Fostering ePCK in pre-service biology teacher education using a video-based simulation

Investigating the effects of scaffolding and exploring the RCM of PCK

Dissertation der Fakultät für Biologie
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Statutory declaration and statement

Affidavit

Herewith I certify under oath that I wrote the accompanying Dissertation myself.

Title:
Fostering ePCK in pre-service biology teacher education using a video-based simulation – Investigating the effects of scaffolding and exploring the RCM of PCK

In the thesis no other sources and aids have been used than those indicated. The passages of the thesis that are taken in wording or meaning from other sources have been marked with an indication of the sources (including the World Wide Web and other electronic text and data collections). Furthermore, all parts of the thesis that were de novo generated with the help of artificial intelligence tools were identified by footnotes/annotations at the appropriate places and the artificial intelligence tools used were listed. The prompts used were listed in the appendix. This statement applies to all text, graphics, drawings, sketch maps, and pictorial representations contained in the Work.

Munich, 25th November 2024

Marie Irmer

Declaration

Hereby I declare

that this work, complete or in parts, has not yet been submitted to another examination institution.

that I did not undergo another doctoral examination without success.

Munich, 25th November 2024

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Abstract

The professional knowledge of teachers encompasses three facets of knowledge: The Pedagogical Knowledge (PK), the Content Knowledge (CK) and the amalgam of these two knowledge facets: The Pedagogical Content Knowledge (PCK). The PCK is unique to teachers and includes all strategies, skills and knowledge to make lesson content available for their students. Therefore, fostering PCK is a crucial part of (pre-service) teacher education. With the publication of the Refined Consensus Model of PCK (RCM of PCK) in 2019, a new perspective on science teachers' PCK was brought to the community. The RCM of PCK divides science teachers' PCK into three realms: the collective PCK (cPCK), the personal PCK (pPCK) and the enacted PCK (ePCK). The cPCK includes all PCK that is commonly accessible, published and discussed on conferences. The pPCK is the individual knowledge of a teacher. It is composed of the parts of cPCK the teacher has internalized and knowledge the teacher has gained from their experience in teaching. The ePCK is tacit knowledge and only shown, when a teacher is planning ($ePCK_P$), teaching ($ePCK_T$) or reflecting ($ePCK_R$) on a lesson.

While the call for more practical insights, especially in early teacher education, is persistent, real-life classroom situations can be overburdening and too complex for pre-service teachers. One possibility to offer practical insights in an early stage of knowledge acquisition, is the use of simulations. *DiKoBi* (diagnostic competences of biology teachers in biology classrooms) is a video-based simulation fostering pre-service biology teachers' ePCK that was developed as part of the COSIMA project (DFG (German Research Foundation), NE-1196/8-1, 8-2). When working on *DiKoBi*, pre-service teachers watch videos of practice situations and complete tasks concerning biology-specific aspects of instructional quality. Through the tasks, their $ePCK_R$ and $ePCK_P$ is assessed and trained. The tasks were developed based on two concepts: Professional Vision and diagnostic competences.

To support learners with little prior knowledge, scaffolding can be a highly effective intervention in complex learning environments, such as simulations. Scaffolding can be performed in various types and modes, being adaptive and personalized or not. It has the goal of enabling learners to learn in their Zone of Proximal development (ZPD), where they are able to complete tasks that they would not be able to complete without support yet.

This dissertation pursues three aims: (1) The investigation of scaffolding opportunities and effects in the simulation *DiKoBi*, (2) The empirical investigation of the RCM of PCK including the interplay of PCK realms, knowledge transfer and acquisition in early biology teacher education and (3) The exploration of adaptation and personalization possibilities in digital simulations.

Three studies in a pre-post-test design with a scaffolding intervention were conducted. $ePCK_R$ and $ePCK_P$ of pre-service biology teachers was assessed with the simulation *DiKoBi*. In the first study (*N* = 57), scaffolding the diagnostic activity of the task was compared to scaffolding the PCK. In the second study (*N* = 78), one treatment group received cPCK-scaffolding, the other treatment group received pPCK-scaffolding. In the third study (*N* = 115), one treatment group had a fixed adaptation of the scaffolding, the other treatment group had a situation-specific adaptation of the scaffolding. To provide answers to the research aims of this dissertation, the findings of the three studies are combined and discussed.

In all three studies, PCK-scaffolding has proven to be an effective intervention for fostering pre-service biology teachers' ePCK. It enables them to learn in their ZPD and supports the training of ePCK in the simulation *DiKoBi*. The findings of study 1 indicate that PCK-scaffolding is effective. Furthermore, the findings of study 2 reveal that scaffolding referring to the prior knowledge of what needs to be applied in the respective practice situation in the simulation (here: pPCK) is beneficial. The findings of the third study indicate that a finer granularity of the scaffolding adaptation (situation-specific) is more effective than a fixed adaptation in advance to working on the simulation. These results underline the effectiveness of personalized learning that simulations can offer.

Although relationships between the realms of PCK could be empirically confirmed, the findings of study 2 and 3 led to a modification of the original model in that, among other things, the pPCK was moved to the center to highlight its importance concerning knowledge acquisition. A detailed description and illustration of the modified RCM of PCK is provided in this dissertation.

For the exploration of adaptation and personalization strategies in simulations, the data obtained from study 1 and 2 was automatically evaluated with the help of *keywords* (= technical terms relevant to the aspect of biology-specific instructional quality of the task in *DiKoBi*). The evaluation via keywords came to the same results as the manual evaluation by human coders with the help of the coding manual. This could be a starting point for an automatic evaluation of the tasks in *DiKoBi* resulting in possibilities for in-time personalization of, e.g., scaffolding. Study 3 revealed that a situation-specific adaptation is more effective than a fixed adaptation supporting the necessity of a personalized scaffolding strategy.

Overall, the findings of this dissertation contribute to a deeper understanding of scaffolding in digital simulations by providing empirical evidence on the effectiveness of different scaffolding types and strategies implemented into the simulation *DiKoBi*. The simulation *DiKoBi* was successfully used as tool for fostering pre-service teachers' ePCK and offers a possible solution for closing the gap between teaching practice and teacher education. Moreover, by introducing a modified RCM of PCK, it contributes to the discussion on the professional knowledge of science teachers.

Zusammenfassung

Das Professionswissen von Lehrkräften kann als Zusammenspiel der Wissensfacetten Pädagogisches Wissen (PK), Fachwissen (CK) und deren Überschneidungsbereich Fachdidaktisches Wissen (PCK) beschrieben werden. PCK wird als spezifisches Wissen für Lehrkräfte angesehen und beinhaltet Strategien, Fähigkeiten und Wissen, um Fachinhalte für Schüler:innen zugänglich zu machen. Folglich ist die Förderung von PCK ein substanzieller Bestandteil der Lehrkräfteausbildung. Mit der Publikation des *Refined Consensus Model of PCK* (RCM of PCK) wurde der wissenschaftlichen Community eine neue Perspektive eröffnet. Das RCM of PCK unterteilt PCK in drei Bereiche: collective PCK (cPCK), personal PCK (pPCK) und enacted PCK (ePCK). cPCK schließt öffentlich verfügbares, publiziertes auf Fachkonferenzen diskutiertes Wissen ein. pPCK beschreibt das individuelle Wissen einer einzelnen Lehrkraft. Es setzt sich aus den Teilen des cPCKs, die eine Lehrkraft verinnerlicht hat und aus durch Unterrichtserfahrung selbst angeeignetem Wissen zusammen. ePCK ist implizites Wissen, welches nur dann gezeigt wird, wenn eine Lehrkraft Unterricht plant ($ePCK_P$), unterrichtet ($ePCK_T$) oder reflektiert ($ePCK_R$).

Während der Wunsch nach mehr Praxisnähe, vor allem in der frühen Lehrkräfteausbildung, persistent ist, können echte Unterrichtssituationen für angehende Lehrkräfte als überfordernd und zu komplex erlebt werden. Simulation bieten eine Möglichkeit, praktische Einblicke in einem frühen Stadium des Wissenserwerbs zu gewährleisten. *DiKoBi* (Diagnosekompetenzen von Biologielehrkräften im Biologieunterricht) ist eine videobasierte Simulation zur Förderung des ePCK angehender Biologielehrkräfte. *DiKoBi* wurde im Rahmen des COSIMA-Projektes (DFG, NE1186/8-1, 8-2) entwickelt. Beim Nutzen der Simulation *DiKoBi* betrachten angehende Biologielehrkräfte Unterrichtsvideos und bearbeiten zugehörige Aufgaben zu biologiespezifischen Unterrichtsqualitätsmerkmalen. Über die Bearbeitung der Aufgaben wird dabei ihr $ePCK_R$ und $ePCK_P$ erfasst and trainiert. Die Aufgaben wurden basierend auf den Konzepten Professionelle Wahrnehmung und Diagnosekompetenz entwickelt.

Zur Unterstützung Lernender mit wenig Vorwissen in komplexen Lernumgebungen, wie z.B. Simulationen, kann Scaffolding eine sehr effektive Unterstützungsmaßnahme sein. Es gibt verschiedene Typen von Scaffolds und vielfältige Modi zum Einsatz, wie adaptives und personalisierbares Scaffolding. Das Ziel von Scaffolding ist es Lernenden zu ermöglichen in ihrer sogenannten „Zone Proximaler Entwicklung (ZPD)" zu lernen. In der ZPD sind sie in der Lage eine Aufgabe mit Unterstützung zu lösen, die sie ohne diese Unterstützung noch nicht hätten lösen können.

Diese Dissertation verfolgt drei Ziele: (1) Die Untersuchung von Möglichkeiten des Scaffoldings und dessen Effekten in der Simulation *DiKoBi*, (2) die empirische Untersuchung des RCM of PCK inklusive des Zusammenspiels der Wissensbereiche sowie der Mechanismen des Wissenstransfers und -erwerbs in der frühen Lehrkräfteausbildung und (3) die Exploration von Adaptations- und Personalisierungsmöglichkeiten in digitalen Simulationen.

Es wurden drei Studien im Prä-Posttest-Design mit einer Scaffolding-Intervention durchgeführt. $ePCK_R$ und $ePCK_P$ angehender Biologielehrkräfte wurde über die Simulation *DiKoBi* erfasst. In der ersten Studie ($N = 57$) wurde ein Scaffolding der diagnostischen Aktivitäten mit einem PCK-Scaffolding verglichen. In der zweiten Studie ($N = 78$) erhielt eine Gruppe ein cPCK-Scaffolding, die andere Gruppe erhielt ein pPCK-Scaffolding. In der dritten Studie ($N = 115$) wurde das Scaffolding der einen Gruppe fixiert adaptiert und das der anderen Gruppe situationsspezifisch. Um die drei Ziele zu erfüllen, wurden die Ergebnisse der drei durchgeführten Studien kombiniert und diskutiert.

In allen drei Studien konnte gezeigt werden, dass Scaffolding eine effektive Intervention zur Förderung des ePCK angehender Biologielehrkräfte ist. Es ermöglicht das Lernen in der ZPD und unterstützt so das Training von ePCK in der Simulation *DiKoBi.* Studie 1 zeigte, dass ein PCK-Scaffolding effektiv ist. Darüber hinaus zeigen die Ergebnisse der zweiten Studie, dass insbesondere Scaffolding, welches sich auf das in der Praxissituation anzuwendende Vorwissen bezieht, also hier pPCK, besonders vorteilhaft ist. Die Ergebnisse der dritten Studie zeigen, dass eine situationsspezifische Anpassung des Scaffoldings effektiver ist als eine fixierte Anpassung. Diese Ergebnisse unterstreichen die Effektivität von personalisiertem Lernen, welches durch Simulationen ermöglicht werden kann.

Obwohl die Beziehungen zwischen den Wissensbereichen des RCM of PCK grundsätzlich bestätigt werden konnten, fordern die Ergebnisse der Studien 2 und 3 eine Modifikation des ursprünglichen Models, in der, unter anderem, pPCK in die Mitte des Models gerückt wird, um seine Relevanz im Wissenserwerb hervorzuheben. Eine detaillierte Beschreibung und Abbildung des modifizierten RCM of PCK wird in der Dissertation diskutiert.

Zur Erforschung von Anpassungs- und Personalisierungsstrategien in Simulationen wurden die aus Studie 1 und 2 gewonnenen Daten automatisiert mit Hilfe von *keywords* (= Fachbegriffe, die für den Aspekt biologiespezifischer Unterrichtsqualität in der Aufgabe in *DiKoBi* relevant sind) ausgewertet. Diese Auswertung über *keywords* kam zu den gleichen Ergebnissen wie die manuelle Auswertung durch menschliche Kodierer:innen mit Hilfe des Kodiermanuals. Dies könnte ein Ausgangspunkt für eine automatisierte Auswertung der Aufgaben in *DiKoBi* sein, wodurch sich Möglichkeiten zur Personalisierung von z.B. Scaffolds während der

Aufgabenbearbeitung ergeben. Die Ergebnisse von Studie 3 unterstützen diese Entwicklung, da gezeigt werden konnte, dass eine situationsspezifische Anpassung der Scaffolds effektiver ist als eine fixierte Anpassung.

Insgesamt tragen die Ergebnisse dieser Dissertation zu einem tieferen Verständnis von Scaffolding in digitalen Simulationen bei, indem sie empirische Belege für die Wirksamkeit verschiedener Scaffoldingtypen und -strategien liefert, die in die Simulation *DiKoBi* implementiert werden können. Die Simulation *DiKoBi* wurde erfolgreich als Tool zur Förderung des ePCK für angehende Lehrkräfte eingesetzt und bietet eine mögliche Lösung, um eine Brücke zwischen Unterrichtspraxis und Lehramtsausbildung zu bauen. Darüber hinaus tragen die Ergebnisse durch die Einführung eines modifizierten RCM of PCK zur Diskussion über das Professionswissen von Lehrkräften und dessen Förderung bei.

Content

Abbreviations

CK	content knowledge
CM	2012 Consensus Model of PCK
COSIMA	Facilitating Diagnostic Competences in Simulation-based Learning
cPCK	collective pedagogical content knowledge
DA	diagnostic activities
DFG	German Research Fundation (Deutsche Forschungsgemeinschaft)
DiKoBi	Video-based simulation *Diagnostic competences for biology teachers in biology classrooms*
e.g.	“exempli gratia”; for example
ePCK	enacted pedagogical content knowledge
KMK	Standing Conference of the Minister of Education and Cultural Affairs of the Länder
PCK	pedagogical content knowledge
PK	pedagogical knowledge
pPCK	personal pedagogical content knowledge
PST	pre-service teacher
PV	Professional Vision
RCM	Refined Consensus Model
ZPD	Zone of proximal development

List of publications

Publications of the cumulative dissertation

Publication I **Irmer, M.**, Traub, D., Kramer, M., Förtsch, C., & Neuhaus, B. J. (2022). Scaffolding Pre-service Biology Teachers‘ Diagnostic Competences in a Video-based Learning Environment: Measuring the Effect of Different Types of Scaffolds. *International Journal of Science Education, 44*(9), 1506-1526.
https://doi.org./10.1080/09500693.2022.2083253

Publication II **Irmer, M.**, Traub, D., Böhm, M., Förtsch, C. & Neuhaus, B. J. (2023). Using Video-Based Simulations to Foster pPCK/ePCK – New Thoughts on the Refined Consensus Model of PCK. *Education Sciences*, *13*(3), 261.
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Declaration of contribution as a co-author

Erklärung über die Eigenanteile bei Ko-Autorenschaften

Hiermit wird bestätigt, dass die folgenden drei Publikationen federführend von Frau Marie Irmer im Rahmen ihrer Dissertation abgefasst wurden. Dies geschah mit folgenden Anteilen:

Publication I

Irmer, M., Traub, D., Kramer, M., Förtsch, C., & Neuhaus, B. J. (2022). Scaffolding Pre-service Biology Teachers‘ Diagnostic Competences in a Video-based Learning Environment: Measuring the Effect of Different Types of Scaffolds. *International Journal of Science Education, 44*(9), 1506-1526. https://doi.org./10.1080/09500693.2022.2083253

Marie Irmer hat bereits erhobene Daten einer Studie im Rahmen des COSIMA-Projektes ausgewertet, weitere Daten erhoben, die Ergebnisse aufbereitet, den Artikel konzipiert und ihn federführend verfasst.
Die Ko-Autorin Dagmar Traub unterstützte substanziell bei der Auswertung der Daten sowie bei der Konzeption des Artikels. Die Ko-Autorin Maria Kramer hat die Daten erhoben und das Tool zur Studie auf der Online-Plattform Unipark (Questback GmbH) entwickelt und validiert. Die Ko-Autor:innen Christian Förtsch und Birgit Neuhaus entwickelten das Studiendesign und unterstützen bei der Datenerhebung sowie der Konzipierung und Überarbeitung des Artikels.

Publication II

Irmer, M., Traub, D., Böhm, M., Förtsch, C. & Neuhaus, B. J. (2023). Using Video-Based Simulations to Foster pPCK/ePCK – New Thoughts on the Refined Consensus Model of PCK. *Education Sciences*, *13*(3), 261. https://doi.org/10.3390/edusci13030261

Marie Irmer entwickelte die Intervention für die durchgeführte Studie, erhob die Daten, wertetet die Daten aus, konzipierte und verfasste den Artikel. Die Ko-Autorin Dagmar Traub unterstütze substanziell bei der Entwicklung der Intervention, der Datenerhebung, der Auswertung und der Konzipierung des Artikels. Die Ko-Autorin Marina Böhm wertete einen Teil der Daten aus. Die Ko-Autor:innen Christian Förtsch und Birgit Neuhaus unterstützen beim Design und bei der Durchführung der Studie, der Konzipierung und der Überarbeitung des Artikels.

Publication III

Irmer, M., Traub, D., Neuhaus, B. J. (2024). Fostering ePCK in pre-service biology teacher education using adaptive scaffolding in a video-based simulation. *Cogent Education*, *11*(1). https://doi.org/10.1080/2331186X.2024.2422272

Marie Irmer entwickelte das Material für die Intervention der Studie, führte die Studie durch, wertete die Daten statistisch aus, konzipierte und verfasste den Artikel federführend. Die Ko-Autorin Dagmar Traub unterstützte bei der Entwicklung des Materials, der Erhebung der Daten und der Überarbeitung des Artikels. Die Ko-Autorin Birgit Neuhaus trug substanziell zur Konzipierung und zur Überarbeitung des Artikels bei und entwickelte das Studiendesign.

München, den 25.11.2024 *Marie Irmer*

München, den 25.11.2024 *Prof. Dr. Birgit J. Neuhaus*

1. Introduction

One of the main challenges in teacher education is the rarity of the involvement of pre-service teachers into real-life practice situations while the call for more practical insights, even in early teacher education, is persistent. On the other hand, real classroom situations can be overburdening, especially, for pre-service teachers in early stages of their studies. Therefore, many researchers and teacher educators try to find a solution that includes more practical insights into early teacher education while also guaranteeing not to overstimulate pre-service teachers. Simulations are a tool that might be part of the solution to close the gap between theory and practice (Chernikova, Heitzmann, Fink, et al., 2020; Chernikova, Heitzmann, Stadler, et al., 2020). This dissertation aims to explore, investigate and further develop ways to effectively foster the enacted Pedagogical Content Knowledge and the diagnostic competences of pre-service biology teachers using the video-based simulation *DiKoBi* (Kramer et al., 2020). Particularly in complex learning environments, such as video-based simulations, scaffolding has been proven to be an effective intervention to increase learning outcomes (Belland, 2017; Quintana et al., 2004). To investigate how scaffolding can be included into the simulation *DiKoBi*, three studies were conducted and evaluated, that include different types of scaffolds, scaffolding strategies and varying adaptation and personalization strategies (Irmer et al., 2023; Irmer et al., 2022; Irmer et al., 2024). Figure 1 was created to serve as an overview of the theoretical framework and the discussed constructs in this dissertation. All of the theoretical concepts mentioned above, can be related to each other as shown in Figure 1 by arrows. The context of the video-based simulation *DiKoBi* is to diagnose aspects of biology-specific instructional quality that are shown in videos representing core practices of science teaching. These core practices are derived from the Pedagogical Content Knowledge of science teachers. In *DiKoBi,* different types of scaffolds were developed to support the learning outcome concerning the diagnostic competences of pre-service biology teachers. Tasks in the video-based simulation *DiKoBi* were developed based on the two constructs of Professional Vision and diagnostic activities and therefore aim to train these very skills.

In the following, the structure of the theoretical framework will be shortly described to explain how the constructs mentioned in this dissertation are linked to each other.

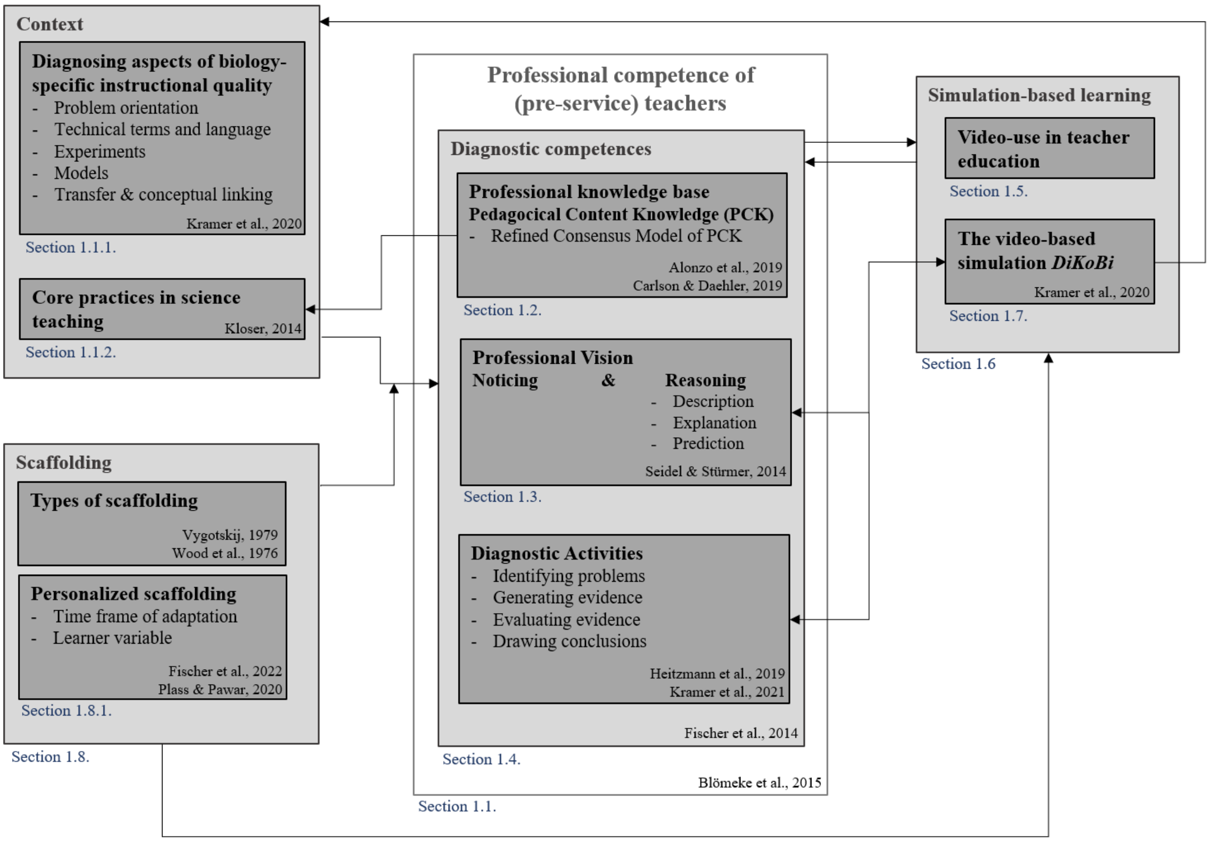

Figure 1. Overview of the theoretical framework of the dissertation. Relevant theories and concepts are included as well as examples of the corresponding literature. Relationships between the concepts are illustrated by arrows.

The video-based simulation *DiKoBi* was developed by Kramer et al. (2020) in order to serve as an assessment tool and as a learning environment for pre-service biology teachers fostering their diagnostic competences and their enacted Pedagogical Content Knowledge. As diagnostic competences are part of a teacher's professional competence (often also synonymously described as assessment knowledge) (Carlson & Daehler, 2019; Herppich et al., 2018), this dissertation starts with an introduction referring to the professional competences of teachers (see section 1.1). According to the competence model of Blömeke et al. (2015), part of a teachers' professional competence, is their professional knowledge base (Shulman, 1986) (see section 1.1.1). The Pedagogical Content Knowledge (PCK) of a teacher is positively related to their students' outcomes (Seidel & Shavelson, 2007). Thus, fostering PCK in pre-service teacher education is important. One possibility to externally evaluate a teacher's Pedagogical Content Knowledge (PCK), is to observe their teaching with regard to aspects of instructional quality (Dorfner, Förtsch, & Neuhaus, 2018; C. Förtsch et al., 2016). For teaching the subject of biology, biology-specific aspects of instructional quality have been found to be empirically effective when implemented into a biology lesson (Dorfner et al., 2019) (see section 1.1.2). Another approach to foster PCK, is to focus on so called core practices (Grossman, 2021). Therefore, section 1.1.3 introduces the core practices of science teaching (Kloser, 2014). To further describe the PCK of science teachers, researchers around Carlson and Daehler (2019) developed and elaborated the Refined Consensus Model (RCM) of PCK, that is described in section 1.2. In section 1.3 and 1.4, two constructs that have been included into the development of the video-based simulation *DiKoBi* are described: Professional Vision (PV) (Seidel & Stürmer, 2014; van Es & Sherin, 2002) and the diagnostic competences of a teacher. As shown in Figure 1, the diagnostic competences of biology teachers include their PCK, their PV skills and the performance of diagnostic activities (DA) (Heitzmann et al., 2019). To train both, PV and diagnostic competences, the use of videos is common (section 1.5). To approximate practice stepwise, simulations can be included into teacher education (Chernikova, Heitzmann, Stadler, et al., 2020) (see section 1.6). In this dissertation, the video-based simulation *DiKoBi* (Kramer et al., 2020) is used to assess and to train pre-service biology teachers' diagnostic competences and enacted PCK (see section 1.7). To support the learning process in the simulation, scaffolding is an effective tool (Belland, 2017; Chernikova, Heitzmann, Stadler, et al., 2020; Quintana et al., 2004). In section 1.8., scaffolding as a type of instructional support is described, including the possibility of personalized, adaptive scaffolding (see section 1.8.1). After this theoretical introduction, three main research aims are derived (see section 2). These aims are addressed in three publications listed in section 3. In section 4 the results are summarized and then discussed, referring to the three research aims (see section 4.1, 4.2 and 4.3). After the limitations of the conducted research is discussed (see section 4.4), an overview of further research following the results of this dissertation (see section 4.5), as well as possible implications for practice and teacher education (see section 4.6), are given.

1.1. The professional competence of a teacher

The question of how to describe the competences a teacher needs to successfully teach a subject to their students has occupied many researchers in the past decades. The COACTIV research program had the aim of empirically and theoretically integrating different approaches to the professionalization of teachers and based on these findings developing a generic model of the professional competences of teachers (Baumert & Kunter, 2013). Baumert and Kunter (2013) developed the COACTIV model of professional competence that includes the professional knowledge bases (see section 1.1.1), but also non-cognitive elements such as the beliefs / values / goals, the motivational orientations and the self-regulations skills of a teacher. This model was one of the firsts to extent the definition of professional competence of teachers with a non-cognitive dimension (beliefs, motivational orientation, etc.). However, the COACTIV model does not consider the dynamic and situation-specific nature of a teacher's professional competence, although this has to be taken into account to fully capture all parts of teachers' competence (Blömeke & Kaiser, 2017; Depaepe et al., 2013). Therefore, Blömeke et al. (2015) developed a model of professional competence, that includes the knowledge of teachers, their cognitive, affective and motivational dispositions, as well as their situation-specific skills. The competence of teachers is modeled as a continuum where knowledge is applied in form of situation-specific skills based on the motivation and beliefs of a teacher (Blömeke et al., 2015). The application of knowledge in form of situation-specific skills leads to an observable behavior in the class the teacher is teaching (Blömeke et al., 2015). In turn, the teaching in a classroom influences the teacher's knowledge and their beliefs (Carlson & Daehler, 2019). By including situations-specific skills into the competence model, it helps to describe the competence of teachers from a subject-specific point of view. Subject-specific knowledge as well as subject-specific core practices can thus be located in and included into the competence model.

1.1.1. Professional knowledge bases

To define the professional knowledge base teachers draw upon when teaching, Shulman (1986) defined three domains of teachers' professional knowledge: The Pedagogical Knowledge (PK), the Content Knowledge (CK) and the Pedagogical Content Knowledge (PCK). Whereas the PK is interdisciplinary knowledge, that applies to all subjects, the CK and the PCK are subject-specific domains of knowledge (Baumert & Kunter, 2013; Shulman, 1986). The PK includes all knowledge about general Pedagogy, but also about classroom management, knowledge about students' learning and development, knowledge on feedback and testing, and, various other subject-general facets depending on what source of literature is considered (Baumert & Kunter, 2013; Shulman, 1986). The CK of a teacher contains all knowledge related to the content the teacher is teaching (Shulman, 1986). In the context of biology, for example, that would be knowledge about evolution, genetics or zoology and knowledge about basic biological concepts and theories. The PCK is not only subject-specific like the CK, but also the domain of knowledge that is unique to teachers and teaching. It can be seen as the overlap between PK and CK (Shulman, 1986). For the development of PCK, CK is theoretically necessary (Baumert & Kunter, 2013). The PCK encompasses knowledge of typical students' mistakes and typical errors in the subject (e.g. knowledge about misconceptions concerning the concept of evolution for biology), knowledge of how to present a specific content in the classroom, of instructional strategies, and knowledge of typical tasks (Baumert & Kunter, 2013; Shulman, 1986). One way to draw conclusions about a teacher's PCK, is to assess the quality of their instruction (C. Förtsch et al., 2016).

1.1.2. Biology-specific instructional quality

The outcome of a successful teaching (e.g. a high student achievement) is primarily mediated by the quality of the instruction of a teacher (Neuhaus, 2007, 2021; Seidel & Shavelson, 2007). Whereas, there is a common understanding of three basic dimension of instructional quality in the German-speaking community (Classroom management, cognitive activation and supportive climate) (Klieme et al., 2006), subject-specific aspects of instructional quality are discussed only rather recently (Dorfner et al., 2017). The impact of biology-specific aspects of instructional quality has been investigated by various researchers (Dorfner, Förtsch, & Neuhaus, 2018, 2020; C. Förtsch et al., 2020; S. Förtsch et al., 2018; Nawani et al., 2018; Oh & Oh, 2011; Wadouh et al., 2014). In the following table, a selection of biology-specific aspects of instructional quality modified according to Kramer et al. (2020) is displayed (Table 1). These aspects of biology-specific instructional quality are part of teachers' professional competence and applying them to teaching leads to effective biology teaching (Kramer et al., 2020; Steffensky & Neuhaus, 2018). The described aspects of biology-specific instructional quality (see Table 1) can also be found within the core science teaching practices by Kloser (2014).

Table 1. Aspects of biology-specific aspects of instructional quality modified according to Kramer et al. (2020). A description of the aspects as well as corresponding relevant literature is listed. The aspects are chosen based on the content of the video-based simulation *DiKoBi*.

aspect of biology-specific instructional quality	**description**	**relevant literature (example)**
problem orientation in the beginning of the lesson	In the introduction of a lesson, the creation of a problem (resulting in a focus question) helps students for conceptual understanding and can create situational interest. A problem orientated introduction can also be cognitively activating.	C. Förtsch et al., 2017; Nawani et al., 2018
Use of technical terms and language	The use of an appropriate number of technical terms in a biology classroom. Furthermore, technical terms should always be introduced in a context and with an explanation. A conscious use of technical terms and language can help students in their conceptual understanding of biology.	Dorfner et al., 2020
Use of experiments	Experiments, as part of scientific inquiry, can be used to solve problems created in a lesson. It is important to follow the path of scientific inquiry from formulating a question, generating hypotheses, planning and conducting an experiment to evaluating and interpreting data and finally drawing conclusions to foster scientific reasoning.	Dorfner, Förtsch, Germ, & Neuhaus, 2018
Use of models	To fosters students' reasoning skills, models can be implemented into biology teaching. Model should be included on an elaborate level to cognitively activate students when working with or on a model. The critical reflection of a model should always be included to complete the modelling process.	S. Förtsch et al., 2018; Oh & Oh, 2011
Transfer at the end of a lesson	In the end of a lesson, new knowledge should not only be applied but also transferred to another context to foster conceptual and deep understanding of the content. Furthermore, the transfer to another context can be seen as a complex task which fosters complex thinking.	C. Förtsch et al., 2020; C. Förtsch et al., 2016; Wadouh et al., 2014

1.1.3. Core practices in science teaching

Following the idea of general core practices for teaching (Grossman, 2021; Grossman & McDonald, 2008), Kloser (2014) presented 10 core practices that are tailored to the context of science teaching with the goal of enabling teachers to create a stimulating learning environment in science classrooms and foster students' learning. Namely, these ten core practices are: (1) Engaging students in investigations, (2) Facilitating classroom discourse, (3) Eliciting, assessing, and using student thinking about science, (4) Providing feedback to students, (5) Constructing and interpreting models, (6) Connecting science to its applications, (7) Linking science concepts to phenomena, (8) Focusing on core science ideas, crosscutting concepts and practices, (9) Building classroom community, and (10) Adapting instruction (Kloser, 2014). In the following, core science practices that are especially relevant in this dissertation will be explained in more detail with reference to the subject of biology (see also section 1.7). The core practice *engaging students in investigations* describes all activities related to experimenting in a biology classroom including the whole path of scientific inquiry – from posing a question to the evaluation of an experiment –, but also data collection and management. Competence in this core science teaching practice is shown by a teacher who includes experiments and other scientific investigations into their teaching (Kloser, 2014). A teacher who identifies their students' pre-concepts and includes them into their teaching shows fluency in the core practice *Eliciting, assessing and using student thinking about science* (Kloser, 2014). The core practice *Constructing and interpreting models* is executed when a teacher provides learning opportunities that include the construction, testing, revision and use of scientific models in their classroom. *Focusing on core science ideas, crosscutting concepts and practices* is, for example, shown when teachers structure their lessons using biological core ideas and concepts (Kloser, 2014). Training these core practices in teacher education programs could be beneficial for facilitating the entry into teaching practice. Core practices of science teaching positively relate to student outcomes (Kloser, 2014) and are therefore an important aspect of instruction.

1.2. The Refined Consensus Model of Pedagogical Content Knowledge

One aspect that is relevant to the quality of the instructional practice (see section 1.1.2) and therefore also for a positive student outcome, is the PCK of the teacher (see section 1.1.1) (C. Förtsch et al., 2016; Schmelzing et al., 2013). In 2012, international researchers from the field of science education met to discuss the professional knowledge of science teachers. This PCK Summit resulted in the "2012 Consensus Model (CM) of PCK" (Berry et al., 2015). When the science PCK researchers met again in 2015 for a second PCK Summit, they came to the conclusion that the CM of PCK is not sufficient to describe and capture the nature of science teachers' PCK and therefore, they developed a new model: the Refined Consensus Model (RCM) of PCK (Carlson & Daehler, 2019).

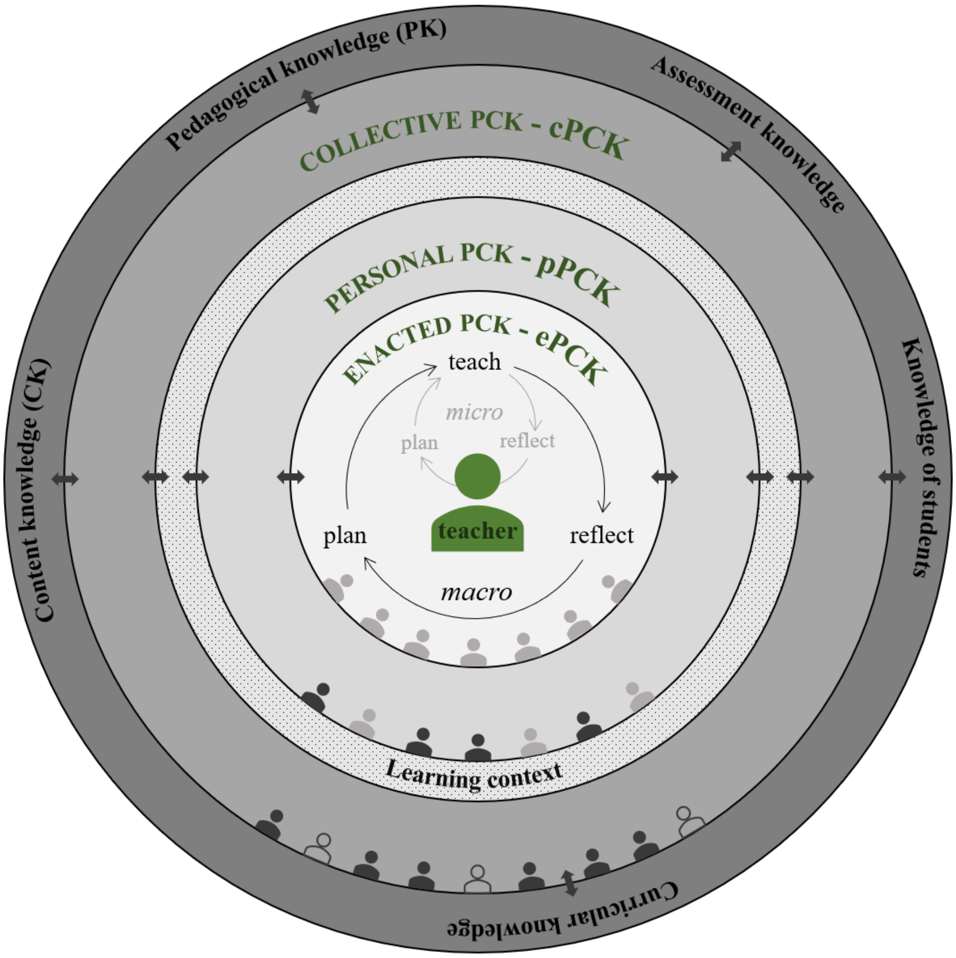

Figure 2. The Refined Consensus Model of PCK modified according to Carlson and Daehler (2019) including the micro- and macro-cycle of the plan-teach-reflect-cycle according to Alonzo et al. (2019). The teacher is the center of the model, the other person icons symbolize contributions of other teachers (darker symbols), outcomes of students (lighter symbols) and contributions of others persons (unfilled symbols). Arrows stand for the exchange of knowledge.

The RCM unites the perspective of the CM, Shulman's (1986) framework on professional knowledge of teachers as well as the framework of Magnusson et al. (2002) (Carlson & Daehler, 2019). The RCM aims to be a theoretical framework for teacher educators, researchers and in-service teachers to understand the nature of science teachers' PCK. It focusses on the practical teaching and thus, puts the process of planning, teaching and reflecting on a lesson into the center of the model (Alonzo et al., 2019; Carlson & Daehler, 2019). The RCM of PCK identifies three distinct realms of science teachers' PCK: The *enacted* PCK (ePCK), the *personal* PCK (pPCK), and the *collective* PCK (cPCK), that are organized in concentric circles around the teacher as a central part of the illustration (see Figure 2). The model also takes other professional knowledge bases than PCK into account: the pedagogical knowledge (PK, cf. Shulman, 1986), the knowledge of students, the curricular knowledge, the assessment knowledge, and the content knowledge (CK, cf. Shulman, 1986). These other knowledge bases influence a teacher's PCK and therefore also have an influence on the teacher's teaching (Carlson & Daehler, 2019). All three realms of PCK can range from *concept-specific* PCK to *topic-specific* PCK to *discipline-specific* PCK. For example, knowledge about how to effectively include experiments in biology lessons is *discipline-specific*, whereas the knowledge about typical student prior knowledge about the skin would be *topic-specific* and the knowledge about strategies to teach the biological core idea "structure and function" (C. Förtsch et al., 2018) would be *concept-specific*. In the following, the model will be explained from the inner to the outer concentric circle (see Figure 2).

enacted PCK (ePCK)

Carlson and Daehler (2019) define ePCK as

> specific knowledge and skills utilized by an individual teacher in a particular setting, with a particular student or a group of students, with a goal for those students to learn a particular concept, collection of concepts, or a particular aspect of the discipline. (Carlson & Daehler, 2019, pp. 83–84)

Thus, ePCK can be considered as highly situation-specific and very specific to an individual teacher. Furthermore, ePCK encompasses not only the teaching itself, but also the acts of planning a specific lesson and reflecting on that lesson after the lesson has been taught (plan-teach-reflect cycle, Alonzo et al., 2019; Carlson & Daehler, 2019). It only exists 'in action' and is generated in the moment a teacher engages with planning, teaching or reflecting on a lesson (Alonzo et al., 2019). This results in three different forms of ePCK: $ePCK_P$ (P for 'plan'), $ePCK_T$ (T for 'teach'), and $ePCK_R$ (R for 'reflect') (Alonzo et al., 2019). To further specify the dynamic and tacit nature of ePCK, Alonzo et al. (2019) describe two different forms of ePCK: micro ePCK and macro ePCK. macro ePCK refers to the knowledge and skills a teacher uses when planning a whole lesson, teaching that complete lesson and later on, reflecting on that lesson. Whereas micro ePCK is shown multiple times and is even more tacit in nature than macro ePCK. Whenever a teacher interacts with their students, even when asking a question or giving a task, a cycle of planning, teaching and reflecting happens (Alonzo et al., 2019). Thus, multiple micro plan-teach-reflect-cycles add up to the teach part of the macro plan-teach-reflect cycle, this is also illustrated in Figure 2. A teacher's micro ePCK is so situation-specific, that it is usually not possible to capture it or to even measure that part of a teacher's knowledge and skills. Mostly, science teachers are not even aware of the planning and reflecting parts of the micro ePCK (Alonzo et al., 2019). To make ePCK visible and measurable, researchers could use science teachers' lesson plans, their reasoning on science teaching including the expression of their knowledge or the articulation of specific teaching moves they chose (Alonzo et al., 2019; Carlson & Daehler, 2019).

Pedagogical reasoning

Carlson and Daehler (2019) name pedagogical reasoning to be the process behind the transformation of ePCK into pPCK and pPCK into ePCK. Therefore, Behling et al. (2022a) suggested to include the pedagogical reasoning into the model by adding a circle between the ePCK and the pPCK. The model of Professional Vision (Seidel & Stürmer, 2014; Sherin, 2007) can be used to describe the process of pedagogical reasoning (Behling et al., 2022a; Seidel & Stürmer, 2014; Sherin, 2007). The transformation of ePCK and pPCK happens whenever ePCK is verbalized (Alonzo et al., 2019).

personal PCK (pPCK)

Just like ePCK, pPCK is also individual to every science teacher. It is characterized by its dynamic and cumulative nature. Other than ePCK, a teacher's pPCK is not only influenced by the students and their outcomes, but also by peers, researchers, and all sorts of knowledge sources teachers can draw upon (Carlson & Daehler, 2019). It "serves as a reservoir of knowledge" (Carlson & Daehler, 2019, p. 85) when teaching and applying knowledge and skills in form of ePCK. The relationship between ePCK and pPCK is closely interwoven: when science teachers apply pPCK, it becomes ePCK, when they verbalize ePCK and gain new knowledge based on experiences, pPCK becomes ePCK. This knowledge exchange and interweaving between the two realms is illustrated by arrows in the graphic model (see Figure 2). In contrast to the ePCK, the pPCK of several science teachers can overlap in some points, especially when they are working together, teaching at the same school, or have been trained in the same teacher training program (Carlson & Daehler, 2019). pPCK also includes theories and concepts of PCK, like, for example, the knowledge about how to include an experiment into a biology lesson following the path on scientific inquiry or knowledge about an adequate use of technical terms and language in biology lessons about a specific topic. pPCK is thus composed of components that are very individual and based on personal experiences as well as components of more general knowledge about teaching, that an individual science teacher possesses.

The learning context

The concentric circle separating the pPCK from the cPCK is called "learning context" (Carlson & Daehler, 2019). The learning context describes all circumstances that teaching takes place in. It encompasses not only the curriculum of the taught subject, but also the learning environment (e.g. the school or classroom itself) and the characteristics of the student (e.g. their mother tongue, their prior knowledge, the socio-economic background, their age, their grade level) (Carlson & Daehler, 2019). The learning context defines the setting teaching is taking place in and serves as an amplifier between pPCK and cPCK.

collective PCK (cPCK)

The cPCK of a teacher is what Carlson and Daehler (2019) consider to be the closest to Shulman's (1986) definition of Pedagogical Content Knowledge. The cPCK is described as all knowledge that the community, consisting of science education researchers, teacher educators, teachers, and other persons related to science teaching, collectively hold. cPCK is knowledge that has been published and is accessible for a wider range of people. In contrast to ePCK and pPCK, cPCK is not as individual and private. Most of it is documented and discussed among the science teaching community. Nevertheless, cPCK can also exist in tacit forms of knowledge, for example, when a group of teachers at one school comes together to develop shared teaching sequences (Carlson & Daehler, 2019). Therefore, in this dissertation, cPCK is treated as a realm that not only describes collectively held knowledge, but also those parts of collectively held knowledge that an individual teacher possesses (Irmer et al., 2023).

Assessment knowledge, Curricular knowledge, Knowledge of students, Pedagogical knowledge and Content knowledge

The outmost concentric circle (see Figure 2) represents the professional knowledge bases that also have an influence on a teacher's teaching and their PCK. It contains, as according to Shulman (1986), the PK and the CK of a teacher, but also, the assessment knowledge, the curricular knowledge and the knowledge of students, as according to Magnusson et al. (2002). All of these knowledge types are connected to the teacher's PCK and the subject they are teaching. They are usually trained and developed during teacher training programs and further expanded when making own experiences in the classroom (Carlson & Daehler, 2019).

1.3. Professional Vision

The term Professional Vision (PV) was first introduced by Goodwin (1994) as a way a social group views and interprets events in a manner, that aligns with their specific interests. The development of a PV during teacher education is crucial to developing teacher expertise of which PV is part. PV is composed of two components: *Noticing* and *Reasoning* (Seidel & Stürmer, 2014; van Es & Sherin, 2002). *Noticing* describes the process of selecting visual and verbal information of relevant teaching situations (Seidel & Stürmer, 2014). Depending on the focus of the observation, this could be the noticing of indicators of instructional quality. The second component, *Reasoning*, has been conceptualized to be done in three steps: (1) describing, (2) explaining and (3) predicting (Borko & Livingston, 1989; Gamoran Sherin & van Es, 2009; Seidel & Stürmer, 2014). Although, these three aspects are qualitatively different, they are highly interrelated (van Es & Sherin, 2002). *Describing* includes "the ability to clearly differentiate the relevant aspects of a noticed teaching and learning component […] without making any further judgements" (Seidel & Stürmer, 2014, p. 745). When *explaining*, a person uses their knowledge to reason about a noticed and described situation. During this step, it is important to link the explanation to relevant theories and concepts concerning the observed situation (Seidel & Stürmer, 2014). In the case of observing a teaching situation in a biology lesson with the goal of evaluating the instructional quality, a person would refer to relevant concepts and their knowledge from the field of PCK. In the last step, a *prediction* of the consequences for students' learning and teaching effectiveness is made (van Es & Sherin, 2002). This affords a deeper knowledge regarding the observed teaching situation and the ability to transfer this knowledge into the observed situation (Seidel & Stürmer, 2014). This reasoning process can result in a decision, like for example, the proposal of alternative teaching strategies or the anticipation of the next teaching move (Kaiser et al., 2015; Kramer, Förtsch, Boone, et al., 2021; Santagata & Yeh, 2016; Yeh & Santagata, 2015).

The competences described in PV can be located in the RCM of PCK. Skills of PV are situation-specific and the assessment of those skills is only possible in a specific learning and teaching situation (Vogt & Schmiemann, 2020). Hence, skills of PV can be assigned to a science teacher's ePCK. The knowledge needed for explaining an observed situation can be assigned to the $ePCK_R$ as well as the knowledge used for predicting. When suggesting an alternative teaching strategy, $ePCK_P$ is used. While doing so, the argumentation happens on the base of one's pPCK. Therefore, Behling et al. (2022a) suggest to include the pedagogical reasoning as a filter into the graphic model of the RCM, because it works as an converter from ePCK to pPCK and vice versa.

1.4. Diagnostic competences

Both conceptualizations of situation-specific skills, PV and diagnostic competences, have the goal to build up assessment skills for evaluating and reflecting on, e.g., the instructional quality of a biology lesson. Diagnostic competences are composed of two components: the knowledge in the specific field of the diagnosis (e.g. biology teaching → PCK) and the process that has to be mastered to come to a diagnosis (situation-specific skills, diagnostic activities) (Heitzmann et al., 2019). Diagnostic competences, as part of the professional competences of teachers, are listed as one of the biology-specific competences pre-service teachers should be trained in during the university teacher education programs in Germany (Kultusminister Konferenz [KMK], 2008). They encompass the teacher's ability to assess indicators of instructional quality in a taught lesson and are thus part of a teacher's professional expertise (Artelt & Gräsel, 2009; Herppich et al., 2018; Hoth et al., 2016; Weinert et al., 1990). The process of diagnostic reasoning (Heitzmann et al., 2019) involves conceptual as well as strategic knowledge (Bichler et al., 2024) from the field of PCK and therefore, training the diagnostic competences of teachers can help them to build up pPCK and even ePCK when diagnosing and deciding in the moment of a teaching situation (Irmer et al., 2023).

The performance of diagnostic activities (DA) to apply knowledge is the practical evidence of diagnostic competence (Heitzmann et al., 2019). To define the situation-specific skills needed to come to a diagnosis, Fischer et al. (2014) introduced eight DA: (1) Problem identification, (2) Questioning, (3) Hypothesis generation, (4) Construction and redesign of artefacts, (5) Evidence generation, (6) Evidence evaluation, (7) Drawing conclusions, and (8) Communicating and scrutinizing. All of these activities have the purpose of generating and evaluating knowledge (Fink et al., 2023; Fischer et al., 2014; Heitzmann et al., 2019). They do not have to be performed in the presented order, nor do they have to be performed all, to come to a diagnosis (Heitzmann et al., 2019). The underlined DA are especially relevant to diagnosing in classroom settings (Kramer, Förtsch, Seidel, & Neuhaus, 2021). During the DA *problem identification*, the first step is the analysis of a specific situation using knowledge in the specific field (e.g., their PCK when analyzing a biology classroom situation). When it comes to a mismatch concerning the knowledge and the observed situation, a problem is identified (Fischer et al., 2014). In a biology classroom situation, such mismatch could be the use of too many technical terms in the classroom without explaining them or linking them to a function. *Evidence generation* can follow either a deductive approach (e.g., planning a theory-driven experimental study) or an inductive approach (e.g., observing and describing a problem based on theoretical knowledge) (Fischer et al., 2014). When *evaluating evidence,* the degree to which a theory or concept is supported by a generated evidence is assessed (Fischer et al., 2014). In a biology classroom situation, the knowledge about how technical terms should be introduced and used in biology classrooms (part a of teacher's PCK) would be compared to the use of technical terms in an observed situation. Differences would be evaluated and the evaluation would be supported by theories. The step of concluding after the evaluation of an evidence is represented by the DA *drawing conclusions* (Fischer et al., 2014). In the chosen example, this could be the suggestion of an alternative for action, e.g., the introduction of new technical terms in a way to link them to a specific biological function.

The interdisciplinary research unit COSIMA (DFG research unit FOR2385) had the goal of investigating and facilitating diagnostic competences in the context of simulation-based learning in teacher and medical education. In this context, Chernikova et al. (2022) developed a theoretical framework for fostering diagnostic competences with the help of simulations (see Figure 3).

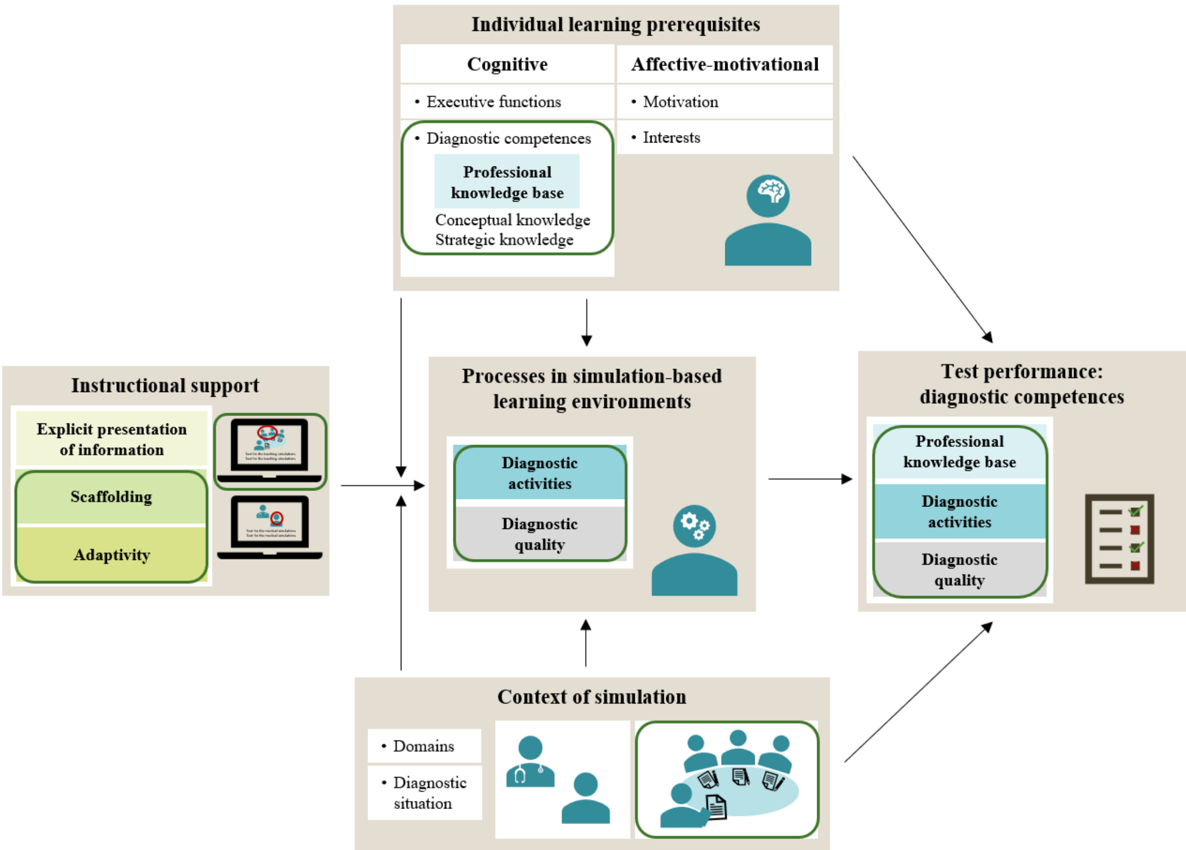

Figure 3. Modified COSIMA framework model "Using simulation-based learning environments to facilitate the development of diagnostic competences" (https://www.en.for2385.uni-muenchen.de/cosima_framemodel1/cosima_frame-model_short_eng.pdf), created by COSIMA research unit, published in Chernikova et al. (2022), licensed under CC BY 4.0. Important aspects for this dissertation are outlined in green.

The model (Figure 3) consist of five blocks representing the core elements for successfully fostering diagnostic competences in teacher education or medical education. Relevant parts of the framework model for this dissertation are circled in green. The model consists of five essential blocks. Following the framework model (Figure 3), this dissertation in the context of teacher education focusses on the professional knowledge base as an individual learning prerequisite, adding instructional support in form of (adaptive) scaffolding, using diagnostic activities as well as the diagnostic quality (diagnostic competences) to measure ePCK during the learning process and as a learning outcome.

1.5. Video-use in teacher education

To train core practices in teacher education und thus, to foster the development of pPCK and ePCK, videos showing classroom situations with the aim of fostering reflection skills in pre-service teachers can be considered. Videos can help to approach the requirements of real-life practice and foster the development of professional competence as well as situation-specific skills (Gamoran Sherin & van Es, 2009; Kersting, 2008; Seidel & Stürmer, 2014; Sherin, 2007). Recently, video-based tools are increasingly used to train skills of professional vision and/or the diagnostic competences of pre-service teachers (Codreanu et al., 2021; Irmer et al., 2023; Irmer et al., 2022; Irmer et al., 2024; Kramer et al., 2020; Kramer et al., 2022; Kron et al., 2022; Nickl et al., 2024). In addition, videos can be specifically developed and used to be included in computer-based simulations for training situation-specific skills (Codreanu et al., 2020; Kramer et al., 2020).

1.6. Simulation-based learning

Simulations are one possibility to meet the demand for more practical insight even in earlier teacher education. As simulation are widely used in various discipline. The term has been defined multiple times, these definitions often contain influences from the field they come from. In this dissertation, I will refer to simulations and a corresponding definition from the field of education. Following the definition of Aldrich (2009), simulations aim to primarily be learning environments. They simulate a process, like e.g. a lesson in biology, and include features that can be manipulated and therefore offer the opportunity to learn complex skills (Chernikova, Heitzmann, Stadler, et al., 2020; Frasson & Blanchard, 2012). Depending on the learning goals of a simulation, two types of simulations exist (Frasson & Blanchard, 2012): (1) simulations as an illustration of the learning content with the aim of training a specific skill (Codreanu et al., 2022; Irmer et al., 2023; Irmer et al., 2022; Kramer et al., 2020; Kron et al., 2022; Nickl et al., 2024) and (2) rather experimental simulations that afford interaction with the learner with the aim of building complex knowledge concerning variables shown in the simulation and their interconnection (Jong et al., 2010). Simulations can be involving humans (often included into medical higher education programs), they can be mechanical (often used for skill training, e.g. flight simulators), or computer simulations (used in all types of contexts, especially in educational contexts) (Frasson & Blanchard, 2012). In the following, the focus will be on computer-based video-simulations with the purpose of training a specific skill. In contrast to learning in real-life settings, simulation-based learning, for example with a video-based simulation, can prevent overburdening of the learner by reducing the complexity and diversity of a real-life situation (Chernikova, Heitzmann, Stadler, et al., 2020; Gartmeier et al., 2015). In addition, simulations offer opportunities to practice specific situations to gain routine, even though these kinds of situations do not happen very often in real-life practice (Chernikova, Heitzmann, Stadler, et al., 2020). Furthermore, especially in early phases of skill acquisition, the possibility of experiencing real-life practice situations might not be given. Hence, approximation of practice as introduced by Grossman et al. (2009) can be realized by including simulation-based learning in teacher education. In the technically developing world, the use of simulations in educational settings has increased. In teacher education, simulations can increase skills of PV and diagnostic competences (Chernikova, Heitzmann, Fink, et al., 2020; Codreanu et al., 2021; Irmer et al., 2022; Kramer, Förtsch, & Neuhaus, 2021b; Nickl et al., 2024).

1.7. The video-based simulation *DiKoBi*

The video-based simulation *DiKoBi* was developed as part of the COSIMA project (funded by the DFG NE 1196/8-1, 8-2; FOR 2385) by Kramer et al. (2020) (Kramer et al., 2022). It was successfully validated as an assessment tool and a learning environment for pre-service biology teachers measuring professional vision as well as diagnostic competences (Kramer, Förtsch, Seidel, & Neuhaus, 2021; Kramer et al., 2020). As mentioned above, training professional vision and the diagnostic competences of pre-service teachers can be assigned to the training of $ePCK_R$ and $ePCK_P$ (Irmer et al., 2023). The name *DiKoBi* is the German acronym for Diagnostic Competences of biology teachers in Biology classrooms. *DiKoBi* is a digital video-based simulation consisting of video vignettes showing classroom situations of a teacher teaching a five-grade class on the topic 'skin'. For an overview on the structure of the simulation see Figure 4. Kramer et al. (2020) developed three scripted biology lessons, resulting in three versions of the simulation with three consecutive lessons on the topics (I) skin as a sensory organ, (II) the protective functions of the skin, and (III) regulation of the body temperature. These three versions are called *DiKoBi* ^{I}, *DiKoBi* ^{II} and *DiKoBi* ^{III}. Each version of the simulation *DiKoBi* originally consisted of six video vignettes, which add up to a complete biology lesson. The videos have been scripted to contain indicators of lower instructional quality referring to five aspects of biology specific instructional quality: (1) problem orientation in the beginning of a lesson, (2) dealing with students' mistakes, (3) use of technical terms and language, (4) use of experiments, (5) use of models, and (6) transfer and conceptual linking in the end of a lesson. In all studies included in this dissertation, we only use the five of those six video vignettes. Over time, and experience, we decided to remove one of the video vignettes (aspect: (2) dealing with students' mistakes), because the indicators shown in the video are not all referring to PCK. Already during the validation of *DiKoBi*, the teaching situation displayed in the second video vignette was not correctly identified by most of the in-service teachers participating in the validation study (Kramer et al., 2020). All of the videos aim to contain core practices from science teaching (see section 1.1.3), for example, *engaging students in investigation* (aspect (4) use of experiments) and *constructing and interpreting models* (aspect (5) use of models) (Kloser, 2014). For all aspects, learners have to complete three tasks: (1) Identifying an indicator for lower instructional quality and describing the teacher's behavior, (2) explaining why the teacher's behavior leads to a lower instructional quality. The explanation should include references to relevant theories and concepts. The third task is (3) suggesting an alternative strategy to improve the instructional quality in the relevant situation. These three tasks were developed to include diagnostic activities (DA) and the concept of Professional Vision (PV) (Heitzmann et al., 2019; Seidel & Stürmer, 2014) and measure pre-service teachers' $ePCK_R$ and $ePCK_P$ (Alonzo et al., 2019; Irmer et al., 2023; Kramer et al., 2020). Kramer, Förtsch, Boone, et al. (2021) found the DA *identifying problem*s, *generating evidence*, *evaluating evidence* and *drawing conclusions* to be largely overlapping with the steps of PV (*noticing* and reasoning including *describing*, *explaining* and *predicting*). The first task (describing) corresponds to the DA *identifying problems* and *generating* evidence as well as to the professional vision steps *noticing* and *describing*. The second task (*explaining*) corresponds to *evaluating evidence*. Whereas the last task (suggesting an alternative strategy) corresponds to the DA *drawing conclusions* and the PV step *prediction* (Kramer, Förtsch, Boone, et al., 2021). Pre-service teachers working on the simulation, fill in open text fields with their answers to the tasks in form of written responses. For all investigations in this dissertation, the written responses were coded according to a coding manual developed by Kramer, Förtsch, Stürmer, and Neuhaus (2021) leading to a score that is than used as a representation of the pre-service teachers' $ePCK_R$ and $ePCK_P$.

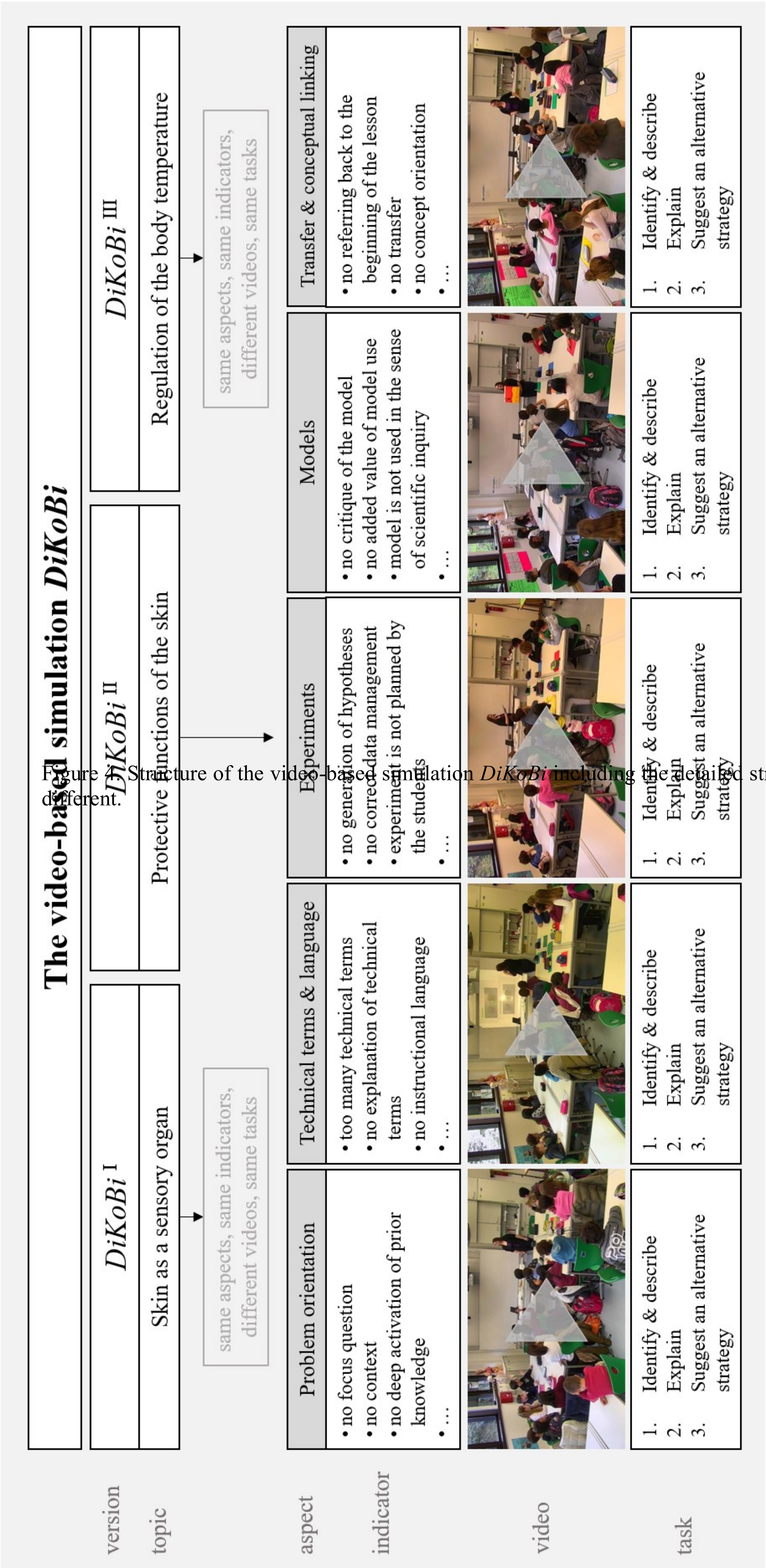

Figure 4: Structure of the video-based simulation *DiKoBi* including the detailed structure of *DiKoBi* II. The structure
different.

1.8. Scaffolding

The video-based simulation *DiKoBi* was designed to offer various opportunities to include different types of scaffolding (Irmer et al., 2023; Irmer et al., 2022; Irmer et al., 2024). In simulations, scaffolding offers a way to tailor the learning process and support learners in maximizing the learning effect (Basu & Biswas, 2016). Wood et al. (1976) defined the process of "scaffolding" as an externally added support that "enables a child or novice to solve a problem, carry out a task or achieve a goal which would be beyond his unassisted efforts" (Wood et al., 1976, p. 90). Scaffolding is controlled by a person that manages aspects of a tasks that are beyond a learner's ability and hence allowing the learner to focus on elements of the tasks that fall into the learner's current level of competence (Wood et al., 1976). This situation was defined as the *Zone of proximal development (ZPD)* (Vygotskij, 1979). In the ZPD, a learner can reach a learning goal with the help of externally added support, that they could not reach without support yet (Vygotskij, 1979). In the following, the term *scaffolding* is used when I refer to the process, whereas the term *scaffold* refers to the externally added support itself. The scaffolding process consists of two steps: first, the scaffolding itself, where a scaffold is added to a task, and then the *fading*, where the scaffold is gradually taken away (Collins et al., 1988). In a successful scaffolding process, a learner is initially not able to complete a task. Then scaffolds are included, enabling a learner to learn in their ZPD. As a result, the learner is able to complete the task, when the scaffold is provided. As soon as they gain security, the scaffolding is gradually faded resulting in a learner that is now able to successfully fulfil the task without externally added support (Collins et al., 1988; Reiser, 2004). Especially for learners in early stages of knowledge acquisition, scaffolding can be a highly effective intervention (Chernikova, Heitzmann, Fink, et al., 2020). In addition, scaffolding has proven itself to be effective in strengthening learners' abilities to complete difficult tasks that involve problem solving (Belland et al., 2017; Quintana et al., 2004).

Scaffolds can be designed for different purposes and in various ways. Hannafin et al. (1999) defined four types of scaffolding in learning environments (e.g. simulations): strategic scaffolding, procedural scaffolding, conceptual scaffolding and metacognitive scaffolding. These scaffold types have different functions and related methods, for an overview see Table 2.

Table 2. Scaffolding classification according to Hannafin et al. (1999).

Type	Function	Methods (example)
strategic	Guidance in how to approach a task/problem, giving a macrostrategy	start-up questions, suggestions of alternative procedures

procedural	Guidance in how to use the feature functions (e.g. in a simulation)	Tutoring on features and functions of the system
conceptual	Guidance in what to consider on a content level	Explicit hints/prompts
metacognitive	Guidance in how to think about a task and what strategies to consider	Progress evaluation, providing strategies for self-regulation

In addition, Belland et al. (2013) described two categories of scaffolding: *context-specific* scaffolding (e.g. specific content information on the content of a specific task (Belland, 2017)), and *generic* scaffolding that corresponds to a specific task, but can be integrated in various contexts. Two types of scaffolding were defined by Fischer et al. (2022) for the context of scaffolding in video-based simulations: scaffolding directed at the *learning process* and *representational* scaffolding. Representational scaffolding is based on the idea of core teaching practices (Grossman, 2021) and describes a scaffolding strategy based on the variation of complexity, typicality, agency and situation dynamics of a video in a simulation (Fischer et al., 2022). Scaffolding directed at the learning process includes all scaffolding types according to Hannafin et al. (1999), thus all scaffolding that adds something to an existing learning environment. This dissertation investigates effects of conceptual, context-specific and strategic, generic scaffolding (directed at the learning process) on the ePCK of pre-service biology teachers in the video-based simulation *DiKoBi*.

1.8.1. Personalized scaffolding in digital simulations

Adapting a learning environment, such as a simulation, to an individual learner's needs can be called personalization. Adding and fading scaffolding based on the progress of a learner is a form of personalization of learning processes. Personalization is defined as the individual adjustment of a task based on relevant learner variables (Tetzlaff et al., 2021). Personalized scaffolding can enhance learning and increase the learning outcome in computer-based learning environments (Azevedo et al., 2005; Molenaar et al., 2012). To choose an adjustment base for personalization, relevant learner variables can be categorized (Plass & Pawar, 2020): (1) *cognitive* learner variables (current knowledge and skills, learning strategies, cognitive skills, etc.), (2) *motivational* learner variables (self-efficacy, individual and situational interest, etc.) (3) *affective* learner variables (regulation of emotions, emotional state, attitude towards learning, etc.) and (4) *socio-cultural* learner variables (cultural context, social context, self-perception, etc.). Furthermore, the time frame of when the personalization is made can be defined. A distinction is made between *micro*-, *meso*- and *macro*-adaptation (Fischer et al., 2022; Plass & Pawar, 2020). In the context of a video base simulation, such as DiKoBi (see section 1.7), a *macro*-adaptive personalization would choose fitting scaffolds for each individual learner based on a knowledge test they completed prior to working on the simulation. Adjusting the scaffold after every video in the simulation based on the previous performance of a learner would correspond to a *meso*-adaptive scaffolding. A *micro*-adaptive scaffolding strategy would be pursued, when the learner variable is measured while a learner completes the tasks so that the simulation adapts during the writing process. In this example, a learner would complete the task describe and dependent on what the learner describes in the open text field, a scaffolding guiding into the right direction or not would be provided by the simulation. In this dissertation only cognitive learner variables were chosen for personalization of the scaffolding (prior knowledge, strategies to complete a task) (Irmer et al., 2023; Irmer et al., 2022; Irmer et al., 2024). The scaffold was personalized in a *macro*-adaptive time frame. To further distinguish different modes of scaffolding in a macro-adaptive adaptation strategy, Irmer et al. (2024) introduced the term of granularity with two associated levels of granularity: (1) a fixed adaptation and (2) a situation-specific adaptation. In digital simulations, such as *DiKoBi*, different practice situations afford knowledge in different aspects of practice. In a biology teaching context, all knowledge referring to instructional quality would belong to a teachers' PCK. The PCK includes knowledge on how to experiment in classrooms or on how to use models in a biology lesson etc. In a fixed adaptation the learner variable, e.g. cPCK, is measured in advance to working on the simulation. The scaffolding is adapted based on the learner variable for the whole simulation (Irmer et al., 2024). Whereas, in a situation-specific adaptation strategy, the scaffolding is also adapted to a learner variable, but it might change for each representation of practice taking into account the prior knowledge in that specific situation (Irmer et al., 2024).

2. Aims

Since the RCM of PCK has been published in 2019, researchers have been encouraged to empirically investigate the model (Mientus et al., 2022). The video-based simulation *DiKoBi* can serve as a suitable assessment tool to approach the ePCK of pre-service biology teachers (Irmer et al., 2023; Kramer et al., 2020). In addition, simulation-based tools have proven to be effective for fostering assessment skills (PV and diagnostic competences) (Chernikova, Heitzmann, Fink, et al., 2020; Nickl et al., 2024; Radkowitsch et al., 2023). One way of assessing teachers' ePCK is by measuring their PV skills and diagnostic competences (Kramer et al., 2020). Therefore, this dissertation aims to contribute to empirically investigate the RCM of PCK while finding ways to include the training of ePCK into early biology teacher education. One promising way of reducing complexity and enhancing learning effects in complex learning environments (such as simulations), is to include scaffolding (Belland et al., 2017; Quintana et al., 2004). By including scaffolding into the video-based simulation *DiKoBi* the following aims were pursued:

1. The investigation of scaffolding opportunities and effects in digital video-based simulations, such as *DiKoBi*. The main focus lies on the question: How can scaffolding enhance learning in digital video-based simulations?
   This aim was addressed in all three publications (I, II, III).

2. The empirical investigation of the RCM of PCK including mechanisms of knowledge transfer, interplay between the PCK realms and knowledge acquisition in early biology teacher education.
   This aim was addressed in Publication II and III.

3. The exploration of possibilities of adaptation and personalization in digital simulations. The focus lies on an automatic evaluation via keywords of written responses and on the investigation of different personalization granularity with the overall goal of installing meso- or even micro-adaptive personalized scaffolding in the future.
   This aim was addressed in Publication I, II and III.

To address the research aims, three theoretical constructs are focused: (1) the diagnostic competences (including the diagnostic activities and the underlying knowledge) (Fischer et al., 2014; Heitzmann et al., 2019), (2) Professional Vision (Seidel & Stürmer, 2014) and (3) the Refined Consensus Model of PCK (Carlson & Daehler, 2019) (see Figure 5).

Referring to research aim 1, three studies were conducted to explore scaffolding opportunities in digital video-based simulations. An overview is given in Figure 5. What type of scaffolding is suitable for a simulation like *DiKoBi*? How can scaffolding be adapted to an individual learner's needs?

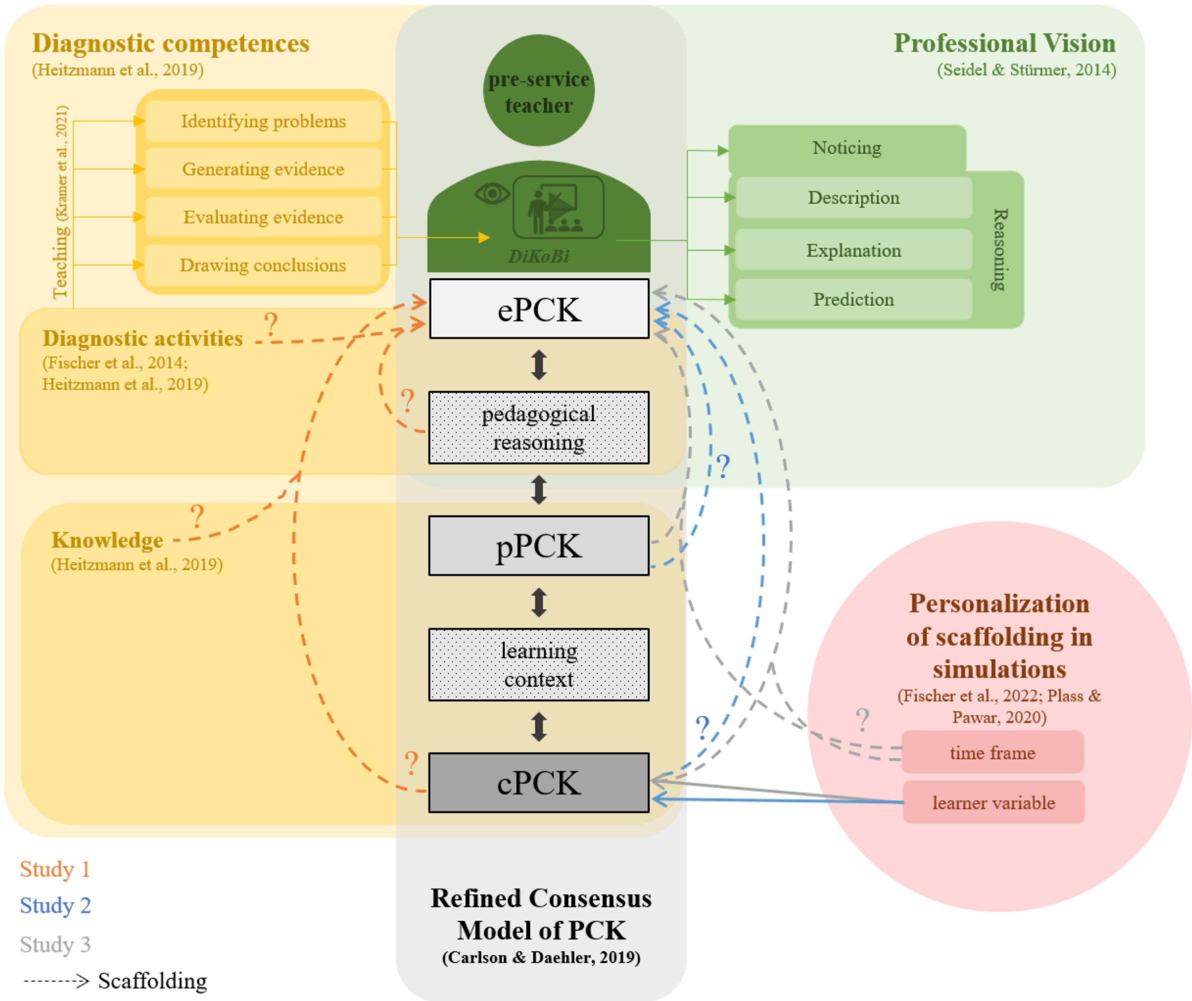

Figure 5. Aims of the dissertation. The question marks stand for the research gaps addressed in Publication I - III. Arrows stand for relationships between elements.

Study 1 investigates the type of scaffold that learners need to enhance their ePCK. The effects of strategic, generic scaffolds focusing on the diagnostic activities (and at the same time on pedagogical reasoning and steps of PV) are contrasted with conceptual scaffolds, context-specific scaffolds referring to the cPCK of pre-service biology teachers. This allows to answer the question of what component of the diagnostic competences has an influence on the training of ePCK of pre-service biology teachers. Study 2 further investigates the knowledge realm that needs to be addressed via scaffolding to optimize the learning effect when training ePCK with the video-based simulation. In study 3, the scaffolds included into *DiKoBi* are not changed, but the effects of personalization of the scaffolding, with a focus on the time frame, was included.

Furthermore, in all three studies mechanisms of knowledge transfer, knowledge acquisition and interplay between the realms of PCK are investigated (cf. research aim 2).

To address research aim 3, study 1 and 2 include the automatic evaluation of the written responses in the simulation *DiKoBi* via keywords, whereas study 3 explores possibilities of personalization in a macro-adaptive scaffolding strategy. An overview of all conducted studies in shown in Table 3.

Table 3. Simplified overview of the three studies addressed in publication I, II and III.

sample	pre		intervention (scaffolding)		post
$N = 57$	**ePCK** video-based simulation *DiKoBi* [I]		video-based simulation *DiKoBi* [II]	DA* vs. cPCK no adaptation no personalization	**ePCK** video-based simulation *DiKoBi* [III]
$N = 78$		cPCK test		cPCK vs. pPCK fixed no personalization	
$N = 115$				cPCK vs. pPCK situation-specific vs. fixed prior cPCK	

* DA = diagnostic activities
type of scaffold
time frame of adaptation
learner variable for personalization

All three studies included in this dissertation follow the same structure. In the pre-test, as well as in the post-test, ePCK of the pre-service biology teachers is assessed via the video-based simulation *DiKoBi*. The evaluation of the written responses to the tasks in *DiKoBi* was done according to the coding manual for the *DiKoBi* simulation (Kramer, Förtsch, Stürmer, & Neuhaus, 2021) and based on keywords (Irmer et al., 2023; Irmer et al., 2022). To assess the prior cPCK of the pre-service biology teachers, a cPCK test with 50 correct-false-items was developed and used in the pre-test of study 2 and 3 (Irmer et al., 2023; Irmer et al., 2024). A Rasch analysis showed a good item reliability (.96) and a sufficient person reliability (.70) of the cPCK test (Malec et al., 2007). During the intervention the scaffolding type and scaffolding strategy (time frame of the adaptation and learner variable for the personalization) varies.

3. Results

The results are presented in three articles published in the *International Journal of Science Education* (Publication I, Irmer et al., 2022), *Education Sciences* (Publication II, Irmer et al., 2023) and *Cogent Education* (Publication III, Irmer et al., 2024).

3.1. Publication I

Marie Irmer, Dagmar Traub, Maria Kramer, Christian Förtsch, and Birgit J. Neuhaus

**Scaffolding Pre-service Biology Teachers‘ Diagnostic Competences in a Video-based Learning Environment:
Measuring the Effect of Different Types of Scaffolds**

published in
International Journal of Science Education

Irmer, M., Traub, D., Kramer, M., Förtsch, C., & Neuhaus, B. J. (2022). Scaffolding Pre-service Biology Teachers‘ Diagnostic Competences in a Video-based Learning Environment: Measuring the Effect of Different Types of Scaffolds. *International Journal of Science Education, 44*(9), 1506-1526.
https://doi.org./10.1080/09500693.2022.2083253

3.2. Publication II

Marie Irmer, Dagmar Traub, Marina Böhm, Christian Förtsch, and Birgit J. Neuhaus

Using video-based Simulations to Foster pPCK/ePCK –
New Thoughts on the Refined Consensus Model of PCK

published in
education sciences

Irmer, M., Traub, D., Böhm, M., Förtsch, C. & Neuhaus, B. J. (2023). Using Video-Based Simulations to Foster pPCK/ePCK – New Thoughts on the Refined Consensus Model of PCK. *Education Sciences*, *13*(3), 261.
https://doi.org/10.3390/edusci13030261

3.3 Publication III

Marie Irmer, Dagmar Traub, and Birgit J. Neuhaus

Fostering ePCK in pre-service biology teacher education using adaptive scaffolding in a video-based simulation

published in

Cogent Education

Irmer, M., Traub, D., Neuhaus, B. J. (2024). Fostering ePCK in pre-service biology teacher education using adaptive scaffolding in a video-based simulation. *Cogent Education*, *11*(1), https://doi.org/10.1080/2331186X.2024.2422272

4. Discussion

In the following, the aims and results of the dissertation are discussed. First, the results of publication I, II and II are summarized and brought into accordance with the aims of the dissertation. Then, I will discuss scaffolding opportunities in the video-based simulation *DiKoBi*, but also in video-based simulation generally. In the following section, the results of publication II and III are discussed with regard to their impact on the empirical validation of the RCM of PCK. Furthermore, an alternative and modified RCM of PCK is presented and explained in detail. Hereafter, I will discuss the possibilities of adaptation and personalization as explored in this dissertation. Moreover, limitations of the studies and results of this dissertation are listed and discussed. The discussion results in ideas for further research and finally gives an overview of the implications of the here presented dissertation on future pre-service biology teacher education.

The aims of this dissertation were addressed in publication I, II and III.
The first aim was to explore and investigate scaffolding opportunities and effects in digital simulations. Overall, scaffolding has be proven to be an effective intervention in the video-based simulation *DiKoBi* to foster pre-service biology teachers $ePCK_R$ and $ePCK_P$ measured by their PV-skills and diagnostic competences. Study 1 (publication I) revealed that scaffolding the PCK of pre-service biology teachers in the video-based simulation *DiKoBi* is effective for fostering $ePCK_R$ and $ePCK_P$, whereas scaffolding the relevant diagnostic activity (DA) was not effective to foster $ePCK_R$ and $ePCK_P$. These results lead to the question of what realm of PCK needs to be addressed with scaffolding when training ePCK. In study 2 (publication II), pre-service biology teachers receiving scaffolds that activate their pPCK could significantly improve their $ePCK_R$ and $ePCK_P$. Although, pre-service biology teachers receiving cPCK-scaffolding did not significantly improve, a tendency towards improvement also in this treatment group could be observed. Both types of scaffolds seemed to be somehow effective and suitable. That raised the question of how the scaffolding effect could be increased. In study 3 (publication III), scaffolding was personalized. Therefore, the prior knowledge (cPCK) of the participants was assessed and the scaffolding was adapted to their prior cPCK. Pre-service biology teachers receiving a situation-specific personalized scaffolding significantly improved their $ePCK_R$ and $ePCK_P$. Participants receiving a fixed scaffolding personalized based on their cPCK, showed a significantly higher $ePCK_R$ and $ePCK_P$ in the moment when the scaffold were presented (during the intervention), but not in the post-test. Further details on the results related

to the first research aim are represented in Figure 6. A detailed discussion is provided in section 4.1.

The second aim was to empirically investigate the RCM of PCK including the mechanisms of knowledge transfer between the realms, the interplay of those and knowledge acquisition in early biology teacher education. By investigating the scaffolding mechanisms in the video-based simulation *DiKoBi*, conclusions could be drawn concerning the empirical investigation of the RCM of PCK. In all three publications, $ePCK_R$ and $ePCK_P$ could successfully be fostered through the video-based digital simulation *DiKoBi*. Especially the implementation of pPCK-scaffolding into the simulation lead to significantly higher ePCK-scores of the pre-service biology-teachers (study 2, publication II). Study 3 revealed that a situation-specific adaptation of the scaffolding is more promising than a fixed adaptation. Combining these results, it becomes clear that knowledge acquisition in teacher education starts from the outer cPCK (learning about PCK in theory) via building up pPCK (contextualized knowledge) and finally using this pPCK to be ePCK (in a specific practice situation). The basic structure of the RCM could therefore be confirmed in this dissertation. In spite of that, a modified representation of the original RCM was made based on the findings of study 2 and 3. This alternative model is shown in Figure 7, a detailed discussion is provided in section 4.2.

The third aim was to explore possibilities of personalization and adaptation in digital simulations. Publication III included first steps towards the personalization of scaffolding in the video-based simulation *DiKoBi*. The conducted study revealed that a situation-specific personalization of the scaffolding is more effective in fostering ePCK than a fixed personalization of the scaffolding. In publication I and II the evaluation of the written responses of the pre-service biology teachers were evaluated via keywords and in addition the responses were evaluated according to the coding manual of the video-based simulation *DiKoBi*. In both cases, there was a high correlation between the evaluation via keywords and the evaluation with the coding manual. A detailed discussion of the third aim is provided in section 4.3.

4.1 Scaffolding in the video-based simulation *DiKoBi*

Contributing to finding answers for research aim 1, all three studies included in this dissertation examined different scaffolds and scaffolding strategies in the video-based simulation *DiKoBi*. The scaffolds for all studies can be found in the appendix of this dissertation (see Appendix: Table A, Table B, Table C, Table D). Figure 6 summarizes the results of research aim 1.

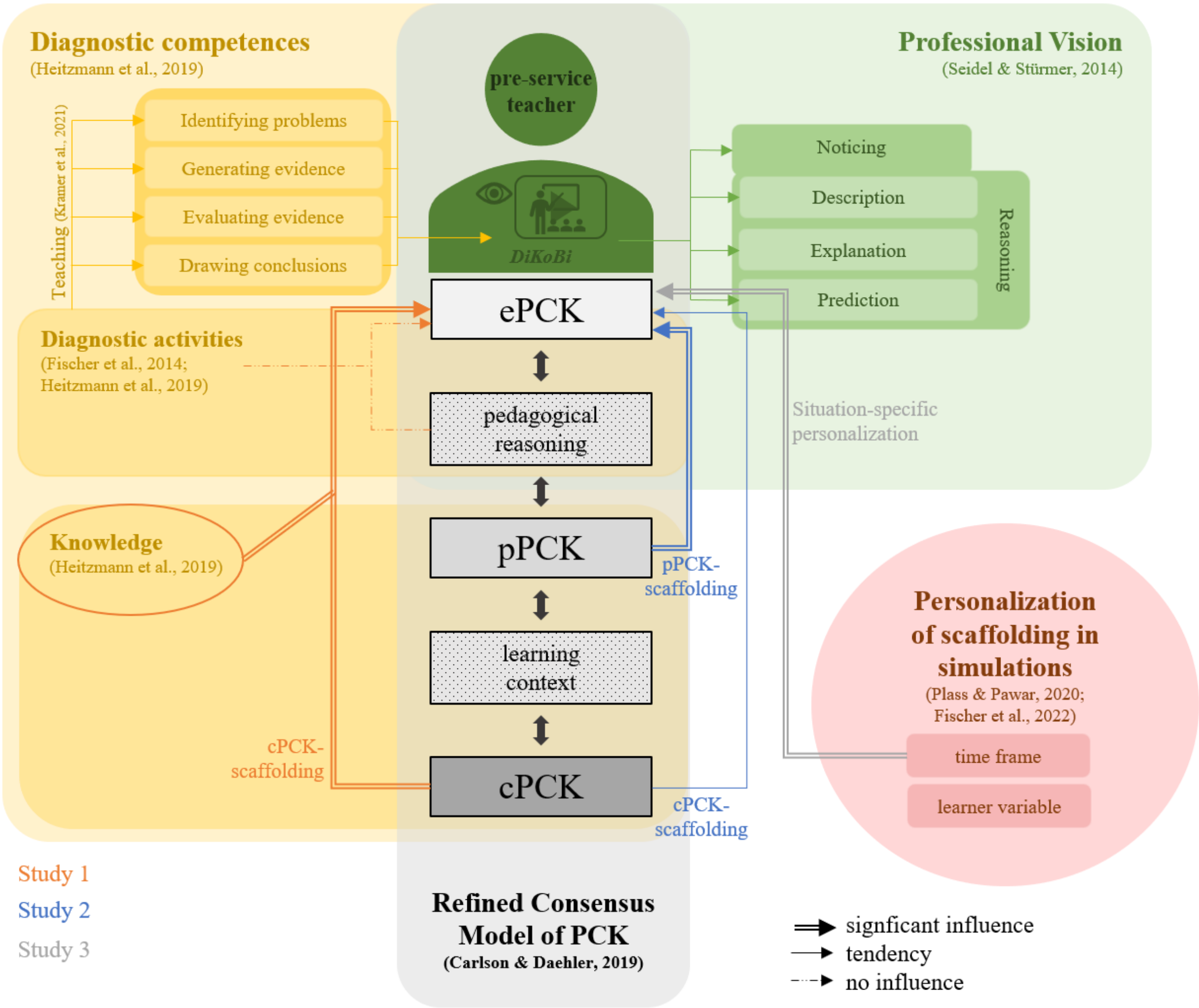

Figure 6. Results of the dissertation (Aim 1).

On all three studies included in this dissertation, the sample included only pre-service teachers in an early state of knowledge acquisition concerning their PCK. The first study (Publication I) aimed to investigate what part of the diagnostic competences (consisting of diagnostic activities and the knowledge in the diagnostic field; Heitzmann et al., 2019) needs to be scaffolded to enhance learning for learners with little prior knowledge in a simulation. The study came to the result that content-related PCK-scaffolds support learners with little prior knowledge better than strategic diagnostic activity scaffolds (DA-scaffolds) (Irmer et al., 2022). These results support the findings of other studies from the field of simulation-based learning (Chernikova, Heitzmann, Stadler, et al., 2020; Sommerhoff et al., 2023). Chernikova, Heitzmann, Stadler, et al. (2020) found that, in the context of simulation-based learning, scaffolding offering a high level of guidance (which applies to the here included PCK-scaffolds) is beneficial for learners with little prior knowledge. Due to the findings of study 1, study 2 investigated which realm of PCK needs to be scaffolded in order to support ePCK in the best possible way. cPCK-scaffolds and pPCK-scaffolds were included into the simulation *DiKoBi*. The scaffolds for study 2 are displayed in the appendix (see Table C and Table D). Study 2 came to the result that knowledge activation in form of pPCK-scaffolds is more effective than scaffolding the pre-service teachers' cPCK. These results do not only give insights into the structure of pre-service teachers' PCK (see section 4.2), but also on scaffolding in learning environments that afford complex skills, such as simulations. When scaffolding the pPCK of pre-service teachers, the prior knowledge is activated. The pPCK-scaffolds thus relate to knowledge specific to each individual learner. In addition, cPCK-scaffolding, although not with a significant effect, also led to higher ePCK-scores in study 2. Scaffolding is supposed to let a learner learn and complete tasks in their Zone of proximal development (ZPD), therefore, it is important that the scaffold is suitable for the individual learner's competence level (Collins et al., 1988; Vygotskij, 1979). A pre-service teacher working on the simulation *DiKoBi*, might not have enough prior knowledge to use concepts and theories to explain a description for the second task in *DiKoBi*. This learner might benefit from a cPCK-scaffold providing enough theoretical information to succeed in that task. On the other hand, a learner that knows the underlying theories and concepts, benefits more from a pPCK-scaffold activating their prior knowledge in the specific moment of working on the task in *DiKoBi*. The sample of study 2 mostly consists of pre-service teachers that have heard a lecture on the underlying concepts for successfully completing the simulation *DiKoBi* by the time they were taking part in the study. Hence, the pPCK-scaffolds help them to learn in their ZPD, whereas the cPCK-scaffold is not suitable and does not help the learners to learn in their ZPD and thus, learning is not as effective (cf. Collins et al., 1988; Vygotskij, 1979). The findings of study 2 lead to a hypothesis: A personalized scaffolding strategy considering the prior knowledge of the learner might be even more effective. Building on the findings and conclusions of the second study, study 3 compares two types of macro-adaptive strategies for personalized scaffolding. Irmer et al. (2024) introduced the term of adaptation granularity to describe the two experimental conditions in study 3. The *situation-specific adaptation* of the scaffolding considers the varying prior knowledge concerning different practice situation so that the scaffolding (pPCK-scaffold or cPCK-scaffolds) might vary in the practice situations shown in the simulation (cf. Grossman, 2021). In the *fixed adaptation* condition, the prior knowledge is assessed and not evaluated separately for each practice situation resulting in the same type of scaffold (pPCK or cPCK) for all videos in the simulation *DiKoBi* (Irmer et al., 2024). The importance of the prior knowledge and thus of the personalization of the scaffolding is underlined by the results of study 3: the situation-specific adaptation of the scaffolding was more effective in fostering ePCK than the fixed adaptation of the scaffolding. The findings of study 3 support the assumption that adaptation of the scaffolding between tasks is more effective than a fixed adaptation before working on the tasks (Tetzlaff et al., 2021). In study 3, the chosen learner variable for the adaption was the cPCK of the pre-service teachers assessed via a cPCK-test with correct-false-items, hence, a cognitive learner variable (Plass & Pawar, 2020). Not having a comparison to an adaptation based on another learner variable, it is not possible to make a statement about the appropriateness of the chosen learner variable (prior cPCK, see Publication III).

Overall, scaffolding was proven to be an effective intervention in video-based simulations such as *DiKoBi* to meet the needs of learners with little prior knowledge. The findings of all three lead to three main conclusions concerning scaffolding in simulations that focus on the training of practice situations that might be transferred to other simulations than *DiKoBi* and also to other contexts than teacher education:

(1) When learning with simulations, scaffolds referring to the prior knowledge that needs to be applied in a practice situation is beneficial, especially for learners in an early stage of knowledge acquisition,

(2) Operating in the ZPD is crucial for successfully completing a task and personalized scaffolding can help to enable learning in the ZPD,

(3) A finer granularity of the adaptive and personalized scaffolding in simulations is beneficial for simulation-based learning.

The findings thus contribute to the exploration and investigation of scaffolding opportunities and effects in simulation-based learning.

4.2 Modification of the Refined Consensus Model

Research aim two includes the empirical investigation of the RCM of PCK (Carlson & Daehler, 2019) as well as the mechanisms of knowledge acquisition and knowledge transfer. The results of Publication II (Irmer et al., 2023) and also Publication III, (Irmer et al., 2024), made me think about alternatives ways to arrange the three realms of PCK according to the RCM (Carlson & Daehler, 2019). Moreover, the empirical findings from these two studies could make valuable contributions for an empirical evaluation of the model. Hence, considering the findings of my studies and discussing with other researchers from the field at conferences and at a research stay, I created an alternative representation of the original model that is shown in Figure 7. This modified model was already published in Publication II (Irmer et al., 2023). The model was revised once again as part of this dissertation.

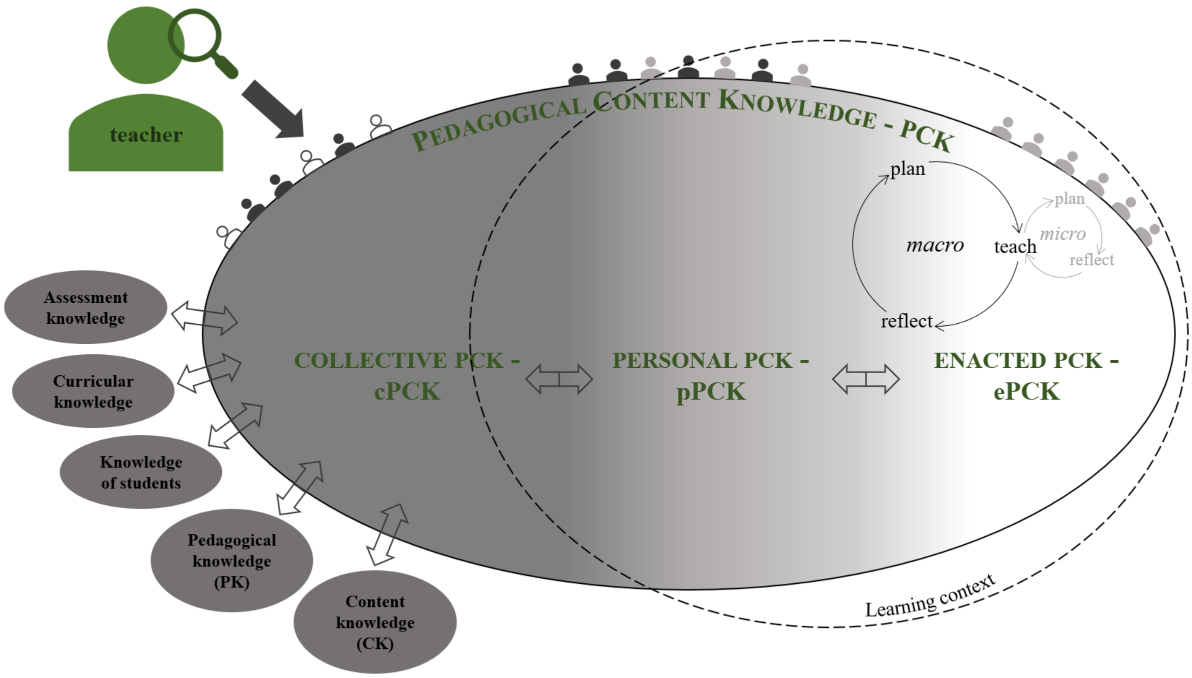

Figure 7. Modification of the RCM of PCK based on empirical findings from this dissertation (Irmer et al., 2023; Irmer et al., 2022; Irmer et al., 2024). Light grey person icons symbolize the influence of students, dark grey person icons symbolize the influence of other teachers, unfilled person icons symbolize the influence of other peers (science teacher community, researchers, teacher educators etc.).

The findings of study 2 indicate that the pPCK is the most important PCK-realm when it comes to ePCK (Irmer et al., 2023). Pre-service teachers receiving scaffolds referring to their pPCK could significantly increase their ePCK in comparison to pre-service teachers receiving cPCK-scaffolds (Irmer et al., 2023). This does not only support the theoretical arrangement of the three realms as suggested by Carlson and Daehler (2019), but also support the assumption that pPCK serves as a reservoir of knowledge for ePCK (Alonzo et al., 2019; Carlson & Daehler, 2019). In the original RCM of PCK, ePCK builds the center of the model, although pPCK is the knowledge base of an individual teacher and the realm of PCK that all actions are based on and that is highly influenced by the cPCK (Carlson & Daehler, 2019). Therefore, the modified RCM of PCK puts the pPCK into the center highlighting its importance for knowledge and skill acquisition.

Furthermore, I decided to blur the lines between the three realms to illustrate the flowing transformation of cPCK to pPCK and vice versa and pPCK to ePCK and vice versa. The modified model understands the PCK as a continuum of knowledge within a teacher and sometimes it can even be hard to decide what realm a specific skill or knowledge belongs to (Irmer et al., 2023). In contrast to the original RCM of PCK, both plan-teach-reflect cycles are included, the macro and the micro cycle (Alonzo et al., 2019). The nature of the knowledge is more tacit the further right it is represented in the illustration, going from cPCK, that can be considered as procedural knowledge (Squire, 1992), to micro ePCK being so tacit it might be difficult to assess (Alonzo et al., 2019).

The macro plan-teach-reflect cycle was moved towards the pPCK. This alteration is also based on the empirical findings in Publications I, II and III. Scaffolding the pre-service teachers' pPCK helps to improve their ePCK as measured in the video-based simulation *DiKoBi*. *DiKoBi* specifically assesses the $ePCK_R$ and the $ePCK_P$ of the pre-service teachers. In the original model, Carlson and Daehler (2019) state that as soon as ePCK is verbalized or written down, it becomes pPCK (Alonzo et al., 2019). Actually, this stands in contrast to the original illustration. Therefore, I decided to move these two steps of the plan-teach-reflect cycle to the blurry border of pPCK and ePCK.

The finding that cPCK-scaffolds are less effective in fostering pre-service teachers' ePCK supports the existence of the filter "learning context" (Irmer et al., 2023). cPCK is described to be published, commonly shared and decontextualized knowledge (Carlson & Daehler, 2019). Hence, the filter of the learning context cannot be overcome by pre-service teachers in such early stage of knowledge acquisition as in the here presented sample. The contextualization of the cPCK-related information given to the pre-service teachers via the cPCK-scaffolds (see Appendix, Table C) cannot be brought into the context of the specific practice situation represented in the video of the *DiKoBi* simulation. Nevertheless, I decided to change the position of the "learning context" in the new model. The learning context in the modified RCM also contains little parts of cPCK, because not all cPCK is decontextualized. Published and commonly discussed student misconceptions in biology, like for example about evolution (Gregory, 2009), are part of cPCK but at the same time highly contextualized.

With this new model, it is possible to draw conclusion about how PCK is acquired. This can help to improve teacher education or in-service teacher training in the future. Putting the pPCK into the center of the model, highlights the importance of this knowledge-realm. In the biology teacher education program that the here presented sample went through, knowledge acquisition usually starts with the hearing of a lecture. The lecture, for example, contains information on relevant theories and concepts from science and/or biology teaching as well as published findings on the effectiveness of certain teaching methods. The pre-service teachers build up cPCK. In the further course of the program, seminars and internships are integrated. In seminars, pre-service teachers try to use the concepts and theories from the lectures to, e.g., plan fictional biology lessons; they build up pPCK. Then, during internships in schools and teaching a class, ePCK is trained. In turn, for in-service teachers, knowledge acquisition might also work the other way around. Inservice teachers use their ePCK every day during their lessons. Their pPCK grows based on their teaching experience. If in-service teachers talk to colleagues about their teaching and share their pPCK it can become *micro* cPCK. This *micro* cPCK is also represented by the part of cPCK that lies within the learning context (cf. Carlson & Daehler, 2019). If the respective teacher shares their knowledge at e.g. a conference or even writes an article that is then published, they contribute to cPCK. Both types of knowledge acquisition (from cPCK to ePCK and from ePCK to cPCK) are supported by putting the pPCK into the center of the modified RCM of PCK (see Figure 7). Figure 7. Modification of the RCM of PCK based on empirical findings from this dissertation (Irmer et al., 2023; Irmer et al., 2022; Irmer et al., 2024). Light grey person icons symbolize the influence of students, dark grey person icons symbolize the influence of other teachers, unfilled person icons symbolize the influence of other peers (science teacher community, researchers, teacher educators etc.).

To illustrate the influence of students, colleagues and other persons (such as researchers from the field of science education), the person icons from the original model were kept. In addition, also the other parts of the professional competence of teachers (including the Ck, the PK, the assessment knowledge, the curricular knowledge and the knowledge of students) were included as part of the model (Carlson & Daehler, 2019).

This modified representation of the RCM of PCK does not intend to replace the original model by Carlson and Daehler (2019), but rather to serve as a supplement for discussion and exchange of knowledge concerning the professional knowledge of science teachers from a different perspective.

4.3 Exploring possibilities of personalization and adaptation

The third aim of this dissertation was to explore possibilities for personalization and adaptation in digital simulation. First steps towards an adaptive and personalized simulation have been made in study 3 (Irmer et al., 2024). When analyzing data of study 1, the idea arose to check whether the participating pre-service teachers have read the content-related scaffolds to include them into their written responses in the video-based simulation *DiKoBi*. The PCK-scaffolds of study 1 contain bold words (see Appendix, Table B). Those words are mostly technical terms from the field of biology education or words that are especially relevant to the aspect of biology-specific instructional quality shown in the video in *DiKoBi* (Irmer et al., 2022). Therefore, the assumption can be made that if participants include those bold words into their written responses, they have (1) read the PCK-scaffold, (2) included the information provided by the PCK-scaffold into their response and (3) used a suitable concept or a suitable theory for the respective aspect of biology-specific instructional quality to complete the tasks in the simulation. In addition, the coding of the video-based simulation *DiKoBi* is not only time-consuming, but also dependent on trained coders. Due to this, the idea arose to think about other possibilities to evaluate the written responses from the open text field in the simulation. In the process of evaluating, coding and analyzing data of study 1, it became clear that participants including more of the bold printed words from the PCK-scaffold scored higher than those who did not include many words. This did not only apply to the intervention time of measurement, but also for the pre-test and the post-test. That rather coincidental result led to a series of new ideas that are described in the following. First, a set of so called "keywords" was defined for each aspect in the video-based simulation *DiKoBi*. The keywords can be found in the appendices (Table E). These keywords include all bold printed words from the PCK-scaffolds and some additional words that are particularly relevant to the aspect of biology-specific instructional quality. To decide which technical terms are relevant to the respective aspect of biology-specific instructional quality, literature from the field of instructional quality was considered (e.g. Dorfner, Förtsch, Germ, & Neuhaus, 2018; Dorfner et al., 2020; C. Förtsch et al., 2017; C. Förtsch et al., 2016; S. Förtsch et al., 2018; Nawani et al., 2018). Second, a correlation between the number of keywords used and the ePCK-score obtained from the coding with the coding manual (Kramer, Förtsch, Stürmer, & Neuhaus, 2021) was calculated ($r = .734$, $p < .001$ for study 1 and $r = .824$, $p < .001$ for study 2). There was a very high correlation not only for the intervention, but also for the pre-test and the post-test. Third, all calculations for the studies 1 and 2 were replicated using the number of keywords instead of the ePCK-score from the coding. The results were similar. All significant differences between treatment groups were significant no matter, if they were calculated with the number of keywords used or the ePCK-score as a measure (Irmer et al., 2023; Irmer et al., 2022). The high correlation between the ePCK-score obtained with the help of human coding and the number of keywords used in the written responses can partly be explained with the coding manual for the simulation *DiKoBi* itself. In the coding manual it is stated that participants receive points when they name the right theories and concepts for the explanation tasks (Kramer, Förtsch, Stürmer, & Neuhaus, 2021). The keywords contain technical terms for the concepts and theories, for example, if a written response for the first practice situation in *DiKoBi* (aspect: problem orientation) contains the word 'catch-component', the coding manual suggests to give two points (Kramer, Förtsch, Stürmer, & Neuhaus, 2021), 'catch-component' is also one of the chosen keywords (see Appendix, Table E), therefore, an evaluation via keywords would also lead to the successful processing of the task. However, the coding manual also considers written responses, that do not refer to any technical terms, theories or concepts, but paraphrase a correct solution of the task. Consequently, it is important to keep in mind, that an automatic evaluation via the number of keywords is not equivalent to the human coding of the written responses. On the other hand, an evaluation via keywords offers new opportunities for adaptation and personalization of scaffolding in the simulation *DiKoBi*. In other context, automatic evaluation of written reflections has already been successfully tested, e.g., in physics education by Wulff et al. (2021). The evaluation via keywords might offer possibilities for a meso-adaptive personalization (cf. Plass & Pawar, 2020) of the scaffolding in the simulation *DiKoBi*. Publication II revealed that a situation-specific adaptation of the scaffolding is more effective than a fixed adaptation (Irmer et al., 2024). In study 3, the scaffolding was set in a macro-adaptive time frame. The results indicate that a more specific adaptation is beneficial, and therefore, choosing a meso-adaptive time frame for the adaptation might be even more promising. An evaluation via keywords could open the door for a more complex evaluation of written responses in simulation in the future, for example, using machine learning (ML) (cf. Wulff et al., 2021, ML in physics education) or even natural language processing (NLP) (cf. Bewersdorff et al., 2023, NLP in educational contexts).

4.4 Limitations

In the following, the limitations of the individual studies as well as limitations concerning the results and conclusions of this dissertation will be discussed. I will distinguish between methodological and conceptual limitations.

The first methodological limitation is the relatively small sample size. The sample in all three studies consists of pre-service biology teachers from the teacher education program at Ludwig-Maximilians-University in Munich. Data collection took place as part of the course “Biologiedidaktische Methoden”, so the number of participants was limited to the students taking part in that course. Despite this small sample size and the associated lower statistical power, we could find significant effects for the scaffolding intervention. But it might also be that some effects could not have been made visible. Hence, for example, in Publication II the non-significant effect of the cPCK-scaffolding was also reported as the assumption can be made that there would be an effect when working with a bigger sample size (Irmer et al., 2023).

The second methodological limitation is that data collection partly happened during the COVID-19 pandemic. The participants worked on the simulation on their own devices and most certainly at home. Accordingly, it was not possible to check if they completed *DiKoBi* without additional support. Although, before the measurements started, a brief introduction was given via Zoom including the request to not use any additional support when working on the simulation, it can, of course, not be ruled out, that some participants did not follow that request. This especially applies to studies 2 and 3. The data of study 1 was collected in presence.

In addition, data was collected in a relatively extended period of time. In all three studies, there was one week between the pre-test and the intervention and then another week between the intervention and the post-test. Thus, it is possible that the study participants gained ePCK elsewhere than via the simulation *DiKoBi* during the period of data collection and consequently that the increase in knowledge might not be explained exclusively by the study interventions.

Especially in study 3 (Publication III), violations of normality and sphericity must be mentioned as a limitation. For the violation of sphericity, a Huynh-Feldt adjustment of the ANOVA was made (Blanca et al., 2023b). Blanca et al. (2023a) encourage to still interpret an ANOVA even when normality is not given.

Concerning the conceptual limitations, four limitations must be reported. This dissertation aims to contribute to research on scaffolding in the context of digital simulation. Obviously, all results and conclusion of the dissertation are made based on one specific simulation (*DiKoBi*) and a very specific context (teaching a five-grade class on the topic ‘skin’). Thus, it is important to replicate the results in other simulations and various contexts. Although, research has shown that affective-motivational aspects, such as interest or motivation, have an impact in problem-based and complex learning environments (Belland et al., 2013) to which a video-based simulation can be assigned, affective-motivational variables were not considered in the studies included in this dissertation. Furthermore, the evaluation via keywords, that was conducted in studies 1 and 2, is not as specific as the evaluation of the written responses by coders with the according coding manual. Correct responses that do not contain any keywords were not taken into account. To address this problem, we also evaluated the whole data sets according to the coding manual and calculated everything with the ePCK-scores. The results were similar; hence, this limitation has no impact on the findings of this dissertation.

Following the theoretical point of view given by the RCM of PCK (Carlson & Daehler, 2019), the learner variable to be considered for supporting the ePCK of pre-service teachers, would more likely be their pPCK. Therefore, the chosen cognitive learner variable for adaptation and personalization in study 3 (prior cPCK) might not be optimal. The prior pPCK or even prior ePCK could be a more suitable learner variable for adaptation.

4.5 Further research

The findings of this dissertation can serve as a starting point to follow up on the results with further research. Firstly, it should be considered to replicate the studies in various context, for example, with a different lesson topic than 'skin' or even in a different science subject (e.g. physics or chemistry), to review the generalizability of the results presented in this dissertation. In further research it might also be interesting to replicate the studies with pre-service teachers in the end of their university education. The results of a meta-analysis by Chernikova, Heitzmann, Fink, et al. (2020) indicate, that learners with little prior knowledge benefit from a different type of instructional support than learners with a higher prior knowledge.

Following the scaffolding definition of Fischer et al. (2022), all scaffolds included in the studies presented in this dissertation would be referred to as *learning process* scaffolds. The influence of *representational scaffolding* on the development of ePCK in pre-service biology teacher education is still completely unexplored. This possibility of further research is particularly interesting with regard to teacher education. Representational scaffolding allows an approximation of practice (Grossman & McDonald, 2008) and can train ePCK in practice representations of varying complexity (Fischer et al., 2022).

Furthermore, so far, only a macro-adaptive time frame has been chosen for the scaffolding adaptation. Using newer technological development and possibilities, such as the integration of NLP for an evaluation of written responses, offers opportunities to adapt scaffolding on a meso- or even micro-adaptive level.

It should also be considered to change the learner variable that the scaffolding is adapted to in order to gain more insights on the effects of scaffolding in digital simulations. With regard to the theoretical embedding of the simulation *DiKoBi* in the RCM of PCK, the cognitive learner variables prior pPCK or prior ePCK are of particular importance. Investigating relationships and effects of pPCK and prior ePCK on the development of ePCK could help to gain valuable insights and further validate the RCM of PCK empirically. Other learner variables (motivational, affective or socio-cultural, see Plass & Pawar, 2020) might also be taken into account.

Currently, a larger research proposal is in preparation, that includes different studies referring to the before mentioned points.

Concerning simulation-based learning in the context of teacher education, it still remains unclear whether the ePCK trained via *DiKoBi* is applicable to real-life classroom situations. Behling et al. (2022b) showed that training pre-service teachers' ePCK trained with the plan-teach-reflect-cycle (Alonzo et al., 2019), including $ePCK_T$ increases their pPCK. These findings give an indication that the $ePCK_T$ might also be increased by training $ePCK_R$ and $ePCK_P$ as part of the simulation *DiKoBi*. An intervention study with an assessment of $ePCK_T$ could be planned to complement the findings of the here presented studies.

When thinking about teaching core practices (Grossman, 2021; Grossman & McDonald, 2008), and particularly core practices in science teaching (Kloser, 2014), the simulation *DiKoBi* can be extended by including new and different practice situations. Focusing on the same aspects of biology specific instructional quality, various videos with different teachers and subjects of lessons could be included and evaluated.

To meet the demand for a deeper understanding of the development of (e) PCK (e.g., Alonzo et al., 2019; Mientus et al., 2022), a longitudinal investigation of pre-service teachers' and also in-service teachers' ePCK could help to evaluate the original model and test the modified RCM of PCK as presented in this dissertation (see section 4.2 and Irmer et al., 2023).

In studies 1 and 2, the evaluation via keywords gave an insight of what might be possible regarding an automatic evaluation or coding of the written responses in the simulation (Irmer et al., 2023; Irmer et al., 2022). In future studies, the written responses could be analyzed using ML (e.g., Wulff et al., 2021) or NLP. This could offer the opportunity of designing fully personalized simulation.

4.6 Implications

From the findings and investigations of this dissertation, theoretical and practical implications can be derived.

First, this dissertation contributes to research on the implementation of digital simulation in higher education programs. The results can serve as a starting point for future research particularly concerning scaffolding possibilities in digital simulations.

All studies conducted were part of the COSIMA project. In section 1.4, the framework of the research unit is pictured (Chernikova et al., 2022). The findings can contribute to proof and describe relationships between the different blocks of the framework: (1) In the context of teacher education, diagnostic competences can be fostered via simulation-based learning environments (Irmer et al., 2023; Irmer et al., 2022; Irmer et al., 2024), (2) instructional support in form of scaffolding improves the effectiveness of learning with the simulation (Irmer et al., 2023; Irmer et al., 2022; Irmer et al., 2024), (3) the relevant component to be scaffolded in simulations to foster diagnostic competences of pre-service biology teachers is their professional knowledge (here: PCK) (Irmer et al., 2023; Irmer et al., 2022), (3) adaptive scaffolding in the simulation is more effective, when the scaffolding is adapted situation-specifically (Irmer et al., 2024). The framework aims to serve as a discussion base and as a base for generating evidence for simulation-based learning in higher education (Chernikova et al., 2022).

Furthermore, the results of this dissertation contribute to the demanded empirical evaluation of the RCM of PCK (Alonzo et al., 2019; Mientus et al., 2022). The findings of this dissertation provide empirical evidence for pPCK to be the "knowledge reservoir" that ePCK is drawn upon (cf. Carlson & Daehler, 2019). In addition, the modified RCM of PCK (see Figure 7) was developed and published as an alternative form of representation of the original model and can therefore contribute to understand the PCK of science teachers' from a different point of view (Irmer et al., 2023).

The practical implications primarily concern simulation-based learning in teacher education. It is possible to successfully foster the development and improvement of ePCK even in early teacher education (e.g. Irmer et al., 2023; Irmer et al., 2022; Irmer et al., 2024; Kramer, Förtsch, & Neuhaus, 2021a, 2021b). Simulations, such as *DiKoBi*, serve as a suitable tool for this. Following Grossman's et al. (2009) idea of "approximating practice", the training of ePCK should be included into early teacher education and simulations seem to be the ideal tool to prevent overburdening for pre-service teachers with little prior knowledge. Combining this with the scaffolding opportunities that have proven to be effective, simulations could serve as an additional learning tool and accompaniment through the university part of teacher education. Personalized learning opportunities could be created and foster pre-service teachers' ePCK in an individualized way.

The *DiKoBi* simulation could be enlarged to contain more videos and/or different lesson topics. Especially with regard to the idea of representational scaffolding (Fischer et al., 2022), practice situations of varying salience could be included to serve as a training tool for pre-service biology teachers with varying levels of prior knowledge. Hence, core practices of science teaching can be addressed and trained in a controlled setting.

Moreover, the results indicate the importance of pPCK. Therefore, there should be a focus on fostering this knowledge realm to have a solid "reservoir of knowledge and skills" (Carlson & Daehler, 2019, p. 85) to draw upon when teaching a real class later.

The findings concerning the keywords can serve as a starting point for a real-time adaptation of scaffolding and/or fading of the scaffolding when a pre-service teacher reaches a certain learning goal.

Overall, the goal should be to implement a personalized and adaptive simulation into teacher education programs, so that pre-service teachers can be confronted with practice situations from an early stage on and develop a good knowledge base for pPCK and ePCK before starting to teach in real classroom settings.

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7. Curriculum vitae

Personal information

Name	Marie Irmer
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Education

since 10/2020	Doctoral student at Ludwig-Maximilians-University in Munich Chair for biology education, Faculty of Biology Adviser: Prof. Dr. Birgit J. Neuhaus
10/2014-02/2020	Study at Ludwig-Maximilians-University in Munich: Biology and chemistry for teaching (Gymnasium) Final Degree: Erstes Staatsexamen für das Lehramt an Gymnasien
10/2013-07/2014	Study at Ludwig-Maximilians-University in Munich: Law

Research experience

Since 06/2020	Research unit COSIMA (NE1196/8-1, 8-2; FOR2385) Facilitating diagnostic competences in simulation-based learning environments in higher education in the university context, Project 3: Facilitating professional knowledge and diagnostic competences of pre-service biology teachers
06-07/2022	Research stay at Stanford University (4 weeks) Center to support excellence in teaching (CSET) Focus: Refined Consensus Model of PCK Prof. Janet Carlson
2015-2020	Research assistant Ludwig-Maximilians-University in Munich Chair for biology education, Faculty of biology

Publications – peer-reviewed journals

2024

Irmer, M., Traub, D., Neuhaus, B. J. (2024). Fostering ePCK in pre-service biology teacher education using adaptive scaffolding in a video-based simulation. *Cogent Education*, *11*(1). https://doi.org/10.1080/2331186X.2024.2422272

2023

Irmer, M., Traub, D., Böhm, M., Förtsch, C. & Neuhaus, B. J. (2023). Using Video-Based Simulations to Foster pPCK/ePCK – New Thoughts on the Refined Consensus Model of PCK. *Education Sciences*, *13*(3), 261. https://doi.org/10.3390/edusci13030261

2022

Irmer, M., Traub, D., Kramer, M., Förtsch, C., & Neuhaus, B. J. (2022). Scaffolding Pre-service Biology Teachers‘ Diagnostic Competences in a Video-based Learning Environment: Measuring the Effect of Different Types of Scaffolds. *International Journal of Science Education, 44*(9), 1506-1526. https://doi.org./10.1080/09500693.2022.2083253

Conference contributions

2024

Traub, D., **Irmer, M.**, Weiß, E., & Neuhaus, B. J. (2024, March). *Längsschnittstudie zur Entwicklung des ePCK von Lehramtsstudierenden in einer simulationsbasierten Videolernumgebung – Machen Scaffolds den Unterschied?,* poster presentation at Tagung der Gesellschaft für Empirische Bildungsforschung (GEBF), Potsdam.

2023

Traub, D., **Irmer, M.**, Förstch, C., & Neuhaus, B. J. (2023, September). *Förderung des pPCK/ePCK von Lehramtsstudierenden mit Hilfe von Scaffolds in einer videobasierten Simulationsumgebung*. In D. Traub (Chair), Das Refined Consensus Model of PCK in der Biologiedidaktik – Was nützt es uns? presentation in a symposium at the international conference of the Fachsektion der Didaktik der Biologie (FdDB), Ludwigsburg.

Irmer, M., Traub, D., Förtsch, C. & Neuhaus, B. J. (2023, April) *The influence of cPCK- and pPCK-Scaffolds on video analysis skills in early pre-service teacher education*, single paper presentation at the 96th annual NARST conference, Chicago.

2022

Irmer, M., Traub, D., Förtsch, C. & Neuhaus, B. J. (2022, July) *An approach to adaptive scaffolding in a simulation-based learning environment*, single paper presentation at the JURE conference, Porto.

Irmer, M., Traub, D., Kramer, M., Förtsch, C. & Neuhaus, B. J. (2022, March) *Effects of different scaffolds in a video-based learning environment for pre-service teachers*, single paper presentation at the 95th annual NARST conference, Vancouver.

2021

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8. Appendices

Scaffolds in Study 1

The diagnostic activity scaffolds (DA-scaffolds, see Table A) for the three tasks in the video-based simulation were the same for each video in the intervention of study 1. The DA-scaffolds appeared in form of prompts. The first scaffold appeared before the videos starts (with the first task), the second DA-scaffold appears when the second task is displayed, the third one together with the third task.

Table A. Diagnostic activity scaffolds as integrated in the simulation *DiKoBi* for study 1.

Task in *DiKoBi*	**Diagnostic Activity**	**Original scaffold (German)**	**Translated scaffold (English)**
Describe	Identifying problems, Generating evidence	<u>Probleme erkennen und beschreiben</u> Nutzen Sie das Textfeld, um ein Problem, welches Sie erkannt haben, zu beschreiben. Bei der Beschreibung geht es darum, dass Sie die Situation möglichst **wertfrei** und **ohne Begründungen** darstellen. Fokussieren Sie rein auf Merkmale und **Details der Situation** bzw. des Lehrerverhaltens, die sie als kritisch erachten.	<u>Identifying and describing problems</u> Use the text field to describe a problem that you have identified. Describing, it is important to present the situation as **value-free** as possible and **without justifications**. Focus purely on features and **details of the situation** or teacher behavior that you consider critical.
Explain	Evaluating evidence	<u>Analysieren und Begründen</u> Zeigen Sie die Relevanz Ihrer erkannten Probleme auf, indem Sie mit Hilfe Ihres Wissens begründen, warum der jeweilige Aspekt problematisch ist. **Verknüpfen** Sie dafür Ihre Beobachtung **mit fachdidaktischen Theorien, Konzepten** und **Fachbegriffen**, die Sie nennen und entsprechend in Ihrer Begründung ausführen.	<u>Analyzing and justifying</u> Highlight the relevance of your identified problems by using your professional knowledge to justify why each observation is problematic. To do this, **link** your observation with **didactical theories, concepts** and **technical terms** that you name and explain in your justification.
Alternative Strategy	Drawing conclusions	<u>Konsequenzen aus den beschriebenen Problemen ziehen</u> Beschreiben Sie ausgehend von den Aspekten, die Sie kritisiert bzw. als problematisch erkannt haben, **Handlungsalternativen**	<u>Drawing consequences from the described problems</u> Based on the aspects you have criticised or identified as problematic, describe **alternative courses of action** for the teaching situation. Be

	für die Unterrichtssituation. Werden Sie bei Ihrer Handlungsalternative **konkret** und führen Sie **Beispiele und entsprechende Begründungen**, die für ihre gewählte(n) Alternative(n) sprechen, nachvollziehbar und **ausführlich** auf.	specific with your alternative and give **examples and corresponding reasons** that speak for your chosen alternative(s) in a comprehensible and **detailed** way.

The PCK-scaffolds changed according to the practice situation (aspect) in the videos of the video-based simulation *DiKoBi* (see Table B).

Table B. PCK-scaffolds as integrated in the simulation *DiKoBi* for study 1.

Aspect	Original scaffold (German)	Translated scaffold (English)
Problem orientation in the beginning of a lesson	In der Hinführungsphase des Unterrichts ist die **Aktivierung** von Schülern, v.a. **kognitiv**, wichtig für den Einstieg in ein Unterrichtsthema. Hierbei sollte das **Vorwissen** der Schüler **aktiviert**, **Schülervorstellungen abgefragt** und wenn möglich ein kognitiver Konflikt erzeugt werden. Zum Einsatz können beispielsweise verfremdete Bilder kommen, die Zweifel, Verwirrung oder Unklarheit auslösen und dadurch kognitiv aktivierend wirken. Letztendlich sollte der Einstieg inhaltlich zum Stundenthema hinführen, das für die Schüler in Form einer **Problemfrage oder Fokusfrage** als Zielrahmen sichtbar ist und am Stundenende wieder aufgegriffen wird.	When the teacher introduces a new topic in class, the **activation** of students, especially **cognitively**, is important. This should involve the **activation of** the students' **prior knowledge, exploring students' ideas** and, if appropriate, generating a **cognitive conflict**. For example, alienated illustrations, which trigger doubt, confusion or ambiguity, can be used und thus, have a cognitively activating effect. Ideally, the introduction should lead to the topic of the lesson, be present for the students in form of a **problem** or **focus question** and should be referred to again at the end of the lesson.
	Das Nutzen von alltagsrelevanten Problemen, verfremdeten Bildern oder auch das Konzipieren des Unterrichtsvorhabens als Wettbewerb kann darüber hinaus Motivation für den Unterrichtsgegenstand bei den Lernenden wecken. Sowohl Alltagsbeispiele als auch der Einsatz von geeigneten Bildern dienen dazu, Emotionen wie Überraschung oder Neugier, aber auch Ich-Nähe zu erzeugen, um die Lernenden auf	The use of problems relevant to everyday life, alienated illustrations or even the conception of the lesson as a competition can also arouse the learners' motivation for the subject matter. Everyday examples as well as the use of appropriate pictures, serve to generate emotions such as surprise or curiosity, but also closeness to the self in order to catch the learners affective-motivationally. These approaches and methods are also

	affektiv-motivationaler Ebene zu erreichen. Man bezeichnet diese Mittel und Methoden auch als **catch-Komponenten**, die während des Unterrichtseinstieges vorhanden sein sollten, um **situationales Interesse** zu wecken.	known as c**atch-components**, which should be present when introducing a new topic in order to arouse **situational interest**.
Use of technical terms and language	**Kommunikation** als Kompetenzbereich der KMK Bildungsstandards fasst auch die **Fachsprache** im naturwissenschaftlichen Unterricht mit ein, die z.B. in Abbildungen, Texten und Diagrammen, aber auch Unterrichtsgesprächen stets präsent ist. Charakteristisch für die Fachsprache ist die Verwendung von vielen Fachbegriffen sowie Passiv- und Nebensatzkonstruktionen. Fachsprache ist von der **Alltagssprache** abzugrenzen, die in jeglichen Alltagssituationen zum Einsatz kommt. Die Sprache des Unterrichts **(Unterrichtssprache)** ist eine Schnittmenge aus Alltagssprache und Fachsprache. Das Fach Biologie zeichnet sich durch eine Vielzahl an **Fachbegriffen** aus, die von Schülern zu lernen sind. Aufgrund der Begrenztheit des Gedächtnisses, neue Begriffe zu erlernen, zeichnet sich ein sprachsensibler Fachunterricht durch eine **überschaubare Anzahl** an für das Unterrichtsthema relevanten Fachbegriffen aus. Zudem sollten Fachbegriffe stets **erklärt** werden und funktional innerhalb eines thematischen Kontextes Verwendung finden. Dies erleichtert die Vernetzung von Fachinhalten und deren späteres Abrufen durch die Schüler. Grundsätzlich zu unterscheiden sind Fachbegriffe auf **Wissenschaftsebene** und Fachbegriffe auf **Unterrichtsebene**. Fachbegriffe auf **Wissenschaftsebene** werden zum Beispiel an Universitäten verwendet	Communication as a competence area defined in the “KMK Bildungsstandards” includes the **technical language** in e.g., Figures, texts and diagrams, but also during classroom discussion, in science lessons. It is characteristic for technical language to include the use of many technical terms and passive and subordinate clause constructions. Technical language can be distinguished from **everyday language**, that is used in situations of the everyday life. The language spoken during lessons (**instructional language**) is the overlap of technical and everyday language. In the subject biology many **technical terms** are used, that students have to learn. As the memory is limited in learning new terms, a language-sensitive teaching considers to only introduce a **limited number** of technical terms relevant for the subject matter. Furthermore, technical terms should always be explained and be introduced as part of a functional context. This enhances the connection of different contents and helps the students to remember those. A basic distinction must be made between technical terms at the **scientific level** and technical terms at the **classroom level**. For example, technical terms on the **scientific level** are used at university and should not be used in classrooms due to the

	und sollten in der Schule aufgrund des hohen Abstraktionsniveaus nicht gebraucht werden.	required level of abstraction that is afforded.
Use of experiments	Das Experimentieren ist in den KMK Bildungsstandards unter dem Aspekt Erkenntnisgewinnung verankert. Hierbei soll den Schülern der naturwissenschaftliche Erkenntnisweg als festes Schema für das Experimentieren vermittelt werden, dessen Phasen sie vorzugsweise auch selbst durchführen sollten. Die Phasen des Erkenntnisweges sind: **Fragestellung** formulieren – überprüfbare **Hypothesen** aufstellen – ein passendes **Experiment planen und durchführen** – gewonnene **Daten analysieren und interpretieren**. Jede der vier Phasen fordert andere Kompetenzen und kann separat gefördert werden. Beispielsweise kann die Lehrkraft schwerpunktmäßig das Aufstellen von Hypothesen fördern, indem die Schüler zu einer bestehenden Problemfrage Lösungsmöglichkeiten (Hypothesen) generieren und auf der Grundlage ihres Vorwissens begründen müssen. Dies hilft beim Planen eines Experiments bzw. dem Nachvollziehen eines bereits vorgegebenen Experiments, dessen Relevanz für die Schüler sichtbar sein sollte. Die naturwissenschaftliche Auswertung von Messdaten umfasst mehrere Datenreihen, um Schwankungen der Messungen ausgleichen oder Messfehler erkennen zu können. Nach dem Auswerten erfolgen dann Interpretationsversuche der Messdaten. Hier sollten die Schüler auch auf die anfangs formulierten Hypothesen zurückkommen, diese abgleichen und diskutieren. Nur so kann prozessbezogen der Kompetenzbereich	Experimenting is anchored in “KMK Bildungsstandards” under the aspect of scientific inquiry. Students should be taught to use the path of scientific inquiry as a fixed scheme, preferably carrying out the steps by themselves. The steps of the path of scientific inquiry are: Formulating a **question** – generating testable **hypotheses** – **planning and conducting** a suitable **experiment** – **analyzing and interpreting the data** obtained. Each of the four steps requires different skills and can be fostered separately. For example, the teacher can focus on fostering to generate hypotheses by having the students generate possible outcome (hypotheses) to an existing problem and justify them referring to their prior knowledge. This helps when planning an experiment or reproducing an existing experiment, of which the relevance should be clear for the students. The scientific evaluation of measurement data compromises several data series to compensate the fluctuation in the measurements or to identify measurement errors. After the evaluation, the data should be interpreted. Here, students should refer back to their generated hypotheses, compare them to the results and discuss them. This is a way to foster process-related competence in scientific inquiry.

	Erkenntnisgewinnung gefördert werden.	
Use of models	Modelle sollen im Unterricht nicht nur als **Anschauungsmittel** eingesetzt werden, sondern ebenso als **Arbeits- bzw. Denkmethode**, um den **Prozess der Erkenntnisgewinnung** zu unterstützen. Am intensivsten beschäftigen sich die Schüler mit Modellen, wenn sie diese hypothesengeleitet selbst entwerfen und bauen. Anhand der eigens erstellten Modelle können nach dem naturwissenschaftlichen Erkenntnisweg die aufgestellten Hypothesen geprüft werden und Voraussagen getroffen werden. Um die Tragfähigkeit der aus der Modellarbeit gezogenen Schlüsse besser einschätzen zu können, muss immer ein Vergleich zwischen dem Modell und dem Original erfolgen, die sogenannte **Modellkritik**. Hierbei wird geprüft, welche **Übereinstimmungen** es zwischen dem Original und dem Modell gibt. Ebenso sollen die **Grenzen/Verkürzungen** des Modells erfasst werden, da Modelle meist auf einzelne Aspekte eines Systems fokussieren und Ausschnitte darstellen. Das **Beiwerk**, das unwesentliche Aspekte beinhaltet, wie zum Beispiel die Farbwahl oder das Material, muss bei der Modellkritik besonders beachtet werden. Durch die **ausschnitthafte Darstellung** sowie das Aufzeigen von **nicht relevanten Eigenschaften** ist eine kritische Auseinandersetzung mit dem Modell unabdingbar, um das Entstehen von **Fehlvorstellungen zu vermeiden**.	Models should not only be used as **visual aids** in lessons, but also as a **work method** or **thinking method** to support the **process of scientific inquiry**. Students engage on the deepest level with models when designing and creating them based on their own hypotheses. Using the models they created themselves, hypotheses can be tested, and predictions based on the path of scientific inquiry can be made. In order to assess the validity of the conclusion drawn from working with the model, a comparison must be made between the model and the original. This is called **critique of the model**. This involves checking the **similarities** between the model and the original. Also, the **limitations/shortenings** of the model must be assessed, because models usually focus on individual aspects of a system and only represent parts of the original. **Additional material**, which includes non-essential aspects such as the choice of color or the material, must be given special attention when critiquing the model. Due to the **fragmentary representation** and the highlighting of **non-relevant features** of the model, a critical reflection of the model is essential to **avoid misconceptions.**
Transfer and conceptual linking in the end of a lesson	Beim problemorientierten Unterricht, bei dem in der Hinführungsphase des Unterrichts ein Problem oder eine Problemfrage aufgestellt wird, ist in der Sicherungsphase ein **Rückbezug zu diesem Einstieg** aus mehreren	In a problem-orientated lesson, in which a problem is brought up or a problem question is posed in the beginning of the lesson, it is important to **refer to the beginning of the lesson** in the end of the lesson

	Aspekten sinnvoll. In erster Linie kann der Unterricht hierdurch besser strukturiert werden, da durch den Rückbezug ein **roter Faden** für die Schüler ersichtlich ist. Zudem kann der **Lernfortschritt** der Schüler überprüft werden, indem die zu Beginn aufgestellten Hypothesen zur Problemfrage verifiziert, beziehungsweise falsifiziert werden. Ebenso kann das Wissen der Schüler **anwendungsbezogen überprüft** werden, indem Kontexte mit dem neu erworbenen Wissen reflektiert/bewertet werden.	for several reasons. First and foremost, this permits a better structure of the lesson, because the reference provides the students with a **common thread**. In addition, the students' learning progress can be checked by verifying or falsifying the hypotheses on the problem question that were generated in the beginning. Also, the students' knowledge can be tested when **applicating** it to new context and reflecting/evaluating those with the newly acquired knowledge.
	Neben dem Rückbezug zum Einstieg ist die **kognitive Aktivierung** der Schüler entscheidend für eine gelungene Sicherungs- und Transferphase. Hierfür ist das Wiederholen des Unterrichtsstoffes als **reine Reproduktion** nicht ausreichend, vielmehr soll eine **Verknüpfung mit dem bisherigen Wissen** erfolgen, um Wissen langfristig abzuspeichern und durch einen hohen Vernetzungsgrad abrufbar zu machen. Förderlich ist beispielsweise das Nutzen von **Basiskonzepten** wie Struktur und Funktion und deren Anwendung auf andere Themenbereiche oder der **Transfer** von Analogien auf den Originalgegenstand.	Besides referring to the beginning, **cognitive activation** of the students is crucial for a successful consolidation and transfer phase of the lesson. It is not sufficient to **just reproduce** the content of the lesson, rather, the students should link the newly gained knowledge to **prior knowledge** to facilitate long-term storage of the knowledge and make knowledge retrievable by linking it to an existing network of knowledge. For example, the use of **core ideas** such as the concept of structure and function and their application to other subject areas or the **transfer** of analogies to the original object, is beneficial.

Scaffolds in Study 2 and Study 3

The cPCK-scaffolds for study 2 and 3 are content-related scaffolds and a shortened version of the PCK-scaffolds of study 1 (see Table C). The pPCK-scaffold serve as knowledge activation prompts (see Table D). Both scaffolds changed according to the practice situation (aspect) in the videos of the video-based simulation *DiKoBi*.

Table C. cPCK-scaffolds as integrated in the simulation *DiKoBi* in study 2 and 3.

Aspect	Original scaffold (German)	Translated scaffold (English)
Problem orientation in the	Zur **kognitiven Aktivierung** beim Unterrichtseinstieg sollte das **Vorwissen** der SuS aktiviert,	For **cognitive activation** in the beginning of the lesson, the **students' prior knowledge** should

beginning of a lesson	**Präkonzepte** abgefragt und, wenn möglich, ein **kognitiver Konflikt** erzeugt werden. Um **Interesse** bei den SuS zu erzeugen, können z.B. Alltagsgegenstände oder verfremdete Bilder genutzt werden, die bei den SuS Emotionen wie Neugier und Überraschung hervorrufen oder Ich-Nähe erzeugen. Solche Mittel und Methoden werden als **catch-Komponente** bezeichnet und können **situationales Interesse** hervorrufen.	be activated, **pre-concepts** should be explored, and if possible, a **cognitive conflict** should be created. In order to generate **interest** in the students, everyday objects which evoke emotions such as curiosity and surprise, can be helpful. Such materials and methods are called **catch-components** and can create **situational interest**.
Use of technical terms and language	Man unterscheidet Fach-, Alltags- und Unterrichtsprache. Während die Fachsprache durch die Verwendung vieler **Fachbegriffe** sowie Passiv- und Nebensatzkonstruktionen gekennzeichnet ist, kommt die **Alltagssprache** in den meisten alltäglichen Situationen vor. Die **Unterrichtsprache** ist als Schnittmenge von Alltags- und Fachsprache zu verstehen. Ein **sprachsensibler Unterricht**, der die SuS nicht überfordert, zeichnet sich durch eine **überschaubare Anzahl** an Fachbegriffen aus, die stets **erklärt** werden und in einen **Kontext** eingebettet sind. Dies erleichtert die Vernetzung von Fachinhalten und so das spätere Abrufen durch die SuS.	A distinction is made between technical language, everyday language and instructional language. Whereas it is characteristic for technical language to include the use of many **technical terms** and passive and subordinate clause constructions, **everyday language** is used in situations of everyday life. **Instructional language** can be seen as the overlap of technical and everyday language. A **language-sensitive teaching**, that is not overwhelming for the students considers to only introduce a **limited number** of technical terms that are always **explained** and introduced as part of a functional **context**. This enhances the connection of different contents and helps the students to remember those.
Use of experiments	Der naturwissenschaftliche Erkenntnisweg erfolgt in vier Schritten: 1. **Fragestellung** formulieren 2. Überprüfbare **Hypothesen** aufstellen 3. Ein passendes **Experiment planen und durchführen** 4. **Daten analysieren und interpretieren** Jede dieser 4 Phasen fördert andere Kompetenzen und kann separat gefördert werden. Nach der naturwissenschaftlichen **Auswertung** von Messdaten (umfasst mehrere Datenreihen, um	The path of scientific inquiry involves four steps: 1. Formulating a **question** 2. Generating testable **hypotheses** 3. **Planning and conducting** a suitable **experiment** 4. **Analyzing and interpreting data** Each of the four steps requires different skills and can be fostered separately. After the scientific evaluation of measurement data (includes several data series to compensate the fluctuation in the measurements/to

	Schwankungen und Messfehler auszugleichen/zu erkennen), erfolgt die **Interpretation** dieser. Hier sollte ein **Rückbezug** durch die SuS zu den anfangs aufgestellten Hypothesen stattfinden.	identify measurement errors), the data should be interpreted. Here, students should refer to their generated hypotheses.
Use of models	Modelle dienen im Unterricht nicht nur als Anschauungsmittel, sondern auch als **Denk- bzw. Arbeitsweise** im Prozess der Erkenntnisgewinnung. Erstellen die SuS ein Modell selbst, können nach dem naturwissenschaftlichen Erkenntnisweg aufgestellte **Hypothesen geprüft** und Voraussagen getroffen werden. Bei der Arbeit mit Modellen sollte immer eine **Modellkritik** erfolgen (Vergleich zwischen Modell und Original). Hierbei werden **Übereinstimmungen** und **Unterschiede** zwischen Modell und Original erfasst und diskutiert. Das **Beiwerk** (z.B. Farbwahl, Material des Modells) muss besonders thematisiert werden, um **Fehlvorstellungen zu vermeiden.**	Models should not only be used as visual aids in lessons, but also as a **work method** or **thinking method** to support the process of scientific inquiry. When students create a model themselves, they can follow the path of scientific inquiry, **test hypotheses** and make predictions. When working with models, a **critique of the model** should always be included (comparison of the model and the original). It involves checking and discussing the **similarities** and **differences** between the model and the original. **Additional material** (e.g., choice of color, material) must be given special attention to **avoid misconceptions**.
Transfer and conceptual linking in the end of a lesson	Beim problemorientierten Unterricht sollte in der Sicherungsphase ein **Rückbezug zum Einstieg** (und so auf die Problemfrage) stattfinden. Der Unterricht erhält dadurch eine bessere Struktur (roter Faden) und der Lernfortschritt der SuS kann überprüft werden (Überprüfung der Hypothesen und Beantwortung der Problemfrage). Eine Aktivierung der SuS kann durch **Verknüpfung mit bisherigem Wissen** sowie durch **Basiskonzeptorientierung** geschaffen werden (langfristiges Abspeichern durch Vernetzung). Durch **Transferaufgaben** kann das Wissen der SuS anwendungsbezogen überprüft werden, indem Kontexte mit dem neu erworbenen Wissen reflektiert/bewertet werden.	In a problem-orientated lesson, is important to **refer to the beginning of the lesson** (and therewith to the problem question) during the consolidation phase. The lesson gets well-structured (common thread) and the students' learning progress can be checked (checking the hypotheses and answering the problem question). Students can be cognitively activated by **linking their knowledge to prior knowledge** or by linking the lesson content to **core ideas** (long-term storage of the knowledge by linking it to an existing network of knowledge). **Transfer tasks** can be used to test the students' knowledge in an application-oriented way by reflecting on/evaluating contexts with the newly acquired knowledge.

Table D. pPCK-scaffolds as integrated in the simulation *DiKoBi* in study 2 and 3.

Aspect	Original scaffold (German)	Translated scaffold (English)
Problem orientation in the beginning of a lesson	Erinnern Sie sich daran, was man für einen gelungenen **Unterrichtseinstieg** braucht. Beziehen Sie bei der Beschreibung ihr Vorwissen zur **kognitiven Aktivierung** und zur Förderung des **Interesses** mit ein.	Remember what you know about successfully starting a lesson. Include your prior knowledge concerning the **cognitive activation** of the students as well as the **generation of interest**.
Use of technical terms and language	Im Biologieunterricht spielt die Verwendung von **Fachsprache** eine große Rolle. Nutzen Sie für die Bearbeitung der Aufgabe ihr Wissen zum Einsatz von und Umgang mit **Fachbegriffen** im Sinne eines **sprachsensiblen** Unterrichts!	The use of **technical language** plays a major role in biology lessons. Use your knowledge concerning the introduction and the handling of **technical terms** in the sense of **language-sensitive** teaching to complete the task!
Use of experiments	Für die Bearbeitung der Aufgabe sollten Sie sich besonders auf den **naturwissenschaftlichen Erkenntnisweg** fokussieren. Beziehen Sie ihr Vorwissen zu den 4 Schritten des Erkenntnisweg mit ein!	Focus on your knowledge about the **path of scientific inquiry** to complete the task. Use your prior knowledge concerning the 4 steps of the path of scientific inquiry!
Use of models	Bei der Bearbeitung der folgenden Aufgaben ist besonders Ihr Vorwissen zum **Einsatz von Modellen im Prozess der Erkenntnisgewinnung** gefragt. Überlegen Sie welche Aspekte und Schritte hierbei für den Unterricht beachtet werden müssen!	When working on the next task, your prior knowledge concerning the **use of models in the process of scientific inquiry** is crucial. Think of what aspects and steps to consider when teaching!
Transfer and conceptual linking in the end of a lesson	Bei den folgenden Aufgaben liegt der Fokus auf dem Unterrichtsende. Wenden Sie hier ihr Wissen zu **Rückbezug** und **Transfer** am Stundenende an!	In the following task, the focus lies on the end of the lesson. Apply your knowledge of **reference** and **transfer** at the end of the lesson!

Keywords

The keywords used for the automatic evaluation of the written responses in study 1 and 2 are displayed in Table E for each aspect separately.

Table E. Keywords for the automatic evaluation of written responses in the simulation *DiKoBi*.

Aspect	Keywords (original)	Keywords (translated)
Problem orientation in	Unterrichtseinstieg, kognitiv, Aktivierung, Vorwissen,	Beginning of the lesson, cognitive, activation, prior knowledge,

the beginning of a lesson	Schülervorstellung, Konflikt, Interesse, catch, situational	student ideas, conflict, interest, catch, situational
Use of technical terms and language	Fachsprache, Alltagssprache, Unterrichtssprache, sprachsensibel, Anzahl, Kontext, erklären/Erklärung, Fachbegriff	Technical language, everyday language, instructional language, language sensitive, number, context, explain/ explanation, technical term
Use of experiments	Erkenntnisweg, Frage, Hypothese, Experiment, planen, durchführen, Daten, analysieren/Analyse, interpretieren/Interpretation, überprüfen/Überprüfung	Path of scientific inquiry, question, hypothesis, experiment, plan, conduct, data, analyse/analysis, interpret/ interpretation, refer/ reference
Use of models	Arbeitsmethode, Erkenntnisgewinnung, Hypothese, Kritik, Model, Gemeinsamkeiten, Unterschiede, Detail, Fehlvorstellung	Working method, scientific inquiry, hypothesis, critique, model, similarities, differences, details, misconception
Transfer and conceptual linking in the end of a lesson	Rückbezug, vernetzen, Konzept, Transfer, Sicherung, Einstieg, Wissen	Reference, linking, concept, transfer, summary, beginning of the lesson, knowledge