoning should be trained together with their PCK, since the findings of this dissertation indicate that the better pre-service teachers' knowledge-based reasoning, the better is their PCK – and from a certain point the lack of knowledge-based reasoning can lead to a decrease of PCK. Therefore, the observation file for biology lessons can be used, and be adapted for chemistry and physics lessons.

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6. Abbreviations

A	Aim
BICS	Basic Interpersonal Communicative Skills
BMBF	Bundesministerium für Bildung und Forschung
CALP	Cognitive/Academic Language Proficiency
CK	Content Knowledge
COACTIV	Cognitive Activation in the Classroom: The Orchestration of Learning Opportunities for the Enhancement of Insightful Learning in Mathematics
cPCK	collective Pedagogical Content Knowledge
ePCK	enacted Pedagogical Content Knowledge
IQB	Institut zur Qualitätsentwicklung im Bildungswesen
ISB	Staatsinstitut für Schulqualität und Bildungsforschung
KMK	Ständige Kultusministerkonferenz der Länder
LPO	Ordnung der Ersten Prüfung für ein Lehramt an öffentlichen Schulen
mRNA	messenger Ribonucleic Acid
NOS	Nature of Science
OECD	Organisation for Economic Co-operation and Development
PCK	Pedagogical Content Knowledge
PISA	Programme for International Student Assessment
PK	Pedagogical Knowledge
pPCK	personal Pedagogical Content Knowledge
Q	Research Question
RCM	Refined Consensus Model of Pedagogical Content Knowledge
Sars-CoV-2	Severe Acute Respiratory Syndrome Coronavirus Type 2

Erklärung über die Eigenanteile bei Co-Autor*innenschaft

Hiermit wird bestätigt, dass folgende fünf Publikationen und ein Manuskript federführend von Franziska Behling im Rahmen ihrer Disseration abgefasst wurden. Dies geschah mit folgenden Anteilen:

Publikation I

Behling, F., Förtsch, C. & Neuhaus, B. J. (2022). The Refined Consensus Model of Pedagogical Content Knowledge (PCK): Detecting Filters Between the Realms of PCK. *Education Sciences*, *12*(9), https://doi.org/10.3390/educsci12090592.

Franziska Behling hat federführend die Studie geplant, die Studie durchgeführt, die benutzten Testinstrumente neu bzw. weiterentwickelt, die Daten statistisch ausgewertet, die Daten für die Publikation aufgearbeitet, den Artikel konzipiert und ihn federführend geschrieben.

Die Co-Autor*innen wirkten bei der Planung der Studie und der Neu- bzw. Weiterentwicklung der Testinstrumente mit, unterstützten bei der Datenerhebung und -deutung und trugen substantiell zur Überarbeitung der Publikation bei.

Publikation II

Behling, F., Förtsch, C. & Neuhaus, B. J. (2022). 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. *Education Sciences, 12*(10), https://doi.org/10.3390/educsci12100654.

Franziska Behling hat federführend die Studie geplant, die Studie durchgeführt, die benutzten Testinstrumente neu bzw. weiterentwickelt, die Daten statistisch ausgewertet, die Daten für die Publikation aufgearbeitet, den Artikel konzipiert und ihn federführend geschrieben.

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Manuskript I

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Behling, F., Förtsch, C. & Neuhaus, B. J. (2019). Sprachsensibler Biologieunterricht – Förderung professioneller Handlungskompetenz und professioneller Wahrnehmung durch videogestützte live-Unterrichtsbeobachtung. Eine Projektbeschreibung. *Zeitschrift für Didaktik der Naturwissenschaften*, *25*(1), 307–316. https://doi.org/10.1007/s40573-019-00103-9.

Franziska Behling hat federführend die Forschungsfragen entwickelt, die Studie geplant, den Artikel konzipiert und ihn federführend geschrieben.

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Publikation IV

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Franziska Behling hat federführend den vorgestellten Bewertungsbogen entwickelt, den Artikel konzipiert und ihn federführend geschrieben.

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Publikation V

Behling, F., Förtsch, C. & Neuhaus, B. J. (2022). Biologieunterricht bewerten II: Vorstellung eines theoriebasierten Bewertungsbogens zur Qualitätseinschätzung von Artikulationsschemata. *MNU Journal*, *75*(2), 154–158.

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München, den 16.11.2022

………………………………..

Franziska Behling

München, den 16.11.2022

………………………………..

Prof. Dr. Birgit J. Neuhaus

Eidesstattliche Erklärung

Ich versichere hiermit an Eides Statt, dass die vorgelegte Dissertation von mir selbstständig und ohne unerlaubte Hilfe angefertigt worden ist.

München, den 16.11.2022

………………………………..

Franziska Behling

Erklärung

Hiermit erkläre ich, dass die Dissertation nicht ganz oder in wesentlichen Teilen einer anderen Prüfungskommission vorgelegt worden ist und dass ich mich nicht anderweitig einer Doktorprüfung ohne Erfolg unterzogen habe.

München, den 16.11.2022

………………………………..

Franziska Behling