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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

Franziska Behling *, Christian Förtsch and Birgit J. Neuhaus

Faculty of Biology, Biology Education, LMU Munich, 80797 Munich, Germany
* Correspondence: franziska.behling@bio.lmu.de

Abstract: In this article, we analyse how to improve pre-service biology teachers' pPCK (personal Pedagogical Content Knowledge), professional values and motivational orientations in the field of academic and scientific language. On the basis of the theory of the Refined Consensus Model of PCK (RCM), we made a two-month quasi-experimental intervention study with 32 pre-service biology teachers. As a treatment, we trained the participants in the *Plan–Teach–Reflect Cycle of enacted PCK* in a school class, in the framework of a seminar. In the control group, the teaching of the cycle was replaced by presentations of their lesson plans. As dependent variables, we analysed participants' pPCK, professional values and motivational orientations. Our results showed an increase in pre-service biology teachers' pPCK ($F(1,28) = 3.51$, $p = 0.04$, part. $\eta^2 = 0.11$, $d = 0.70$) and motivational orientations ($F(1,23) = 29.68$, $p < 0.01$, part. $\eta^2 = 0.56$, $d = 2.26$) in both groups, but no effects on participants' professional values. The teaching experience in a school class strengthened the effects both in participants' pPCK ($F(1,28) = 2.92$, $p = 0.04$, part. $\eta^2 = 0.10$, $d = 0.67$) and motivational orientations ($F(1,23) = 7.64$, $p < 0.01$, part. $\eta^2 = 0.25$, $d = 1.15$). We recommend integrating the use of the *Plan–Teach–Reflect Cycle of ePCK* into science teacher education programmes.

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

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1. Introduction

Recent PISA measures have demonstrated that German students' average science performance follows an increasingly negative trend across PISA assessments [1]. What is the problem? Possibly the fact that students need to have scientific language proficiency in solving PISA scientific literacy tasks [2] and that it is impossible to perform in science without having the appropriate language proficiency [3]. Students' achievement in biology indirectly depends on teachers' pedagogical content knowledge (PCK; [4]), which is considered to be most relevant for teaching and, therefore, for students' educational success [5–7]. The focus in science education research has been on teachers' PCK since the 1980s when Shulman [8] proposed his idea of teachers' knowledge of students' (pre-)conceptions and how to deal with them, as well as useful forms of representation to make content comprehensible for learners. Hereby, he thinks of teachers' PCK as an overlap between their pedagogical knowledge (PK) and their content knowledge (CK) [8]. For several years, researchers have suggested adding a further component to this model, technological knowledge (TK, e.g., [9,10]). Therefore, the component of technological pedagogical content knowledge results from the overlap between teachers' PCK and their TK [9,11]. Following Shulman's [8] definition of PCK, Carlson and Daehler [7] described the Refined Consensus Model of PCK (RCM), in which several international researchers brought together the different models of teachers' PCK. In describing the RCM, they also assumed that several factors influence teachers' construction of PCK, e.g., their attitudes and beliefs [7], which are also called professional values and motivational orientations [12]. Since there are hints that there is a lack of biology teachers' PCK in the field of academic and scientific language [13], we briefly describe the RCM and use it as a basis for an intervention study designed to examine pre-service biology teachers' professional values and motivational orientations and to improve their PCK in the field of academic and scientific language.

1.1. The Refined Consensus Model of PCK (RCM)

The RCM [7] describes teachers' PCK in the form of a concentric circle with three realms of PCK lying within each other (Figure 1): *collective PCK* (cPCK, PCK shared among the science education community) as an outer circle, *personal PCK* (pPCK, each teacher's assimilated PCK) as a middle circle, and *enacted PCK* (ePCK, each teacher's applied PCK appearing only in a concrete teaching situation) as an inner circle.

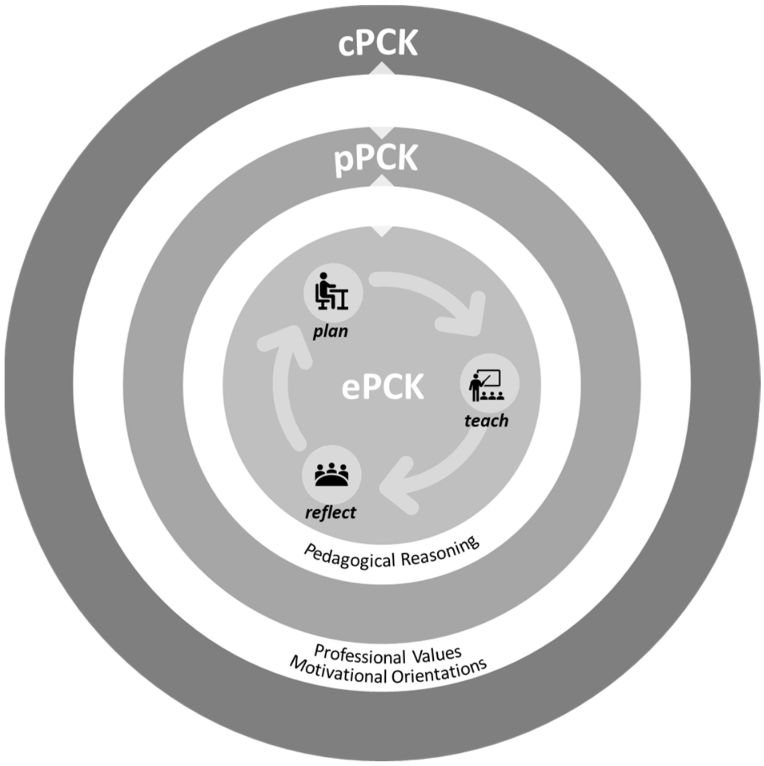

Figure 1. The Refined Consensus Model of Pedagogical Content Knowledge (RCM) based on Carlson and Daehler [7] with the *Plan–Teach–Reflect Cycle of ePCK* in the centre: the white circles symbolise the assumed filters between the three realms of PCK.

Collective PCK (cPCK). The science education community permanently collects, shares and publishes PCK; teaching experience documented by teachers contribute to this collection of PCK, adding to the professional knowledge bases content knowledge and pedagogical knowledge [8,12]. This kind of PCK is called *cPCK* [7].

Personal PCK (pPCK). When teachers are confronted with cPCK, e.g., in the framework of teacher training sessions or communication situations with colleagues, they integrate (parts of) it into their own knowledge and construct an internalised form of PCK, which is called *pPCK* [7]. When teachers share their pPCK with the science education community, e.g., by articulating their knowledge and experiences, pPCK will be transformed into cPCK.

Teachers' attitudes and beliefs, which are also known as professional values and motivational orientations [12], are considered to play decisive roles as so-called filters in the transformation process between cPCK and teachers' pPCK [7]. In the following text, we use the terms professional values and motivational orientations.

Professional values address moral aspects such as teachers' care and responsibility for students, fairness and integrity [14–17], their dealing with their own prejudices, and the power they possess over their students [18–21]. It is assumed that teacher's professional values influence their professional performance, but it has not yet been clarified in which way they exactly do that [14,17,22]. The inverse is also assumed; that a person's (professional) values can be changed by external influences [23–25], e.g., teaching situations or dealing with one's own power and prejudices [26].

Motivational orientations describe teachers' ability beliefs and enthusiasm [12,27,28]. They determine the intensity, quality and duration of teachers' behaviour [27–29]. Teachers having strong ability beliefs use more innovative and effective methods and seem to be more resilient in their professional life [28,30]. Teachers' enthusiasm—for their profession and the subject they teach—is considered an important characteristic of effective teaching [31,32]. Research results indicate that motivational orientations are not stable personality traits but vary depending on the learning group or the professional context [28,33], which indicates that they can be enhanced by teaching situations or teacher training.

Enacted PCK (ePCK). In any teaching situation, teachers have to apply their pPCK by choosing teaching strategies, teaching materials or tasks to structure students' learning process. This applied PCK, which only occurs in action, is called *ePCK* [7]. Since each teaching situation is unique and not repeatable, ePCK is unique and not repeatable either. That is why Alonzo et al. [5] differentiate between the three steps of teaching: in the first step, teachers **p**lan their lessons and therefore generate $ePCK_P$. In the next step they use their lesson plan to **t**each the lesson in class, which is when they generate $ePCK_T$. In the final step, they **r**eflect on the lesson taught and generate $ePCK_R$. This reflection feeds into their next lesson planning process—the *Plan–Teach–Reflect Cycle of ePCK* is complete. Each expression of ePCK influences and develops teachers' pPCK.

Teachers' pedagogical reasoning, also known as knowledge-based reasoning [34], is thought to moderate the transformation process between teachers' pPCK and ePCK [7,35].

The visualisation of the RCM as concentric circles (Figure 1) shows the close relationships between the three realms of PCK: the *Plan–Teach–Reflect Cycle of ePCK* builds the core of PCK symbolised by the inner circle; this is embedded in pPCK, symbolised by the middle circle, and enclosed by cPCK, symbolised by the outer circle ([7]; Figure 1).

Since we are going to apply the RCM to pre-service biology teachers' PCK in the field of academic and scientific language, we briefly introduce the importance of language in teaching and learning biology.

1.2. Language in Teaching and Learning Biology

It is impossible to access cognitively demanding learning subjects without language proficiency [2,3,36]. Several studies have shown that students' social background and, in particular, academic language skills are the most relevant predictors of educational success [37–39]. What are these "academic language skills"? For science education, three so-called language registers, areas of language characterised by specific vocabulary and grammar [40], are considered relevant: the everyday register, the academic register and the science register [37,41,42].

The biology-specific *science register* is characterised by specific forms of representation and technical terms [43,44]. Students weak in language struggle especially with technical terms having different meanings in the science register than they do in the everyday register [45], e.g., the term "niche" in everyday language describes a small space, but in biology-specific scientific language, it relates to habitat adaption. Biology lessons often contain models or schemes to make abstract concepts and processes accessible for students [46], so students have to be enabled to use and to create such forms of representation themselves.

The *academic register*, to which "academic language skills" are related, is particularly characterised by such grammatical structures as passive constructions, nominalisations and a high level of abstraction and information density [42,47–49]. Academic language skills are necessary for understanding articles in newspapers or news programmes, reading texts in school books, and understanding exam questions. Since academic language proficiency is the greatest impact factor for educational success [38,49] and forms the basis of scientific language proficiency [36,50], students weak in language are at risk of being excluded from learning subjects [21,51,52], and not all students attend school prepared well enough to engage in the academic register [53].

The *everyday register* relates to everyday contexts where (oral) communication usually takes place between physically present persons. In these situations, it is not necessary to use especially precise language since one can use gestures and miming [47].

Students need to be able to switch between these registers in an appropriate way and to understand and produce texts themselves [41] for them to be able to achieve scientific literacy. There are many demands to support students' academic language proficiency [52–58].

1.3. The RCM and the Language in Biology

Since teachers' PCK indirectly influences students' performance [4], biology teachers need appropriate PCK in the field of academic and scientific language to improve their students' academic and scientific language proficiency. They, therefore, need biology-related linguistic knowledge for teaching biology adequately (described for chemistry by Markic [59]) and in the areas of knowledge about language registers, language-related learning difficulties and appropriate scaffolding strategies.

Many science teachers are not aware that language education might be one of their tasks [60,61]. Furthermore, the German school system, in particular, is characterised by the so-called monolingual habitus [62,63], the phenomenon that teachers expect their students to speak one language, in this case, German, while multilingualism has long been a reality in German schools [62,64,65] as well as in many other countries. Teachers do not tend to appreciate this fact and rank students' languages according to their social prestige: there are prestigious languages such as English and French, and languages considered to have linguistic deficits that need to be "remedied", such as Bosnian and Turkish [20,51,64,66]. We assume these aspects to be very important for the teachers' task of improving their students' performance in academic and scientific language and suggest considering teachers' *professional values regarding multilingualism and responsibility for language education* when using the RCM to determine teachers' development of PCK in the field of academic and scientific language. Since teachers' enthusiasm and ability beliefs influence their achievement choices, their professional performance, effort and persistence [12,67,68], teachers' *motivational orientations to implement language-sensitive biology instruction* should influence their development of PCK in the field of academic and scientific language as well. These assumptions are congruent with the findings of Mönch and Markic [61], who identified teachers' awareness of scientific language and their own role in students' learning process in this field as an important factor for the transformation process between cPCK and pPCK in the field of scientific language. Since it is assumed that both professional values [23,24,26] and motivational orientations [22,28,33] can be influenced by teaching situations, they should also be influenced by teachers' PCK in the field of academic and scientific language and associated classroom experiences.

Considering the importance of academic and scientific language proficiency for students' learning in biology (e.g., [3,37,45,49]), we strongly need appropriate teacher education programmes to improve (future) biology teachers' PCK in the field of academic and biology-specific scientific language as well as their professional values regarding multilingualism and responsibility for language education and motivational orientations to implement language-sensitive biology instruction.

2. Research Questions and Hypotheses

Within this study, we varied the use of the *Plan–Teach–Reflect Cycle of ePCK* [6] as independent variable and analysed its effects on pre-service biology teachers' (a) pPCK, (b) professional values and (c) motivational orientations (Figure 2). We were interested in the following research questions and hypotheses:

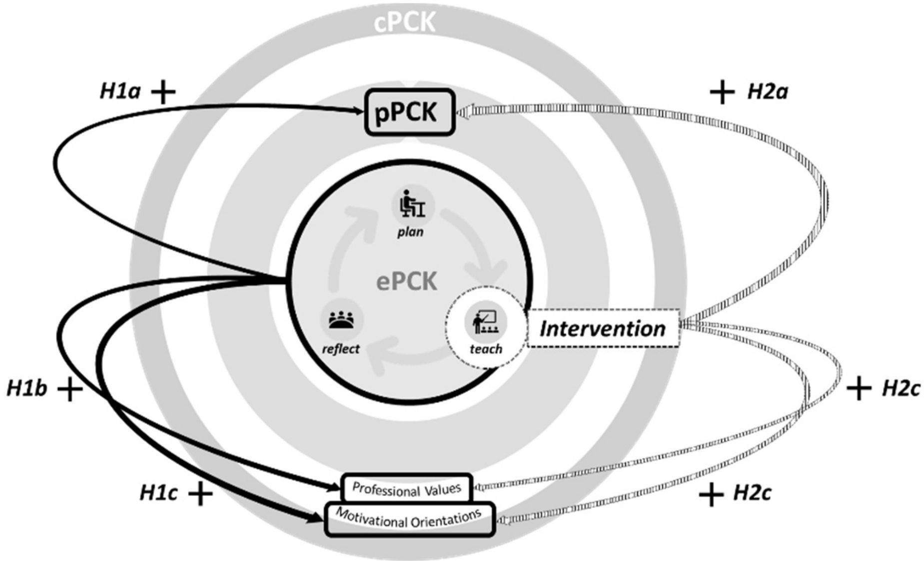

Figure 2. Graphical illustration of hypotheses 1 & 2.

Research Question 1: How does the training of the *Plan–Teach–Reflect Cycle of ePCK* as a whole or in part influence pre-service biology teachers' pPCK, professional values and motivational orientations?

Hypothesis 1: Training the *Plan–Teach–Reflect Cycle of ePCK* to pre-service biology teachers enhances their . . .

H1a: . . . pPCK.

H1b: . . . professional values regarding multilingualism and responsibility for language education.

H1c: . . . motivational orientations to implement language-sensitive biology instruction.

Research Question 2: How important is the *Teach* component in the *Plan–Teach–Reflect Cycle of ePCK?*

Hypothesis 2: Training the whole *Plan–Teach–Reflect Cycle of ePCK* has a higher effect on pre-service biology teachers *than replacing the Teach component with oral presentations of lesson plans.* This higher effect can be assumed for pre-service biology teachers' . . .

H2a: . . . pPCK.

H2b: . . . professional values.

H2c: . . . motivational orientations.

3. Methods

3.1. Setting

In this study, we tested our hypotheses in an obligatory beginners' seminar for pre-service biology teachers in the framework of our teacher education programme. This seminar imparts biology-specific PCK, including academic and scientific language. The pre-service teachers had to use it to plan parts of biology lessons, e.g., an introduction or the elaborate use of a model. The seminar's duration was 90 min, once a week for two months. Three ECTS credits (European Credit Transfer and Accumulation System; one ECTS-credit corresponds to 25–30 working hours) can be acquired.

3.2. Design and Procedure

The quasi-experimental study was conducted in a pre-post-test design (Figure 3). As an independent variable, the *Plan–Teach–Reflect Cycle of ePCK* [5] was varied as described below. As the dependent variable, we measured pre-service biology teachers' pPCK, professional values and motivational orientations before and after the intervention.

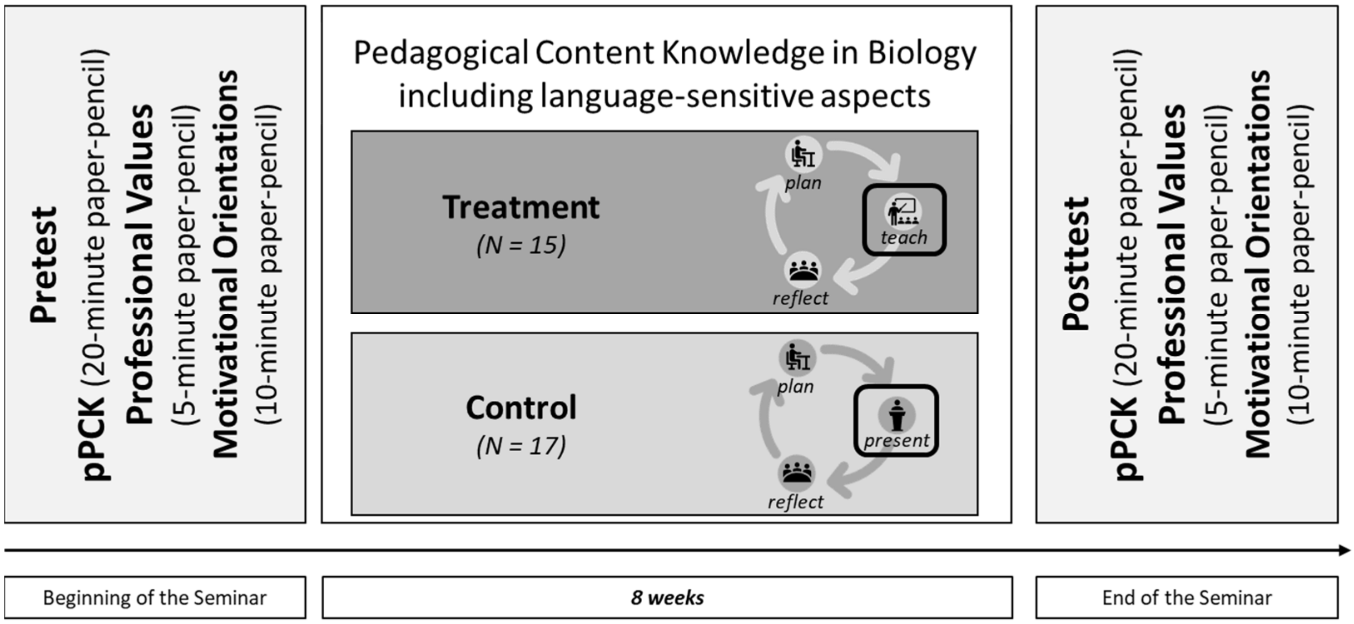

Figure 3. Research design and procedure.

The pre-test took place at the beginning of the seminar, and the post-test at the end of the seminar (Figure 3). At both times, participants' pPCK, professional values and motivational orientations were tested by using paper-and-pencil tests. Between these tests, pre-service biology teachers joined a two-month biology education seminar.

3.3. Sample

Participants of the study were 32 pre-service teachers, on average, in their 5th semester (M = 5.59; SD = 1.81). The group was divided into a treatment group (*N = 15*; 7 female, 8 male; all with German as first language, 2 bilingual) and a control group (*N = 17*; 10 female, 7 male; all with German as first language, 3 bilingual). As the seminar was obligatorily scheduled and there were two time slots owing to organisational reasons, they decided themselves which time slot and thereby which group they joined.

3.4. Intervention

In the treatment group, pre-service biology teachers taught parts of biology lessons at school as part of the *Plan–Teach–Reflect Cycle of ePCK* [5]: the participants had to plan parts of biology lessons to generate $ePCK_P$. These parts could be the introduction, the elaborate use of a model to test a hypothesis or the work with a diagram. The concrete part of a lesson and the lesson topic were decided randomly. Afterwards, each pre-service biology teacher would teach the planned parts of a biology lesson with students to generate $ePCK_T$. During the following joint reflections, which focused on academic and scientific language, the participants generated $ePCK_R$. Thereafter they were asked to describe the observed classroom situations, especially those regarding academic and scientific language, to explain their relevance to students' learning and to propose alternative instruction strategies. Teaching and reflecting on their biology lessons was possible because of a partner school, which is a secondary school with about 900 students largely having first languages other than German. In this school, we could use a biology classroom once a week where the teaching situations were videotaped and live-broadcast to a neighbouring observation room where the fellow pre-service teachers and the lecturer observed them. In this way, the pre-service teachers were trained in the whole *Plan–Teach–Reflect Cycle of ePCK* once a week.

In the control group, pre-service biology teachers only made oral presentations of their planned parts of biology lessons to the seminar group instead of teaching them in a school class. All other aspects of the seminar were the same, including the reflection: the pre-service teachers had to describe the planned classroom situation, especially those involving academic and scientific language; to explain their relevance for students' learning; and to propose alternative instruction strategies. That way, the pre-service teachers were trained only in two parts of the *Plan–Teach–Reflect Cycle of ePCK* once a week: the *Teach* component was replaced by oral *presentations* of lesson plans.

3.5. Test Instruments

pPCK, professional values and motivational orientations were measured from standardised paper-and-pencil tests. All test instruments showed acceptable values for objectivity and for homogeneity (except professional values; Table 1). We used Rasch theory to compute values for reliability, which enables conversion of the non-linear raw scores from our measurements to linear person ability scores that can be used for data analysis [69]. The person's ability scores were converted to a range from 0–100 [70]. We used the programme Winsteps [71], and all data met the desired requirements [71–73].

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	$N = 12$	<1.4	<1.5	0.97	0.88	ICC (59,59) = 0.91, $p < 0.001$
Professional Values	$N = 20$	<1.5	<1.5	0.97	0.36	-
Motivational Orientations	$N = 36$	<1.5	<1.5	0.93	0.89	-

In the following, each scale is described in more detail:

pPCK. We measured pre-service biology teachers' pPCK with a focus on academic and biology-specific scientific language by paper-and-pencil tests with 12 items (7 multiple choice and 5 open response), which took the participants 20 min. The test was based on a proven test [74] adapted to our content area of PCK. For content validity, we followed the recommendations of Reeves and Marbach-Ad [75]: based on a literature review (e.g., [37,42,43,45,59]), the content area of language in biology education and learning objectives for pre-service biology teachers were defined [76], and theory-based items according to those of Author 3 [74] were constructed. For construct validity, we used the Wright map of the Rasch analysis [77,78], which showed an even distribution of item difficulties. Thereby, items that were easier to agree with were located at the lower end of the Wright map, e.g., "Assign the respective language register to the example.", and items that were more difficult to agree with were located at the upper end of the Wright map, e.g., "Highlight characteristics of academic language in the following text." The open-response items were based on the Rasch Partial Credit Model (PCM; [71,79]), which allows consideration of multiple-level items. The test included seven multiple-choice items about the three classroom-relevant language registers [40,42,80], two items requesting highlighting of characteristics of academic and scientific language in a schoolbook's text, one item asking for as many terms as possible with different meanings in everyday and biology-specific scientific language, and two items requesting lightening the linguistic load of a biology task in a well-founded way [45,81,82]. For objectivity, 10% of the sample was double-coded by two independent researchers, showing a high agreement (ICC(59,59) = 0.91, $p < 0.001$). After the application of the Rasch PCM, the scale showed acceptable values for homogeneity (item reliability = 0.97, person reliability = 0.88), and all items showed good fit values (Table 1).

Professional Values. We measured participants' professional values regarding multilingualism and responsibility for students' language development on a four-point Likert scale (ranging from strongly disagree to strongly agree) paper-and-pencil test with 20 items, which took the pre-service teachers five minutes. This test instrument was developed in the context of this study since there were no existing test instruments at the time [75]. During the development process, former freshly graduated students with a non-German native language were first interviewed about their experiences at school, especially in biology class and with biology teachers. In the second step, literature about language-and-migration-related discrimination was consulted (e.g., [51,66]). This procedure formed the basis for the development of 20 items: attitude towards their own responsibility for language education in their classes (5 items; [21]; e.g., "If there are language difficulties in biology lessons, it is my job as a biology teacher to take care of them."), attitude towards the coincidence of linguistic and content-specific proficiency (4 items; [2,36]; e.g., "If a student struggles in my biology lessons, it could be that the necessary linguistic tools for the content have not been addressed."), attitude towards multilingualism among their students (6 items; [18,21]; e.g., "Only German is spoken in my lessons."), attitude towards the teaching of scientific language as a goal of biology lessons (5 items; [83]; e.g., "The aim of biology lessons is to master the biology-specific science language accurately."). To strengthen content validity, we gave the items to a group of in-service biology teachers and asked them to write down their thoughts, e.g., if the questions were clear, if they missed anything important according to the topic, or if they would recommend another wording. For construct validity, we used the Wright map of the Rasch analysis [77,78], which showed an even distribution of item difficulties. Thereby, items that were easier to agree with were located at the lower end of the Wright map, e.g., "If students struggle with science language it is my task as a biology teacher to care about it.", and items that were more difficult to agree with were located at the upper end of the Wright map, e.g., "Students are allowed to use their non-German first language such as Turkish or Arabic in my classes when working in a group." Data were analysed using the Rasch PCM and showed partly acceptable values for homogeneity (item reliability = 0.97, person reliability = 0.36) and good item fit values (Table 1).

Motivational Orientations. Pre-service biology teachers' motivational orientations to implement language-sensitive biology instruction were measured by a paper-and-pencil questionnaire with 36 items on a five-point Likert scale (ranging from strongly disagree to strongly agree), which took the participants ten minutes. The test was based on the expectancy-value-theory of achievement motivation [68,84] and was adapted to language-sensitive biology instruction [85], whereby only the term "Language-sensitive" replaced the original term "concept-orientated": the expectation of success (5 items; e.g., "If I offer language-sensitive classes, I will get more recognition from students and parents."), ability beliefs (5 items; e.g., "I am able to develop language-sensitive tasks."), perception of task demands (6 items; e.g., "There are enough subjects during teacher education on the topic of language-sensitive teaching."), utility value (8 items; e.g., "Language-sensitive lessons are more structured than others."), intrinsic value (4 items; e.g., "I enjoy teaching language-sensitive lessons."), personal cost (8 items; e.g., "In order to offer language-sensitive lessons, I have to invest a lot of time to familiarise myself with the concept myself."). For construct validity, we used the Wright map of the Rasch analysis [77,78], which showed an even distribution of item difficulties. Thereby, items that were easier to agree with were located at the lower end of the Wright map, e.g., "There are enough subjects during teacher education on the topic of language-sensitive teaching.", and items that were more difficult to agree with were located at the upper end of the Wright map, e.g., "I am so well versed in the idea of language-sensitive teaching that I can pass it on to fellow pre-service teachers." The Rasch PCM was applied to analyse data, which showed acceptable values for homogeneity (item reliability = 0.93, person reliability = 0.89), as well as good item-fit values (Table 1).

3.6. Data Analysis

3.6.1. Descriptive Analyses

We used mean values and standard deviations of all resulting person ability scores (Table 2) and calculated Pearson correlations and coefficients of determination between all measured variables (Table 3). Unpaired *t*-tests for all variables between the treatment group and control group were calculated to make sure the two groups would not differ significantly (Table 4).

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

Variable	Mean of Person Ability Score		SD		Min		Max	
Group	Treatment	Control	Treatment	Control	Treatment	Control	Treatment	Control
$pPCK_{pre}$	47.36	47.80	1.22	0.44	43.92	46.78	48.41	48.31
$pPCK_{post}$	48.25	47.81	0.48	1.42	47.20	42.58	49.31	52.83
Professional Values$_{pre}$	51.90	51.85	0.35	0.44	51.52	51.17	52.83	52.63
Professional Values$_{post}$	52.00	51.85	0.49	0.49	51.41	50.81	53.43	52.67
Motivational Orientations$_{pre}$	48.92	48.36	0.45	0.35	48.10	47.61	49.57	49.00
Motivational Orientations$_{post}$	49.49	49.47	0.67	0.83	48.45	47.79	50.63	51.28

Table 3. Summary of intra-correlations between the measured variables (pre-test).

Variable	$pPCK_{pre}$	*Professional Values*$_{pre}$	*Motivational Orientations*$_{pre}$
$pPCK_{pre}$	1		
Professional Values$_{pre}$	0.27	1	
Motivational Orientations$_{pre}$	−0.09	0.33	1

Table 4. Summary of unpaired *t*-tests (pre-test).

Variable	$pPCK_{pre}$		*Professional Values*$_{pre}$		*Motivational Orientations*$_{pre}$	
Group	Treatment	Control	Treatment	Control	Treatment	Control
t	T(17.18) = 1.33		T(26) = −0.35		T(26) = −0.63	
p	0.10		0.73		0.001	
d	-		-		1.37	
95%CI	[−0.2578, 1.1399]		[−0.3657, 0.2596]		[−0.8691, −0.2410]	

3.6.2. ANOVA

To check our hypotheses, three mixed ANOVAs were calculated with the described intervention as an independent variable and pre-service teachers' pPCK, professional values and motivational orientations as dependent variables (Table 5). To test Hypothesis 1, we interpreted the effects of time as the effects of training the *Plan–Teach–Reflect Cycle of ePCK* to pre-service biology teachers, which we did both in the treatment and the control group. To test Hypothesis 2, we focused on interaction effects to identify the effect of the training of the full *Plan–Teach–Reflect Cycle of ePCK* in comparison with *replacing the Teach component with oral presentations of lesson plans*.

Table 5. Summary of mixed ANOVAs.

Hypothesis	Dependent Variable	F	*p* (One-Tailed)	Part. η^2	d
H1			**Effect of time**		
H1a	*pPCK*	F(1,28) = 3.51	0.04	0.11	0.70
H1b	*Professional Values*	F(1,24) = 0.05	0.41	-	-
H1c	*Motivational Orientations*	F(1,23) = 29.68	<0.001	0.56	2.26
H2			**Interaction effect**		
H2a	*pPCK*	F(1,28) = 2.92	0.04	0.10	0.67
H2b	*Professional Values*	F(1,24) = 0.47	0.25	-	-
H2c	*Motivational Orientations*	F(1,23) = 7.64	<0.01	0.25	1.15

4. Results

The descriptive results of all measured variables are shown in Table 2.

4.1. Correlations

We found no correlations between pre-service biology teachers' pPCK and their professional values (r = 0.27, R^2 = 0.07, p = 0.17), between their pPCK and their motivational orientations (r = −0.09, R^2 = 0.01, p = 0.67) or between their professional values and their motivational orientations (r = 0.33, R^2 = 0.11, p = 0.11; Table 3).

4.2. Unpaired t-Tests

There was a significant difference in the pre-test motivational orientations of pre-service biology teachers' person ability scores between the treatment group (M = 48.92, SD = 0.45, Min = 48.10, Max = 49.57) and the control group (M = 48.36, SD = 0.35, Min = 47.61, Max = 49.00); the unpaired t-test displayed a large effect (t(26) = −0.63, p = 0.001, d = 1.37, 70). Thus, the treatment group's mean person ability score was higher than the control group's; no other group differences were significant (Table 4).

4.3. Mixed ANOVAs

To analyse the treatment effect of our intervention described above, we calculated three mixed ANOVAs with the described intervention as an independent variable and pre-service biology teachers' pPCK, professional values and motivational orientations as dependent variables (Table 5).

According to Hypothesis 1, we interpreted the effect of time, which would allow a statement about the effect of training in the *Plan–Teach–Reflect Cycle of ePCK* on pre-service biology teachers in both the treatment and the control groups. Results showed a medium effect of time on pre-service biology teachers' (a) pPCK (F(1,28) = 3.51, p = 0.04, part. η^2 = 0.11, d = 0.70), no effect of time on their (b) professional values (F(1,24) = 0.05, p = 0.41), and a strong effect of time on their (c) motivational orientations (F(1,23) = 29.68, p < 0.001, part. η^2 = 0.56, d = 2.26; Table 5).

To check Hypothesis 2, we interpreted the interaction effect between treatment and time. This allows a statement if training in the full *Plan–Teach–Reflect Cycle of ePCK* to pre-service biology teachers enhances their pPCK, their professional values and their motivational orientations in comparison with *replacing the Teach component with oral presentations of lesson plans.* Results showed a medium interaction effect on pre-service biology teachers' (a) pPCK (F(1,28) = 2.92, p = 0.04, part. η^2 = 0.10, d = 0.67), no interaction effect on their (b) professional values (F(1,24) = 0.47, p = 0.25), and a strong interaction effect on their (c) motivational orientations (F(1,23) = 7.64, p < 0.01, part. η^2 = 0.25, d = 1.15; Table 5).

5. Discussion

The results of our study indicate that training in the *Plan–Teach–Reflect Cycle of ePCK* [5] *as a whole or in parts* enhances pre-service biology teachers' pPCK in the field of academic and scientific language and their motivational orientations to implement language-sensitive biology instruction. Including the *Teach* component in the Cycle improves the effectiveness of the *Plan–Teach–Reflect Cycle of ePCK* (Figure 4).

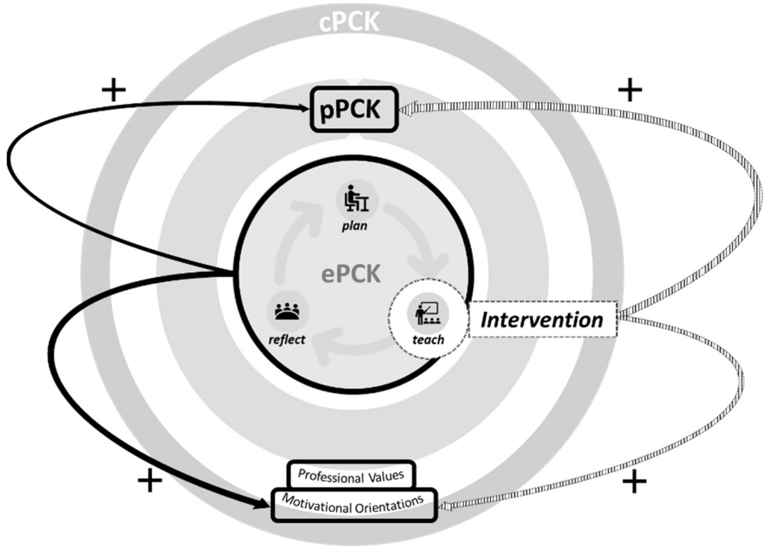

Figure 4. Graphical illustration of the research findings.

We further hypothesised that training in the *Plan–Teach–Reflect Cycle of ePCK* [5] to pre-service biology teachers would enhance their professional values regarding multilingualism and responsibility for language education and that this effect would be strengthened by teaching parts of a biology lesson at school, neither of which we were able to prove.

The variables professional values and motivational orientations were not correlated. These are both affective components assumed to play a decisive role in the transformation process between cPCK and pPCK [7,35]; the subscales "attitude towards their own responsibility for language education" [21], "utility value" and "intrinsic value" [68,84] in particular refer to a similar mindset. From these and the fact that values influence motivational goals [86], one might have assumed a strong correlation. However, they are also described as separate constructs [12], and our results would support this assumption.

We are convinced that especially their professional values have a decisive influence on teachers' behaviour in class [17,22,86] and on the transformation process between cPCK and pPCK in the field of academic and scientific language [61]. There was no measurable change in pre-service biology teachers' professional values, although these are considered to be changeable [23,25]. Values, teachers' professional values as well, often function as schemes, also called "truisms": people tend to ignore things that are incongruent with their internalised schemes [23] and do not question their truisms [87]. Education, as well as teacher education, influences people's values [17,88], but to introduce changes in value commitments, people have to become aware of their own implicit value commitments [20,26,89]. We assume this to be the decisive factor: the setting of our study did not arrange an explicit confrontation with one's own professional values. Furthermore, it takes time to change value commitments since they are more persistent than beliefs [90], so we perhaps should consider eight weeks not to be long enough for such change processes.

Further research would be useful to examine the nature of science teachers' professional values regarding multilingualism and responsibility for language education in greater depth by examining the individual subscales since they are considered to play a decisive role in their PCK in the field of academic and scientific language [61]. On this basis, effective strategies influencing pre-service teachers' professional values in a positive way can be developed. We suggest setting an intervention over a longer period, e.g., according to Bardi and Goodwin's [23] theoretical routes to value change or Derman-Sparks' [26] Anti-Bias Curriculum.

We assumed and found an increase in pre-service teachers' motivational orientations to implement language-sensitive biology instruction after their training in the *Plan–Teach–Reflect Cycle of ePCK* [5]. This was strengthened by the teaching of a biology lesson at school: focusing on academic and scientific language proficiency as a biology teachers' task, and providing knowledge about linguistic hurdles and scaffolding strategies for both treatment and control group, led to stronger motivational orientations. The practical experience and lesson observation at school were able to strengthen this effect, which is in agreement with other authors' results [68,84,91]. The teaching experience at school seems to help pre-service biology teachers to be better prepared for (linguistic) diversity at school, which is something they wish for [32].

We expected to find an increase in pre-service biology teachers' pPCK in the field of academic and scientific language. Training in the *Plan–Teach–Reflect Cycle of ePCK* [5] enhanced pre-service teachers' pPCK, which was strengthened by teaching parts of a biology lesson at school. We explain the finding of the increase in participants' pPCK due to the training in the *Plan–Teach–Reflect Cycle of ePCK* by the fact that we imparted cPCK in this field in the framework of the seminar, and the focus on academic and scientific language during the joint reflection of the presented or taught parts of biology lessons. We explain the finding of the strengthening due to teaching parts of a biology lesson at school by the experience of the direct interaction with (multilingual) students at school, the responsibility (pre-service) teachers feel for their students [16,92], and the experience of existing linguistic hurdles [21,93]. These results indicate that our approach helps foster pre-service biology teachers' pPCK in the field of academic and scientific language and encourages us to continue our approach.

Until now, research about PCK in the field of academic and scientific language has concentrated more on the question of which needs students have and which concrete strategies help them in the classroom [37,57,94,95]. In our opinion, there is a great need to examine more closely the nature of PCK in the field of academic and scientific language, as started by Mönch and Markic [61], and its impact on students' performance. Therefore, we recommend future research: in the first step, the correlations between pre-service as well as in-service science teachers' (1) PCK in the field of academic and scientific language, (2) their professional values regarding multilingualism and responsibility for language education, and their (3) motivational orientations to implement language-sensitive instruction should be detected, as started by [35], and thereby it should be verified if there is a difference between pre-service and in-service teachers. In the second step, the three components of the *Plan–Teach–Reflect Cycle of ePCK* [5] and how they influence each other should be investigated, as started by [96]. In the third step, the impact of (1), (2) and (3) on students' performance in science should be explored. Since science teachers' TPACK is assumed to be a predictor of the quality of their lesson plans with technology integration [97], further research should include this component.

6. Limitations of the Research

We are aware of several limitations of our study: first, the sample size is quite small; therefore, the study does not provide representative results. To collect representative data, more than one cohort of pre-service teachers should be included in the study. Second, we were not able to provide fully experimental conditions: the distribution of the participants between the treatment and control group was not random since the pre-service teachers decided themselves which group they joined, mostly due to the timeslot which was appropriate for them. The t-test explored a significant difference in participants' PCK between the treatment and control group. Nevertheless, our results showed an effect of time as well as an intervention effect. Third, the RCM [7] formed the theoretical basis of our research, which describes the PCK of in-service teachers, whereas the participants of our study were pre-service teachers. Although it can be anticipated that there are differences in the PCK, professional values and motivational orientations of in-service and pre-service teachers, we do not assume that this makes a difference for our measurements: we did not explore the nature of the three constructs but tried to identify strategies to enhance them. Fourth, the person reliability scores of the professional-values test were at the lower end, so the test instrument only was able to distinguish between two groups of pre-service teachers, those with high and those with low professional values. Therefore, all results on pre-service teachers' professional values should be regarded with caution. For future research, more items should be added [98].

7. Implications for Teacher Education

Teachers' PCK influences students' performance indirectly [4], and their motivational orientations determine the intensity, quality and duration of teachers' behaviour [27–29]. Therefore, if we want to increase our students' performance in science, we should start with the science teachers' PCK in the field of academic and scientific language and their motivational orientations to implement language-sensitive biology instruction to improve students' academic and scientific language proficiency. Therefore, we suggest focusing on academic and scientific language in science teacher education programmes for pre-service as well as for in-service science teachers.

Our study is related to biology teacher education, but we consider our results to be applicable to chemistry and physics education as well: although the biology-specific science register differs from the chemistry- and physics-specific science register, the way of thinking is the same as is the way of constructing knowledge.

We acted within the framework of the structural conditions of the German teacher education system to explore a realistic and permanent possibility of integrating our approach into existing science teacher education programmes. This approach provides neither a large sample size nor fully experimental conditions, but it does provide high ecological validity. This is why we are convinced that the approach will also work for biology, chemistry and physics teacher education programmes in other countries. Therefore, we recommend the use of the *Plan–Teach–Reflect Cycle of ePCK* [5] in the framework of teacher education programmes to enhance pre-service teachers' pPCK and motivational orientations, if possible, including teaching situations at school, which have to be guided by a university to be most effective [99].

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