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Using Video-Based Simulations to Foster pPCK/ePCK—New Thoughts on the Refined Consensus Model of PCK

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Abstract: This article aims to investigate relationships between the different realms of PCK by referring to the refined consensus model of PCK. We conducted a pre–post study with an intervention using a video-based simulated learning environment to measure different realms of PCK of 78 pre-service biology teachers. The participants were randomly assigned to three groups receiving different treatments in the form of scaffolds while working on the learning environment during the intervention. Only the participants receiving scaffolds referring to their personal PCK significantly improved from the pre-test to the post-test ($F_{pPCK}(1,27) = 9.592$, $p = 0.005$, *partial* $\eta^2 = 0.262$, $n = 28$). These scaffolds encourage participants to use their prior knowledge when reflecting on instructional quality, as shown in the simulation. Although the findings of the present study support the theoretical view of the refined consensus model of PCK, more focus on the personal PCK could be helpful to understand how PCK is acquired and organized "within one teacher".

Keywords: refined consensus model (RCM); pedagogical content knowledge (PCK); simulation-based learning; pre-service teacher education; scaffolding

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1. Introduction

When the refined consensus model of pedagogical content knowledge was proposed in 2019, a whole new point of view on the professional knowledge of science teachers was offered to the community of researchers and teachers in science education [1]. Since then, the call for an empirical evaluation of this model has been persistent [2]. In this article, we aim to investigate the relationships between the different realms as described in the refined consensus model for pre-service biology teachers. We are especially interested in how pedagogical content knowledge is built up in the early stages of pre-service teacher education.

2. Theoretical Background

The professional knowledge of a teacher has been conceptualized by many researchers in past decades. Shulman [3] described three areas of the professional knowledge of a teacher: pedagogical–psychological knowledge (PK), content knowledge (CK), and pedagogical content knowledge (PCK) (for a list of all abbreviations used in this article, see the Appendix A, Table A1) [4]. The PK of a teacher includes all general knowledge related to classroom management, students' learning processes, cognitive processes, dealing with interruptions in a lesson, etc. [3,5]. CK refers to all topic-specific content knowledge of a teacher. For a biology teacher, this could be his/her knowledge about biological facts and concepts and builds, in combination with their PK, which is the prerequisite for PCK. PCK is a set of knowledge and skills that make CK accessible to their students [3,6]. It includes teaching strategies as well as knowledge about students' misconceptions that are specific to the subject and subject-specific teaching strategies [7]. In the literature, there is some evidence that a higher or richer PCK is related to and beneficial for effective teaching practices [2,8]. Förtsch et al. [9] found PCK to be the determining factor for effective biology teaching. However, all three areas of a biology teacher's professional knowledge determine the instructional quality (CK, PK, and PCK) and, thus, influence the students' learning outcomes [6,9–11]. Therefore, it seems necessary to focus on the professional knowledge that is already in pre-service teacher education. It is important to mention that these correlations cannot be reported equally for all science subjects [12]. Simulated learning environments can offer an opportunity to train the professional knowledge of pre-service teachers without overburdening them with the complexity of a real life setting [13,14]. Simulated classrooms are often used in pre-service teacher education to meet the demand for more practical insights [15] and train the PCK of pre-service teachers (e.g., [8,16–20]). A popular method to support learning and learning processes in video-based simulations is the implementation of scaffolds (cf. [21]). This article aims to investigate the PCK of pre-service biology teachers using a video-based simulation with scaffolds included. We suggest a model in order to explain and understand the knowledge acquisition of PCK based on empirical findings and recent PCK theories.

2.1. The Refined Consensus Model (RCM) of PCK

To further specify Shulman's [3] model for the professional knowledge of teachers and especially the PCK of science teachers, international researchers met in Colorado Springs in 2012 to develop the so-called consensus model (CM) [22]. The most important novelty that the CM brought to defining PCK was that PCK is seen as a part of classroom practice and a dynamic knowledge facet of a science teacher's professional knowledge that is influenced by experiences and their students. However, it was criticized that PCK was not defined with sufficient precision and, thus, the complexity of the knowledge facet was not captured by the CM. As a result of that, the refined consensus model of PCK [1] was developed by international researchers to describe and explain the pedagogical content knowledge and skills (PCK) of science teachers more precisely. It includes the definition of three realms of PCK: the collective PCK (cPCK), personal PCK (pPCK), and enacted PCK (ePCK) (see Figure 1).

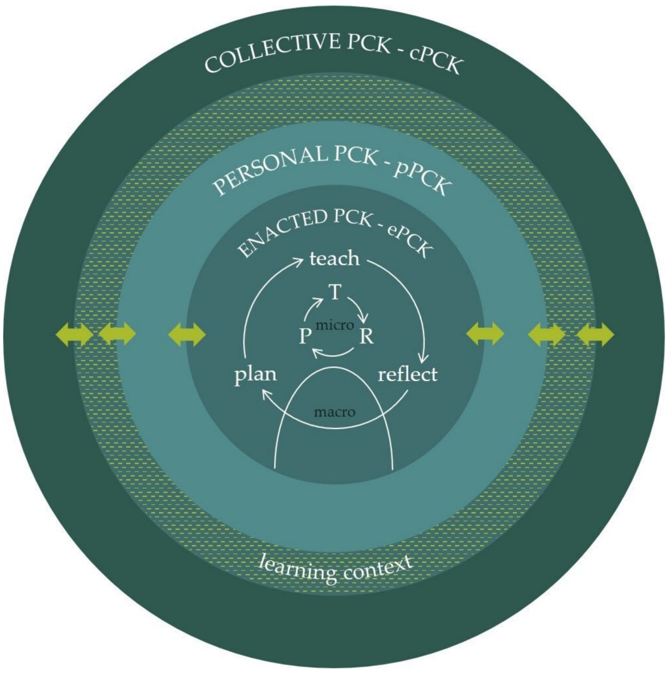

Figure 1. The refined consensus model of PCK (reduced version) was graphically adapted by including the micro- and macrocycle of ePCK [1,23].

2.1.1. The Collective PCK (cPCK)

The collective PCK (cPCK) incorporates all pedagogical content knowledge related to a particular subject that more than one person possesses [1]. It is public knowledge that researchers, teachers, and other practitioners share and contribute to. The cPCK is often published in books and research articles or discussed at conferences. It consists of commonly held knowledge bases as well as the teaching experiences that single teachers contribute with respect to this public knowledge. It is closest to Shulman's [3] definition of PCK [1]. The cPCK can vary from rather general knowledge (discipline-specific) to more specific knowledge (topic-specific) [1]. Although it is clearly defined that the cPCK is the collective knowledge and many people contribute to it, it remains a matter of interpretation whether a single teacher can possess cPCK. Carlson et al. [1] describe cPCK as closest to Shulman's [3] definition of PCK. In this article, we assume that cPCK can be possessed by a single person, meaning that all general knowledge a person possesses that has also been published and discussed can be referred to as his/her cPCK. In our way of understanding, it is, in contrast to a person's pPCK, not necessarily influenced by their personal experiences and could be acquired, e.g., by taking part in a university lecture.

2.1.2. The Personal PCK (pPCK)

The personal PCK (pPCK) is all knowledge a single teacher possesses based on his/her teaching experiences, knowledge acquired from all students he/she ever taught, discussions with colleagues, and contributions from educational researchers or scientists [1]. In contrast to our definition of cPCK, the pPCK of a teacher is applicable in various contexts. This is also supported by the RCM; the learning context is located between the cPCK and pPCK (see Figure 1), making pPCK a rather contextualized realm of knowledge [18]. The pPCK can thus be seen as the contribution of a single teacher to the cPCK or the part of cPCK a single teacher possesses and includes in his/her teaching. It serves as a knowledge base to draw upon when planning, teaching, or reflecting on a lesson.

2.1.3. The Enacted PCK (ePCK)

Once a teacher's pPCK is put into action, it becomes enacted PCK (ePCK). In contrast to the pPCK, the ePCK is very specific to a particular teaching situation. The ePCK is knowledge in action visible when an individual teacher interacts with a particular student/group of students in a specific setting with a specific learning goal [1,23]. The ePCK is tacit knowledge, and as soon as it is verbalized, ePCK becomes pPCK. Alonzo et al. [23] describe the plan–teach–reflect cycle as the core interaction between the pPCK and ePCK of a teacher; they distinguish a macro-cycle and several micro-cycles. The teacher's pPCK provides the knowledge base for each step of the plan–teach–reflect cycle. When teaching a lesson, the teacher proceeds through the macro-plan–teach–reflect cycle. Before the lesson starts, there is usually a lesson plan during the defined time frame of a lesson (macro-ePCK$_{\text{Plan}}$). Then, the teacher actively teaches the lesson (macro-ePCK$_{\text{Teach}}$). After the lesson, teachers reflect on the lesson using macro-ePCK$_{\text{Reflect}}$. During the lesson, whenever the teacher interacts with students, several micro-cycles happen. During every instructional move, a teacher uses his/her micro-ePCK$_{\text{Teach}}$. The spontaneous changing of plans or reactions to students' answers or other unplanned events can be assigned to micro-ePCK$_{\text{Plan}}$ and micro-ePCK$_{\text{Reflect}}$. Hence, every lesson and even every interaction contribute to a teacher's pPCK, which can then be used to build up new and richer ePCK [23]. This interconnectedness between ePCK and pPCK offers the opportunity for using, e.g., reflection tools to investigate the realms of a teacher's PCK.

2.2. Simulation-Based Tools in Teacher Education

A teacher's classroom performance is closely interwoven with his/her PCK, particularly with the pPCK and ePCK. To train these realms of PCK, simulations of classroom situations or lessons can be helpful. Simulation-based learning environments, e.g., with videos, offer the opportunity to give practical insights into classroom situations during pre-service teacher education [14]. Following the concept of the approximation of practice [24], video-based simulations can reduce overburdening and complexity in comparison to real-life teaching experiences [13]. Thus, video-based simulations can be introduced step-by-step in teacher education for pre-service teachers. Video-based tools are often included in pre-service teacher education to measure professional vision or to practice reasoning about instructional quality [25,26]. Research has shown that using video-based simulations can improve pre-service teachers' professional knowledge [27–29].

The Learning Environment *DiKoBi*

One example of a video-based simulated learning environment is the learning environment *DiKoBi* (Diagnostic Competences of Biology teachers in Biology classrooms). *DiKoBi*, which was developed by Kramer et al. [16] as a video-based simulated learning environment for pre-service biology teachers ($DiKoBi_{Learn}$) and as an assessment tool for their reflection skills in classroom situations ($DiKoBi_{Assess}$). The learning environment consists of three consecutively recorded lessons ($DiKoBi^{I}$, $DiKoBi^{II}$, and $DiKoBi^{III}$) on the topic "skin", and the teacher is teaching a fifth-grade class [16]. Each of the three lessons is divided into five videotaped classroom situations. Every classroom situation focuses on another aspect of biology-specific instructional quality: (1) the beginning of a lesson and the activation of prior knowledge and ideas, (2) the use of technical terms and language, (3) the use of experiments, (4) the use of models, and (5) the transfer of knowledge at the end of a lesson [16]. Pre-service teachers are asked to complete three tasks for every classroom situation: (1) *describe*, (2) *explain*, and (3) suggest an *alternative strategy* (see Figure 2). These tasks were developed based on the concept of professional vision [26].

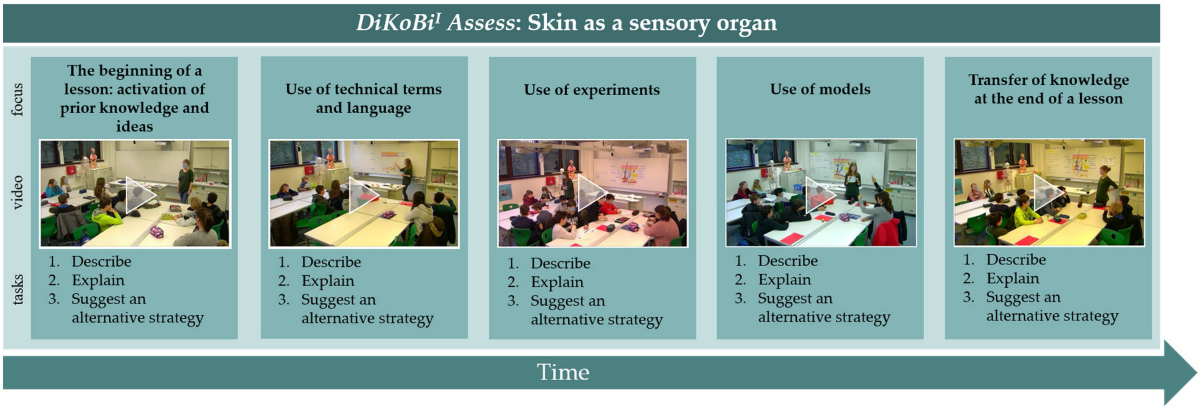

Figure 2. The learning environment $DiKoBi^{I}$ as an example. The learning environment consists of five videos showing classroom situations with different foci. The pre-service teachers complete the three tasks *describe*, *explain*, and *suggest an alternative strategy* for each video.

The pre-service teachers wrote down their answers to the tasks in open text fields. The first task for every classroom situation is *describe*. The pre-service teachers were asked to write down observed problematic aspects in the classroom situation. Even though pointing out the positive aspects of the performed teaching method would be part of the reflection process in a "real-life" reflection, we decided to focus on problematic aspects only, as the videos were scripted to illustrate typical mistakes teachers in biology classrooms make concerning PCK aspects. In the following tasks (*explain*), the described observation must be linked to didactical concepts and theories by using technical terms from the field of biology instruction with the aim of explaining and justifying why the observed event was problematic. In the last task (*alternative strategy*), alternative courses of action must be described, containing a detailed description and theory-based explanation. For an example, refer to Table 1.

Table 1. An example of the three tasks to be completed for the first classroom situation in *DiKoBi* [17].

Classroom Situation	**Beginning of the Lesson, Activation of Prior Knowledge and Ideas**				
What is happening in the video	The lesson starts with the teacher asking the students what they remember from the last lesson (sensory organs). Afterward, the teacher introduces the topic of the current lesson (skin as a sensory organ).				
Task *describe*	Students tell their prior knowledge without dealing with the subject of the previous lesson in more depth.	The teacher names the topic of the lesson instead of letting the students formulate it.	The teacher only asks reproductive questions; no explanations by the students are required.	No problem orientation.	No example, no context, nothing new or surprising, and no relevance for everyday life is pointed out; therefore, the students are not motivated.
Task *explain*	The students are not cognitively activated. They should connect their prior knowledge to subordinated concepts at the beginning of a lesson.				No sufficient activation of the students. There is no catch component to create situational interest.
Task *alternative strategy*	The teacher could start the lesson with a cognitive conflict leading to a problem-orientated question that could then serve as the topic of the lesson. The teacher could activate the prior knowledge of the students by asking concept-orientated questions, instead of just letting the students repeat what they remember from the last lesson.				To create situational interest, an experiment, something surprising or something bringing up more relevance for everyday life, could serve as a catch component.

Kramer et al. [8] revealed, in a path analysis, that the PCK of pre-service teachers is significantly related to their reflection skills in classroom situations. The three tasks can be assigned to the ePCK macro-cycle described by Alonzo et al. [23] as they encourage pre-service teachers to reflect on teaching [2]. The first two tasks (describe and explain) can be assigned to $\text{ePCK}_{\text{Reflect}}$, and the third task (suggesting an alternative strategy) can be assigned to $\text{ePCK}_{\text{Plan}}$. $\text{ePCK}_{\text{Teach}}$ is not represented in the videos, as the pre-service teachers do not teach themselves but watch another teacher teach a class. However, the pre-service teachers need to use their pPCK as a basis to complete the tasks. As soon as they write down their reflections on the presented classroom situation, $\text{ePCK}_{\text{Reflect}}$, and $\text{ePCK}_{\text{Plan}}$ are transformed into pPCK [23]. Therefore, we suggest locating the learning environment on the dynamic border between measuring ePCK and pPCK and training $\text{pPCK/macro-ePCK}_{\text{Reflect + Plan}}$.

2.3. Scaffolding

The term *scaffold* was initially introduced by Wood et al. [30] to describe externally added support that assists a learner in achieving a certain learning goal that he/she could not (yet) achieve without help. The zone in which a learner can complete tasks with help, but not without, is called the *zone of proximal development* [31]. The provision of explicit hints and prompts is called Vygotskian scaffolding [32]. In particular, for difficult and complex tasks, scaffolding can be a highly effective intervention and help learners reach the *zone of proximal development* [33,34]. By implementing scaffolds in a learning environment requiring problem-solving, learners significantly improve in comparison to those that do not receive scaffolds [35]. For learners with little prior knowledge, scaffolds that provide high-level guidance are very beneficial [21]. Scaffolds have already been successfully included in the learning environment *DiKoBi*. PCK-scaffolds helped pre-service teachers with little prior knowledge significantly improve their reflection skills in classroom situations, whereas scaffolds providing additional support on the task itself did not lead to a significant improvement [17]. These results support Chernikova et al.'s [36] findings that only learners with higher prior knowledge benefit from action-related support in simulation-based learning environments.

3. Research Questions and Objectives

The last study conducted with the learning environment *DiKoBi* revealed that PCK-scaffolds supported pre-service teachers in significantly improving their reflection skills in classroom situations [17]. This finding is also supported by several studies that observed reflection to have positive effects on different aspects of PCK [2,37,38]. Therefore, the present study focuses on supporting pre-service teachers in developing and training their pPCK/macro-ePCK$_{\text{Reflect + Plan}}$ by adding support in the form of PCK-scaffolds (cPCK- and pPCK-scaffolds) to the learning environment *DiKoBi*. The scaffolds were developed based on the realms described in the RCM of PCK (see Section 4.3). The first research question we aim to investigate is stated as follows.

RQ1: *What PCK realm needs to be scaffolded to support pre-service teachers in developing their pPCK/macro-ePCK$_{Reflect + Plan}$—assessed through the learning environment* DiKoBi—*at the beginning of their university education? (RQ1)*

In most German university programs, PCK is acquired first in the form of theoretical knowledge by, for example, a lecture on biology education. This corresponds to teaching cPCK, because the lecture is usually about common knowledge and published findings, building a theoretical knowledge base that students can draw from. Later, students are introduced to more practical courses, where they can apply the cPCK in different contexts. They train their pPCK. To build up ePCK, "real" teaching situations need to be offered, which happens during school internships included in the teaching program. The ePCK gained during those internships closely interacts with the pPCK acquired before, while at the same time building up more pPCK based on the classroom experiences they make during internships (cf. [1]). Pre-service teachers at the beginning of their university education assumingly have little prior knowledge concerning their pPCK and draw their pPCK from the cPCK that they have been taught in the lecture. Thus, we derive the following hypothesis regarding RQ1.

H1: *Scaffolding the cPCK of pre-service teachers in an early stage of PCK acquisition helps them build up their pPCK/macro-ePCK$_{Reflect + Plan}$. (H1)*

Furthermore, there is a need for more quantitative research on the realms of the RCM of PCK to test and stabilize the model [2,30,39]. To further test the RCM of PCK and understand the relationships between the three realms, we formulated the following research question.

RQ2: *How does training the pre-service teachers' pPCK/macro-ePCK$_{Reflect + Plan}$ in a video-based simulated learning environment influence their cPCK? (RQ2)*

The learning context as a filter between the cPCK and a pPCK permits the decontextualization of knowledge [1,40]. The decontextualization of the trained pPCK/macro-ePCK$_{\text{Reflect + Plan}}$ might be very challenging for pre-service teachers with little prior knowledge concerning PCK. Thus, we derive the following hypothesis for RQ2.

H2: *The cPCK of pre-service teachers does not change by training their pPCK/macro-ePCK$_{Reflect + Plan}$ with the learning environment* DiKoBi. *(H2)*

By analyzing the two research questions listed above, another rather general finding could be discussed.

What are the relationships between the realms of the RCM inside an individual teacher, and how does knowledge acquisition work when it comes to pPCK/macro-ePCK$_{\text{Reflect + Plan}}$?

4. Method

4.1. Sample

The sample consisted of 78 pre-service biology teachers (88.5% female and 11.5% male) in the German school system. This gender imbalance mirrors the current gender imbalance for pre-service teachers at our university. As the first biology education classes are planned for the second semester, pre-service teachers can be considered to be at an early stage in their university education (M_{semester} = 2.82, SD = 0.88, Min = 2, and Max = 6). We decided to conduct the study with pre-service teachers in such an early stage to ensure that the sample exhibits similar prior knowledge concerning their teaching experiences and PCK. Following the concept of the approximation of practice [24], pre-service teachers are engaged in teaching practices early in their university education without being overburdened by the complexity of real-life teaching. All data were collected in February and June 2021. The study was embedded in a university course that the pre-service teachers were taking part in. The course was about the basic theories of biology PCK.

4.2. The cPCK-Test

To measure the cPCK of the pre-service teachers, we developed a test containing 60 correct or false items. We chose the true–false format in order to be as close to measuring cPCK as possible. The pre-service teachers only have to identify a general finding as either correct or false. None of their personal PCK (pPCK) is measured, and they do not have to actively produce answers but rather identify general and published pedagogical content knowledge. These sixty items can be assigned to six constructs, with each measuring one aspect of biology-specific cPCK that is also addressed in the learning environment *DiKoBi*, namely the following: (1) the beginning of a lesson and the activation of prior knowledge and ideas, (2) dealing with students' ideas and misconceptions (not addressed in the form of a classroom situation in the learning environment), (3) the use of technical terms and language, (4) the use of experiments, (5) the use of models, and (6) the transfer of knowledge at the end of a lesson. One example from each construct is shown in Table 2.

Table 2. Exemplary items of the cPCK-test.

Construct	Item	Relevant Literature (Example)
The beginning of a lesson and the activation of prior knowledge and ideas	The use of everyday and real-life context at the beginning of a lesson results in a better understanding, which can generate interest in the students. [1]	[41]
Dealing with students' ideas and misconceptions	Knowing about students' pre-conceptions is only useful for new, very complex content since the students' pre-conceptions and the scientific concepts are sometimes far apart. [2]	[42]
Use of technical terms and language	By defining technical terms in class, they are put in context. New terms can be linked to existing concepts making them easier to remember. [1]	[43]
Use of experiments	According to Mayer, in the first step of the scientific inquiry process, a hypothesis is generated to be tested. [2]	[44]
Use of models	The purpose of models is not only to provide explanations of relationships and phenomena that are already known, but also to predict future findings. [1]	[45]
Transfer of knowledge at the end of a lesson	To achieve cognitive activation at the end of a lesson, students can be asked to reproduce the content of the lesson, as this will activate their newly acquired knowledge. [2]	[46]

[1] Correct item. [2] False item.

All items are not tailored to a specific context, and general statements are derived from the published literature. Therefore, we consider them to be measuring the cPCK of pre-service teachers. The test was developed, edited, and reviewed by several researchers from the field of biology education. A Rasch analysis run on the cPCK-test showed good item reliability (0.96) (target value 0.90) and sufficient person reliability (0.70) (target value 0.80) [47].

4.3. Development of Scaffolds

A former study showed that the implementation of PCK-scaffolds can significantly improve the diagnostic competencies of pre-service biology teachers assessed in the learning environment *DiKoBi* [17]. To support the pre-service teachers in completing tasks in the learning environment, two different types of PCK-scaffolds were developed: cPCK-scaffolds and pPCK-scaffolds. The cPCK-scaffolds contain general information about the aspect of instructional quality in question in a classroom situation. They are not tailored to a specific classroom situation; however, they contain all the necessary information to correctly complete the tasks. An example is shown in Figure 3 for the first classroom situation (the beginning of a lesson and activation of prior knowledge and ideas). All cPCK-scaffolds were developed based on published findings and theories relevant to the aspect of instructional quality in each situation.

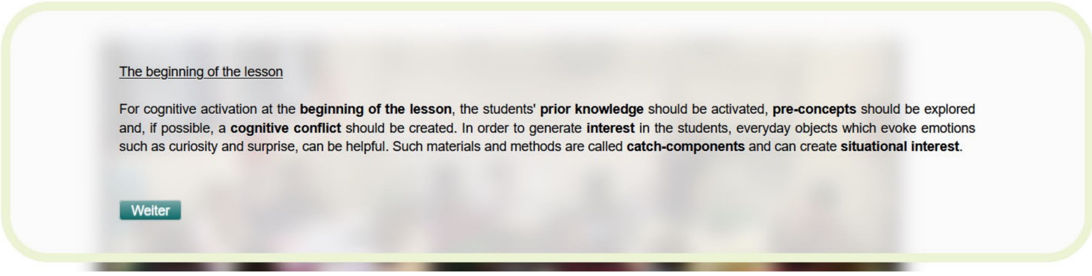

Figure 3. A cPCK-scaffold from the first classroom situation in the simulated learning environment *DiKoBi*.

pPCK-scaffolds are supposed to activate the prior knowledge of pre-service teachers concerning the aspect of instructional quality that the classroom situation is focusing on. They are referred to as pPCK-scaffolds because they do not offer new information but only encourage pre-service teachers to use their own knowledge (their pPCK) to complete the tasks. An example of the first classroom situation is presented in Figure 4.

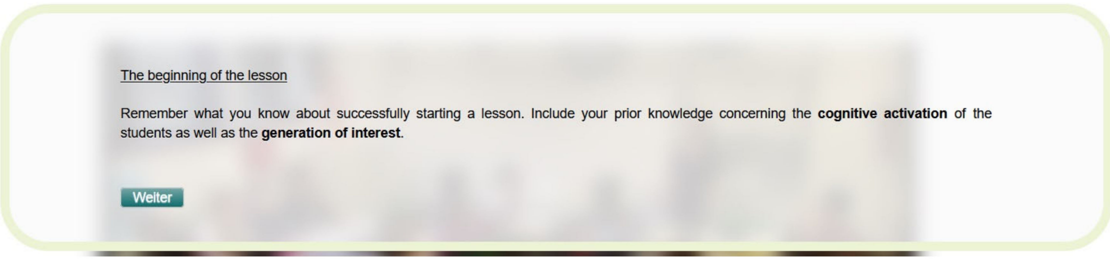

Figure 4. A pPCK-scaffold from the first classroom situation in the simulated learning environment *DiKoBi*.

The scaffolds appear in the form of prompts during videotaped classroom situations in the learning environment. The video then stops, and the pre-service teachers can read the scaffold. When pressing "continue", the scaffold disappears, and the videotaped classroom situation continues. Scaffolds are only implemented in *DiKoBi*$_{Learn}$.

4.4. Study Design

Data collection took place in February and June of 2021, meaning that all data were collected during the COVID-19 pandemic, and pre-service teachers were taking part in the study from home. Participation was voluntary but embedded in a university course that the students were taking part in. They worked on the study individually during all measurement periods. The study was conducted using a pre–post-test design (see Figure 5). In the pre-test, all pre-service teachers completed the cPCK-test as well as $DiKoBi^{I}{}_{Assess}$. In the intervention, pre-service teachers were randomly assigned to three groups. The pPCK-group completed $DiKoBi^{II}{}_{Learn}$, with pPCK-scaffolds included. The cPCK-group completed $DiKoBi^{II}{}_{Learn}$ with cPCK-scaffolds included, and the third group completed the learning environment without any scaffolds included (control group). Due to the small sample size, we used a slightly smaller control group in favor of the treatment groups. In the post-test, all pre-service teachers completed $DiKoBi^{III}{}_{Assess}$ without scaffolds included and the cPCK-test.

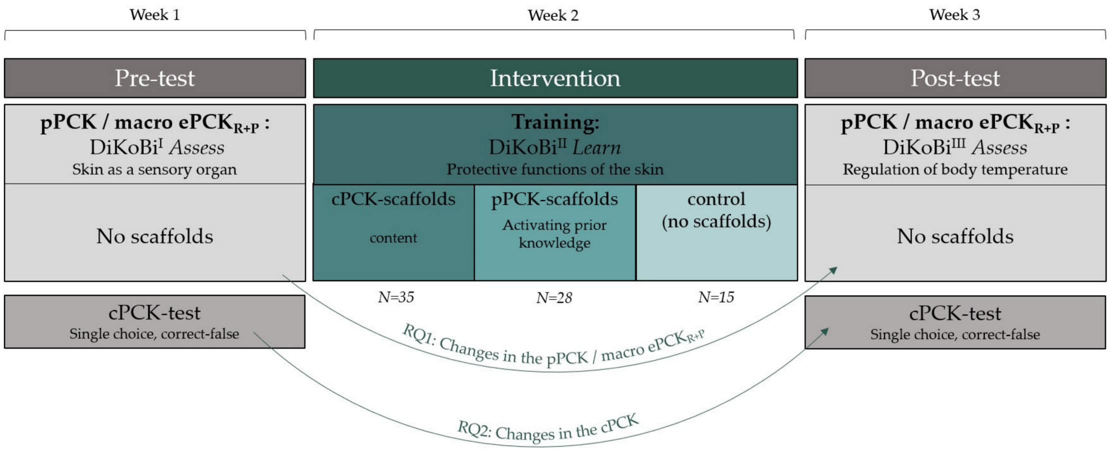

Figure 5. Study's design.

4.5. Measurements and Data Analyses

All data analyses were conducted using IBM SPSS Statistics 26. In previous studies, we could identify the number of certain keywords (technical terms from the field of PCK that are suitable for reflecting the aspect of instructional quality that a classroom situation is focusing on) that pre-service teachers use in their reflections in the learning environment as an operationalization of their reflection skills and, thus, their $pPCK/ePCK_{Reflect + Plan}$ [17]. For the first research question (RQ1), an ANOVA was calculated for the pre-test. The ANOVA was calculated to assure that there are no differences in the pre-test that already concern the three intervention groups. To check for within and in-between treatment changes, we calculated a mixed ANOVA. We used the number of keywords in the pre-service teachers' answers in the open text fields as a measure for their $pPCK/ePCK_{Reflect + Plan}$ in the learning environment *DiKoBi* [17]. We counted the keywords for every pre-service teacher in every classroom situation for each of the three tasks.

For the second research question (RQ2), an ANOVA was conducted for the pre-test. We also conducted a mixed ANOVA to check for pre–post changes and interaction effects (time*treatment). The maximum of points to be achieved in the cPCK-test is 60 (1 point per item). We summed up all achieved points for each pre-service teacher.

5. Results

5.1. RQ1: The Learning Environment

In the pre-test, ANOVA revealed no differences between the three groups regarding the number of keywords (operationalization of the $pPCK/macro\text{-}ePCK_{Reflect + Plan}$) used in the open text fields ($F(2,75) = 0.013$, $p = 0.987$, $n = 78$). Mixed ANOVA showed no interaction effect between the time of measurement and the treatment ($F(2,75) = 1.193$, $p = 0.309$, *partial* $\eta^2 = 0.031$ $n = 78$). However, it revealed a significant main effect with respect to the time of measurement on the number of keywords used ($F(1,75) = 5.596$, $p = 0.021$, *partial* $\eta^2 = 0.069$, $n = 78$). Post hoc tests revealed a significantly higher number of keywords used in the post-test than in the pre-test for the pre-service teachers receiving pPCK-scaffolds ($F_{pPCK}(1,27) = 9.592$, $p = 0.005$, *partial* $\eta^2 = 0.262$, $n = 28$). Pre-service teachers receiving cPCK-scaffolds and the control group (no scaffolds) did not use significantly more keywords in the post-test than in the pre-test ($F_{cPCK}(1,34) = 3.175$, $p = 0.084$, *partial* $\eta^2 = 0.085$, $n = 35$; $F_{control}(1,14) = 0.001$, $p = 0.972$, *partial* $\eta^2 = 0.000$, $n = 15$). For an overview of the descriptive statistics, we refer the reader to Table 3.

Table 3. Descriptive statistics for the number of keywords used in the pre-test and the post-test.

	Treatment	*M*	*SD*	*N*
Pre-test	cPCK-scaffolds	13.00	10.68	35
	pPCK-scaffolds	12.61	9.70	28
	control (no scaffolds)	13.00	10.32	15
Post-test	cPCK-scaffolds	15.89	12.78	35
	pPCK-scaffolds	16.79	11.10	28
	control (no scaffolds)	13.07	8.05	15

5.2. RQ2: Pre-Service Teachers' cPCK

ANOVA showed no significant differences between the three treatments in the pre-test ($F(2,75) = 0.258$, $p = 0.774$, $n = 78$). Mixed ANOVA did not reveal any effects with respect to interactions for the treatment ($F(2,75) = 0.203$ $p = 0.817$, $n = 78$). Moreover, no main effect of the time on the cPCK-test result can be reported ($F(1,75) = 1.422$, $p = 0.237$, $n = 78$). For an overview of the descriptive statistics, we refer the reader to Table 4.

Table 4. Descriptive statistics for the cPCK-test (pre- and post-test).

	Treatment	*M*	*SD*	*N*
Pre-test	cPCK-scaffolds	34.04	4.98	35
	pPCK-scaffolds	33.07	5.81	28
	control (no scaffolds)	33.87	5.63	15
Post-test	cPCK-scaffolds	33.11	6.43	35
	pPCK-scaffolds	32.86	5.58	28
	control (no scaffolds)	33.07	5.05	15

6. Discussion

6.1. Effects of Scaffolding on pPCK/Macro-ePCK$_{Reflect + Plan}$

Hypothesis 1 (H1) could not be confirmed. Although we assumed that supporting the cPCK would help pre-service teachers complete the tasks in *DiKoBi*, they only significantly improved when receiving pPCK-scaffolds despite their little prior knowledge. Although, a tendency toward an improvement of the pre-service teachers' pPCK/macro-ePCK$_{\text{Reflect + Plan}}$ could be observed for the cPCK-group ($p < 0.10$). We assume that, with a bigger sample, this effect could become significant as well. Having a look at the RCM of PCK, the realms are arranged in concentric circles with cPCK on the outside and ePCK in the middle. There are two filters in the model: the learning context between the cPCK and the pPCK, and pedagogical reasoning between the pPCK and ePCK [1,40]. When receiving instructional support in the form of general cPCK-information, pre-service teachers need to overcome the filter of the learning context and place the received information into the context of the presented classroom situation. This can be difficult for several reasons. (1) The cognitive load is already high, as video-based learning environments, such as *DiKoBi*, are intense. If a scaffold with a rather long text is added to the videos, the cognitive load of the pre-service teachers increases (cf. [48]). (2) The learning context (again) works as a barrier. Contextualizing the knowledge given in the scaffolds and including it to complete the tasks in *DiKoBi* may be challenging for pre-service teachers with little prior knowledge. Even though all information necessary to correctly complete the tasks is given, the barrier of the context cannot be overcome. Thus, supporting the pre-service teachers' pPCK is more beneficial for them. When receiving pPCK-scaffolds, pre-service teachers are encouraged to activate their pPCK concerning the aspect of biology-specific instructional quality in question in the classroom situation. In contrast to the cPCK-group, the pPCK-group does not have to overcome the barrier of the learning context. This might lower the cognitive load and make knowledge more accessible. pPCK-scaffolds activate the pre-service teachers' knowledge network and deep knowledge structures (cf. [49]). This makes their pPCK (needed to complete the tasks in *DiKoBi*) easily accessible when confronting pre-service teachers with a cPCK that requires them to include external knowledge and, therefore, produces a higher cognitive load. It is remarkable that even though all keywords were presented to the cPCK-group, pPCK-scaffolds lead to the use of more keywords in the post-test. This supports the finding that supporting the pPCK of pre-service teachers is more beneficial than adding support in the form of cPCK-information, even if this information contains all keywords. Nevertheless, the cPCK-group also descriptively increases the number of keywords used, just not as drastic and, thus, insignificant compared with the pPCK-group. The control group did not improve their reflection skills. Due to little prior knowledge, pre-service teachers need scaffolding in order to be able to complete the tasks in *DiKoBi* successfully. The scaffolds (cPCK and pPCK) help them reach the *Zone of proximal development* and lead to increased reflection skills in the post-test. To make the cPCK easily accessible for analyzing classroom situations, training the contextualization of general knowledge would be necessary. Overall, these findings support the RCM of PCK and the order of the realms. There is no direct approach from the cPCK to ePCK, and before cPCK becomes accessible for teaching or reflection, it has to be put into a context and be transformed into pPCK, which closely interacts with the plan–teach–reflect cycle [1,23].

6.2. Development of cPCK when Training pPCK/macro-ePCK$_{Reflect + Plan}$

In accordance with Hypothesis 2 (H2), no changes in the pre-service teachers' cPCK could be observed. Referring to the RCM of PCK, one explanation could be the learning context working as a filter between the cPCK and pPCK [1,40]. This filter might, in this case, work more as a barrier. As pre-service teachers train their pPCK/macro-ePCK$_{\text{Reflect + Plan}}$ for specific situations in individual settings, the generalization of the trained PCK realm cannot be decontextualized and, thus, only training pPCK/macro-ePCK$_{\text{Reflect + Plan}}$ does not improve their cPCK. Moreover, the cognitive load of the pre-service teachers completing the learning environment is presumably very high. In particular, for learners with little prior knowledge, integrating and generalizing the knowledge acquired through the learning environment might be too difficult. Thus, these results also support the theoretical point of view of the RCM of PCK.

6.3. Limitations

Since *DiKoBi* is a rather complex learning environment, limitations cannot be avoided. The cPCK-test only contains true–false items; the possibility of correct guessing has to be kept in mind. However, the Rasch analysis showed satisfying results. Concerning the results of the learning environment, the evaluation via keywords is discussed as a limiting factor. The keywords were chosen based on the relevant literature and already established in previous studies; they highly correlate with the evaluation of reflections by a human coder using a precise coding manual [17]. We assume that an evaluation via keywords is only suitable for pre-service teachers in early university education and little prior pedagogical content knowledge. Pre-service teachers might draw most of their professional knowledge from lectures and university courses where the use of those technical terms (e.g., the here-defined keywords) is highly encouraged and practiced. Analyzing classroom situations and including the keywords is, thus, likely, whereas expert teachers might use other words to describe and analyze the situation while being neither less precise nor less correct in their analyses. Nevertheless, this could also occur in the sample presented here, and some correct reflections are not considered because they do not contain keywords. Furthermore, the number of keywords used by pre-service teachers has a very high standard deviation. This can be attributed to very heterogeneous prior knowledge and perceived cognitive load. The present study is also facing motivational issues. The three tasks (*describe*, *explain*, and *alternative strategy*) have to be completed five times every time pre-service teachers complete the learning environment. This can decrease motivation from the first to the last classroom situation [50]. Test fatigue can also occur as they have to complete the learning environment three times (pre-test, intervention, and post-test) [51].

6.4. Implications

In conclusion, the findings of this study support the demand for practical insights into teacher education. To foster the acquisition of pPCK, it is helpful to provide context and enrich the taught cPCK with examples from teaching practices. This allows pre-service teachers to include cPCK in their pPCK by building up knowledge networks that they can draw from. The cPCK-scaffolds implemented in the learning environment could be revised once again so that they might be more beneficial for pre-service teachers. They are still long in comparison to pPCK-scaffolds and thus create a higher cognitive load, especially for learners with little prior knowledge [48]. Simulations, such as *DiKoBi*, offer the opportunity to practice and build up $\text{ePCK}_{\text{Reflect}}$ and $\text{ePCK}_{\text{Plan}}$ without overburdening pre-service teachers with the complexity of real classroom situations, especially in an early stage of knowledge acquisition. To guarantee a personalized learning experience with the learning environment *DiKoBi*, we are currently working on new video vignettes to demonstrate different levels of complexity in classroom situations. These new video vignettes are currently developed for primary school pre-service biology teachers and secondary school pre-service biology teachers separately. We decided to focus on school-specific features more in order to guarantee more authentic classroom situations in the videos. Furthermore, the effects of training in the learning environment on real-life teaching could be investigated.

6.5. Implications for the RCM of PCK—Knowledge Acquisition

The present study investigates the relationships between the realms described in the RCM of PCK by Carlson et al. [18]. In particular, the findings concerning RQ2 led us to think about reviewing the model from another perspective and to ask ourselves what realm is crucial for an individual teacher's performance. In the RCM, the ePCK builds the center of a teacher's professional knowledge. When it comes to knowledge acquisition in teacher education in Germany, the ePCK is built up rather late. We developed the following alternative form of representation to describe the realms of PCK inside an individual teacher by referring to the suggestions of the RCM of PCK [18,19]. This is to be understood as an addition to the RCM of PCK and not as a replacement.

The model shown in Figure 6 aims to explain the structure of PCK "within one teacher". The pPCK builds the center of the model. The realms are arranged in the form of a continuum without strict borders; instead, we blurred them. Blurring is supposed to show how fluent a teacher's PCK is and that it sometimes might even be difficult to decide what realm is currently used. Two scales are added on the top and bottom of the graphic to categorize the knowledge realm in accordance with existing knowledge models (e.g., [52]). One describes the nature of knowledge, declarative to procedural; the other describes the accessibility of the knowledge, general to individual. Squire [52] describes knowledge as a continuum ranging from declarative and explicit knowledge to procedural and implicit knowledge. This can be transferred to the RCM of PCK. cPCK is rather declarative knowledge that is accessible to the public; thus, it is general. When we move toward the ePCK or even the micro-ePCK of a teacher, the more procedural and individualized the knowledge realm becomes. The learning context lies over/behind the realms of the PCK, except for the parts of cPCK that are fully decontextualized. In contrast to the RCM of PCK—which does not graphically consider the contextualized collective PCK (although there is a differentiation between subject- and context-specific cPCK), such as published and common student misconceptions, e.g., on the topic of "evolution" for biology teaching [53]—this model attempts to illustrate that parts of cPCK can also underlie a very specific context. Furthermore, the alternative form of representation places the pPCK in the center; the RCM centers the ePCK. The pPCK can be described as a reservoir of knowledge that a teacher draws from [1], but it also builds the base for cPCK (see further on in this section). The findings of the present study support the idea of focusing more on pPCK. Pre-service teachers receiving pPCK-scaffolds significantly improved their macro-ePCK$_{\text{Reflect + Plan}}$. Therefore, pPCK is centered in this model. We also included the macro- and micro-cycle [23] in the model. However, we moved the plan and reflected part of the macro-cycle at the blurred border from ePCK to pPCK. When reflecting on a lesson, teachers have to use their pPCK to evaluate the lesson. Then, when planning a new lesson, pPCK is used and is ideally based on the results of the reflection. This is also where we would place the learning environment *DiKoBi*. We aim to train the transition from pPCK to ePCK.

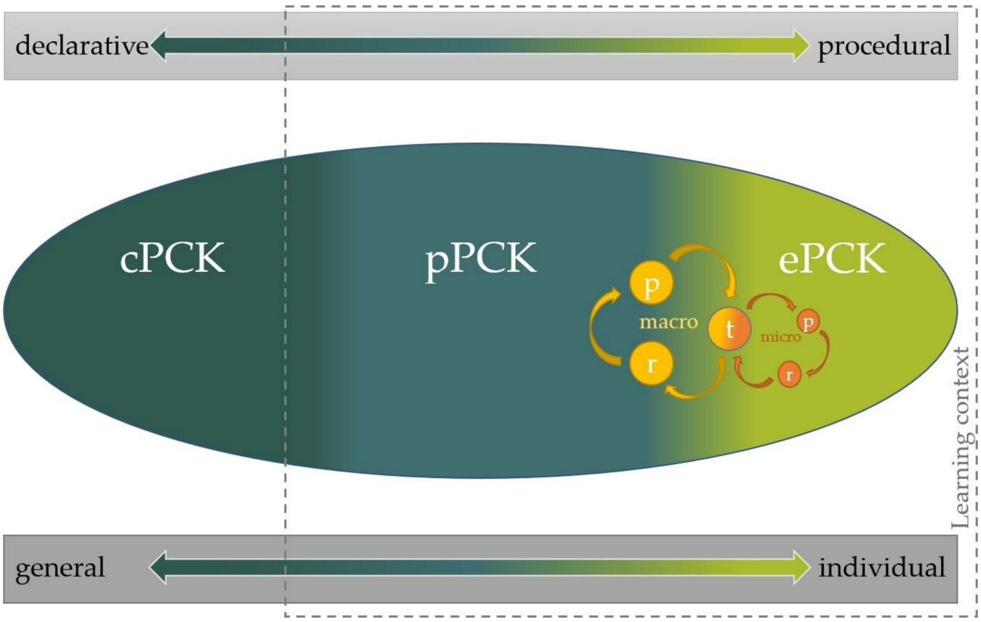

Figure 6. Suggesting a new form of representation: knowledge acquisition and structure of knowledge from the theoretical point of view of the RCM.

With the help of this alternative form of representation, we can explain the acquisition of PCK in teacher education as well as for in-service teachers. In German teacher education, knowledge is built up starting with cPCK (in form of, e.g., a lecture in university) and then introducing pre-service teachers to examples from practice (pPCK) until they try out their first lessons in real classrooms (ePCK). An in-service teacher, on the other hand, usually builds up their knowledge based on ePCK, e.g., by discovering new teaching techniques or methods in their everyday teaching. When reflecting on them, the ePCK becomes pPCK. Perhaps this teacher will talk to his/her colleagues about the newly discovered method or even share the method in a conference. Hence, this teacher has then successfully contributed to cPCK.

Figure 6 can be observed as an alternative point of view on the RCM of PCK; it is not supposed to replace the existing model. When developing such alternative forms of representation, we see the opportunity to start a conversation and discussion about the professional knowledge of science teachers.

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Data Availability Statement: Information and queries on the data can be obtained from the authors of this article.

Conflicts of Interest: The authors declare no conflict of interest.

Appendix A

Table A1. List of abbreviations.

Abbreviation	
PK	Pedagogical knowledge
CK	Content knowledge
PCK	Pedagogical content knowledge
CM	Consensus model of PCK
RCM	Refined consensus model of PCK
cPCK	Collective PCK
pPCK	Personal PCK
ePCK	Enacted PCK
$\text{ePCK}_{\text{Teach}}$	Enacted PCK, step "teach"
$\text{ePCK}_{\text{Plan}}$	Enacted PCK, step "plan"
$\text{ePCK}_{\text{Reflect}}$	Enacted PCK, step "reflect"
$\text{ePCK}_{\text{Reflect + Plan}}$	Enacted PCK, steps "reflect" and "plan"
DiKoBi	Name of the video-based learning environment
$DiKoBi^{I}{}_{Assess}$	Video-based learning environment, the first lesson in the assess version (used for measuring pPCK/$\text{ePCK}_{\text{Reflect + Plan}}$ in the pre-test)
$DiKoBi^{II}{}_{Learn}$	Video-based learning environment, the second lesson in the learn version (with scaffolds included as an intervention)
$DiKoBi^{III}{}_{Assess}$	Video-based learning environment, the third lesson in the assess version (used for measuring pPCK/$\text{ePCK}_{\text{Reflect + Plan}}$ in the post-test)

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