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Systematizing Professional Knowledge of Medical Doctors and Teachers: Development of an Interdisciplinary Framework in the Context of Diagnostic Competences

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Abstract: Professional knowledge is highlighted as an important prerequisite of both medical doctors and teachers. Based on recent conceptions of professional knowledge in these fields, knowledge can be differentiated within several aspects. However, these knowledge aspects are currently conceptualized differently across different domains and projects. Thus, this paper describes recent frameworks for professional knowledge in medical and educational sciences, which are then integrated into an interdisciplinary two-dimensional model of professional knowledge that can help to align terminology in both domains and compare research results. The models' two dimensions differentiate between cognitive types of knowledge and content-related knowledge facets and introduces a terminology for all emerging knowledge aspects. The models' applicability for medical and educational sciences is demonstrated in the context of diagnosis by describing prototypical diagnostic settings for medical doctors as well as for teachers, which illustrate how the framework can be applied and operationalized in these areas. Subsequently, the role of the different knowledge aspects for acting and the possibility of transfer between different content areas are discussed. In conclusion, a possible extension of the model along a "third dimension" that focuses on the effects of growing expertise on professional knowledge over time is proposed and issues for further research are outlined.

Keywords: professional knowledge; medical sciences; educational sciences; diagnosis

1. Introduction

Professional knowledge is regarded as an essential prerequisite for successfully acting as a professional in complex domains (e.g., Reference [1]) such as medical and educational sciences. For example, medical doctors have to apply their knowledge to solve clinical problems or to find the right diagnosis [2]. In an instructional context, teachers have to apply their knowledge to implement instructional strategies or to diagnose students' (mis)conceptions or their current level of knowledge [3,4]. The need for knowledge has been described as the *Knowledgeable Teacher Hypothesis* [3,5] as well as in theoretical models of teaching and learning (e.g., Reference [6]) that highlight professional knowledge as a key factor for teaching. Recent findings from empirical studies in medical and educational sciences support this view [3,7]. However, these findings can only be regarded as first steps and unfortunately, it is currently difficult to compare results from different projects or even domains, as terminology and underlying frameworks differ.

To advance current knowledge, the COSIMA project (Facilitating diagnostic competencies in simulation-based learning environments in the university context), which is an interdisciplinary project from medical education, mathematics education, physics education, biology education, and learning sciences aims to further analyze the role of knowledge for developing diagnostic competences. To compare the role of professional knowledge for acquiring diagnostic competences of medical doctors and teachers, an interdisciplinary framework is needed, which allows to systematize professional knowledge in both domains. Comparing and systematizing these two fields appear promising as medical doctors and teachers are subject to similar requirements when diagnosing. Additionally, practice and research from both domains can benefit from each other: In medical education, practical-oriented approaches on how to foster diagnostic competences have already been developed and evaluated. In contrast, beginning with the approach of Shulman, educational science has a huge tradition of conceptualizing and measuring professional knowledge. Therefore, based on current findings concerning professional knowledge, this paper sets out to develop, describe, and discuss a first approach for an interdisciplinary model of professional knowledge in the context of diagnosis, incorporating perspectives from medical and educational sciences as well as from psychological research in general. The emerging model is intended to structure and integrate current perspectives, help to get a more accurate view of different aspects of professional knowledge and build the basis for describing the acquisition of diagnostic competences across domains. The model's aim is to provide a shared language to address different knowledge aspects across both domains, which, of course, have to be specified and operationalized domain-specifically, taking into account the specifics of each domain. Therefore, besides the mere description of the model, the main emphasis of this contribution is on substantiating the interdisciplinary applicability and showing its domain-specific adaptations throughout several domains. For this reason, the applicability of the interdisciplinary model for professional knowledge is demonstrated within the context of diagnostic competencies by analyzing diagnostic situations from clinical medicine and instruction. Subsequently, emerging issues, questions, and new insights derived from the interdisciplinary comparison and the new model are discussed. These relate to current conceptions of knowledge in both, medical and educational sciences, as well as to the acquisition and development of competencies and represent major areas of future research with regard to the structure of professional knowledge and the development of professional competencies.

2. Recent Frameworks for Professional Knowledge in Medical and Educational Sciences

Although the term "knowledge" appears to be well known and intuitive on first sight, its use, its description, and its features vary considerably in everyday life and in research. Currently, various terms and categories are being used to describe and systematize different aspects of knowledge [8–10]. In particular, several models for professional knowledge exist and are used in parallel, both in medical and educational sciences (e.g., Reference [11]). To develop an interdisciplinary framework for professional knowledge, influential and currently used models of professional knowledge from medical and educational sciences, often derived from recent large-scale studies, are presented first. Due to the huge number of models for professional knowledge, especially in the field of educational sciences, this presentation cannot be comprehensive, and models other than the ones presented in this paper do exist. However, these show a heavy overlap and are mostly structurally similar to one or multiple of the presented models.

2.1. Medical Sciences

2.1.1. Types of Knowledge by Mayer

In an attempt to apply the science of learning in medical sciences, Mayer [12] introduced a model, which included five aspects of knowledge that he proposed as required to be proficient in most cognitive tasks. Partially based on the taxonomy by Anderson and Krathwohl [13], Mayer described the following aspects of knowledge: *Factual knowledge* which refers to "knowledge about the characteristics of elements in the world, such as knowing that the right ventricle is a part of the heart", whereas *conceptual knowledge* refers to the "knowledge of models, principles, categories, and schemas, such as knowing the cause-and-effect mechanism for how the human heart works" [12] (p. 546). These two kinds of knowledge are complemented with *procedural knowledge* which consists of the "knowledge of step-by-step processes for how to carry out an action, such as knowing how to carry out long division computations", and *strategic knowledge* which is the knowledge about "general methods for approaching problems, such as breaking a problem into parts". Finally, *beliefs* or *attitudinal knowledge* refers to the knowledge about "how one's own learning works and about one's competence as a learner, such as thinking: 'I am good at this'".

2.1.2. A Model of Diagnostic Knowledge

In their work on diagnostic competencies, Kopp, Stark, and Fischer [14] postulated a model for a diagnostic knowledge base that is partially based on the findings by van Gog, Paas, and van Merriënboer [15]. The model includes *conceptual knowledge* ("what information") as a declarative knowledge component and two action-related knowledge components: *strategic knowledge* ("how information"), and *teleological knowledge* ("why information"; e.g., the rationale behind the selection and application of specific actions). Furthermore, it includes more abstract structures (schemata) that can integrate these different components to allow the effective retrieval of knowledge in diagnostic settings. In a later publication [16], the three different knowledge components remain but are slightly renamed as *conceptual*, *strategic*, and *conditional knowledge*. Here conceptual knowledge refers to "factual knowledge concerning domain-specific concepts and relations between these concepts" [16] (p. 1211). *Strategic knowledge*, in contrast, includes "knowledge about problem-solving strategies and heuristics" [16] (p. 1211). Finally, *conditional knowledge* is "knowledge about the conditions of application of conceptual and strategic knowledge", including also "knowledge about the rationale behind the selection" [16] (p. 1211).

Based on these models, Schmidmaier et al. presented a model for clinical knowledge that again holds three components: *conceptual knowledge* (facts and "what" information), *strategic knowledge* ("how" information), and *conditional knowledge* ("why" information) [2]. Schmidmaier et al. provided a further distinction between these three components, describing conceptual knowledge as "declarative textbook facts", whereas strategic and conditional knowledge are interpreted as "*procedural knowledge*" [2].

2.1.3. The MOT Model of Clinical Reasoning Processes

A different categorization of knowledge components can be derived from the *MOT model of clinical reasoning processes* by Charlin et al. [17]. In the MOT-approach (Modelling using Typified Objects), Charlin et al. [17] generated a hierarchical model of processes of clinical reasoning that also includes four "repertoires of knowledge", namely *clinical knowledge* and *biological*, *psychological*, and *sociological knowledge*. The latter three refer both to basic knowledge, for example acquired at university, as well as to more encapsulated forms of knowledge. Encapsulated knowledge can be described as a combination of numerous lower-level concepts and their relationships using higher-level concepts without loss of explanatory power [7]. Through clinical encounters, this knowledge is further modified and enriched as well as reorganized into clinical knowledge. In comparison to both models above, the MOT-Model gives a categorization of knowledge based on different content areas (biology, psychology, sociology). It additionally refers to different types of knowledge, separating basic knowledge and encapsulated knowledge, in particular, so-called illness scripts [7]. The latter are described as networks of knowledge that are highly adapted to clinical tasks and link different illnesses, their attributes, consequences, treatments, as well as memories of prior encounters of the illness.

2.2. Educational Sciences

2.2.1. Content-Related Facets of Knowledge

In contrast to models from medical sciences, most models in educational sciences concentrate explicitly on different contents of knowledge required by teachers. This can be related to the taxonomy of Shulman that has been of great influence and is, at least, with regard to its core assumptions, widely accepted [5,10]. Based on Shulman's taxonomy, professional knowledge in educational sciences can be differentiated into seven, mostly disjoint content-related facets: (1) *content knowledge*, (2) *pedagogical content knowledge*, (3) *general pedagogical knowledge*, (4) *curriculum knowledge*, (5) *knowledge of learners and their characteristics*, (6) *knowledge of educational contexts*, and (7) *knowledge of educational ends, purposes, and values, and their philosophical and historical grounds*. Based on this taxonomy, recent educational research mainly focuses on three facets, which have been researched extensively during the last years: *content knowledge* (CK), *pedagogical content knowledge* (PCK), and *pedagogical-psychological knowledge* (PK). Here, both CK and PCK are mainly described as content-specific facets, whereas PK can be seen as a content independent facet [18–23]. Each of these facets can be sub-divided into several sub-facets, which in return cover further facets of Shulman's taxonomy. For example, pedagogical content knowledge includes, at least, the sub-facets "knowledge about students' errors" and "knowledge about instructional strategies" (e.g., [24,25]).

The facets CK, PCK, and PK have been used in different recent large-scale studies for capturing and describing professional knowledge in mathematics (TEDS-M, [26]; KiL, [27]; COACTIV, [28]; MT21, [29]) and in the natural sciences (ProwiN, [22]; KiL, [27]).

Within these studies, content knowledge generally refers to knowledge about facts and terms, as well as the conceptual understanding of these contents. Additionally, content knowledge includes knowledge about connections between contents within one subject and elaborated knowledge, including a deep understanding within this subject and knowledge about a large number of details [10,30,31]. That is why a subject- and in parts, a topic-specificity of content knowledge are assumed [32].

Pedagogical content knowledge is currently conceptualized via two alternative approaches: the integrative model and the transformative model [33]. The integrative model conceptualizes pedagogical content knowledge not as a unique knowledge facet, but as an "amalgam" [5] of, at least, content knowledge and pedagogical-psychological knowledge, and possibly also, of other knowledge facets. Therefore, pedagogical content knowledge is not regarded as a knowledge facet on its own, but rather as the composition of other knowledge facets [33]. In contrast, the transformative model conceptualizes pedagogical content knowledge as an original knowledge facet (e.g., References [4,20,33,34]). This approach goes back to the initial conceptualization by Shulman, where he argued that PCK should be regarded as a substantially new facet [5]. It also lays the foundation of most conceptualizations in current large-scale studies (e.g., References [4,20,26,27,29]). Based on the original description of Shulman, pedagogical content knowledge is often conceptualized with, at least, two sub-facets: knowledge about students' errors and knowledge about instructional strategies [10] (for an overview see References [24,25]), which both have to be operationalized more narrowly, depending on the specific domain and content area, as for example prototypical errors in mathematics, biology, or other domains naturally differ to a certain extent.

In contrast to both knowledge facets described above, pedagogical-psychological knowledge is conceptualized as domain-general and comprises multiple aspects with regard to general aspects of teaching. Initially, classroom management is mentioned as a key sub-facet of pedagogical-psychological knowledge [5], yet within the frameworks of TEDS-M, COACTIV, and ProwiN, three additional sub-facets were introduced: general knowledge about instructional methods, performance assessment, and individual learning processes [35–37].

Current approaches in educational sciences further conceptualize multiple knowledge qualities that underlie teachers' actions. These approaches describe constructs such as action-related competences [38] and professional vision [39–41]. Action-related competences include skills that lead to spontaneous actions in specific situations that are often performed under time pressure [38]. Professional vision can be described as the ability to apply knowledge in complex situations, by noticing relevant situations and reasoning about these situations [40,41]. Both constructs are based on professional knowledge and may be generally described as situation-specific skills, which influence acting [1]. Within this article, however, focus is laid on the integration of theoretical models for professional knowledge across two professional domains and does not include according approaches. However, these approaches are important to understand how professional knowledge underlies actions in complex professional situations.

2.2.2. Types of Professional Knowledge: Shulman's Model and Realization in Different Projects

Besides the content-based structure of professional knowledge described above [5], Shulman also proposed a cognitive structure of professional knowledge types, which he called "forms of knowledge" [10]. He distinguished between three forms of knowledge: *propositional knowledge*, *case knowledge*, and *strategic knowledge*. Propositional knowledge refers to knowledge about "principles, maxims, and norms" [10] (p. 11), whereas case knowledge refers to knowledge about practical experiences that build the foundation of how a teacher applies her propositional knowledge in typical situations and knowledge about sequences of events. The third form of knowledge, strategic knowledge, includes knowledge about what practice is used in a specific situation and why this practice is used. Several projects in the field of educational sciences, which are based on this differentiation, are described in the following.

Professional Competence of Teachers, Cognitively Activating Instruction, and Development of Students' Mathematical Literacy Project (COACTIV). COACTIV employed a model that describes mathematics teachers' professional knowledge and focuses solely on a content-related distinction of professional knowledge. Based on Shulman's taxonomy, CK, PCK, and PK were distinguished, as well as organizational knowledge and counseling knowledge [28,42]. Furthermore, these knowledge facets contained several sub-facets, for example, knowledge of representations and knowledge of student mathematical cognitions for PCK, which were further differentiated based on different mathematical content areas [42].

Mathematics Teaching in the 21st Century (MT21) and Learning to Teach Mathematics—Teacher Education and Development Study (TEDS-M). The model of teachers' professional knowledge in TEDS-M (and its precursor MT21) shows a pattern that is similar to Shulman, differentiating three content-related knowledge facets (CK, PCK, PK) on a first dimension and "cognitive sub-dimensions" on a second dimension [5,10]. Consequently, a two-dimensional model for mathematics teachers' professional knowledge was used [21,26]. The cognitive activities were formulated specifically in the context of mathematics and based on Anderson and Krathwohl's differentiation in declarative, procedural, and metacognitive knowledge types [13] and Polanyi's differentiation in "knowing that", "knowing how", and "knowing why" [43]. For CK and PCK, three cognitive sub-dimensions were used: *knowing*, which includes recalling and computing, *applying*, which includes representing and implementing, and *reasoning*, which includes analyzing and justifying [44]. For PK, similar cognitive sub-dimensions were used that only differ slightly in their terminology: *recall*, *understand/analyze*, and *generate* [45].

Professional Knowledge of Science Teachers (ProwiN). In the framework of ProwiN, the three content-related facets of professional knowledge CK, PCK, and PK were combined with three types of knowledge: *declarative knowledge*, *procedural knowledge*, and *conditional knowledge* [4]. This distinction was based on the descriptions of Anderson and Paris, Lipson, and Wixson [46,47]. Within ProwiN, declarative knowledge includes knowledge about terms, facts, and principles. It can be described as "knowing that". Procedural knowledge refers to the knowledge about (instructional) practices and processes. It is described as "knowing how". Conditional knowledge includes knowledge about conditions under which decisions and practices are appropriate and knowledge about reasons for performing specific practices. Therefore, it is described as "knowing when and why" [4]. Both procedural knowledge and conditional knowledge are described as specific for certain teaching situations [4] and were, thus, summarized as *strategic knowledge*, which is interpreted as an application-oriented knowledge [36].

Measuring the Professional Knowledge of Pre-service Mathematics and Science Teachers (KiL). A similar differentiation of content-related facets of professional knowledge was used in the KiL-project, that distinguished among the facets CK, PCK, and PK [27,48]. In mathematics, these facets were complemented by an additional facet of school-related content knowledge (SRCK). However, these knowledge facets were not differentiated based on their type. Similar to COACTIV, a differentiation of the knowledge facets based on contexts was made [49,50]. In science, each facet was additionally divided into several types of knowledge (in physics; [27]) or cognitive processes (in biology; [48]). Within physics, three types of knowledge have been used: *declarative knowledge*, *procedural knowledge*, and *schematic and strategic knowledge*. Similar to this, in biology, two knowledge types, which refer to two different cognitive processes *remember & retrieve* and *apply & understand*, have been differentiated [48]. Both processes were based on the description of Krathwohl [51]. Remember & retrieve includes retrieving "relevant knowledge from long-term memory into working memory" [48] (p. 294). In contrast, apply & understand refers to knowledge about "the meaning of instructional messages, including oral, written, and graphic communication" [48] (p. 294), as well as knowledge about carrying out a procedure [48].

2.3. Summary

In medical sciences, most frameworks for professional knowledge focus on separating different cognitive knowledge types such as conceptual and procedural knowledge (see Figure 1, upper part). However, a content-related distinction was only rarely considered. Only the MOT-model explicitly addresses different content-related knowledge facets such as biology or physiology. This distinction can be regarded as different domains of content knowledge comparable to sub-facets of CK in the field of educational sciences. So far, a distinction in CK, PCK, and PK as proposed by Shulman's model has not been used.

In contrast, most models for professional knowledge in educational sciences comprise a content-related distinction of multiple knowledge facets (CK, PCK, and PK) that is based on Shulman's initial taxonomy and in some cases further differentiated. Except for the model of the COACTIV study, these models for professional knowledge additionally comprise a distinction in different knowledge types, which are based on underlying cognitive processes, cognitive models, and the purposes of the specific knowledge types. However, despite a partial amount of overlap between the different knowledge types in all models, nomenclature and even conceptualization differs vastly between the different models (see Figure 1, lower part).

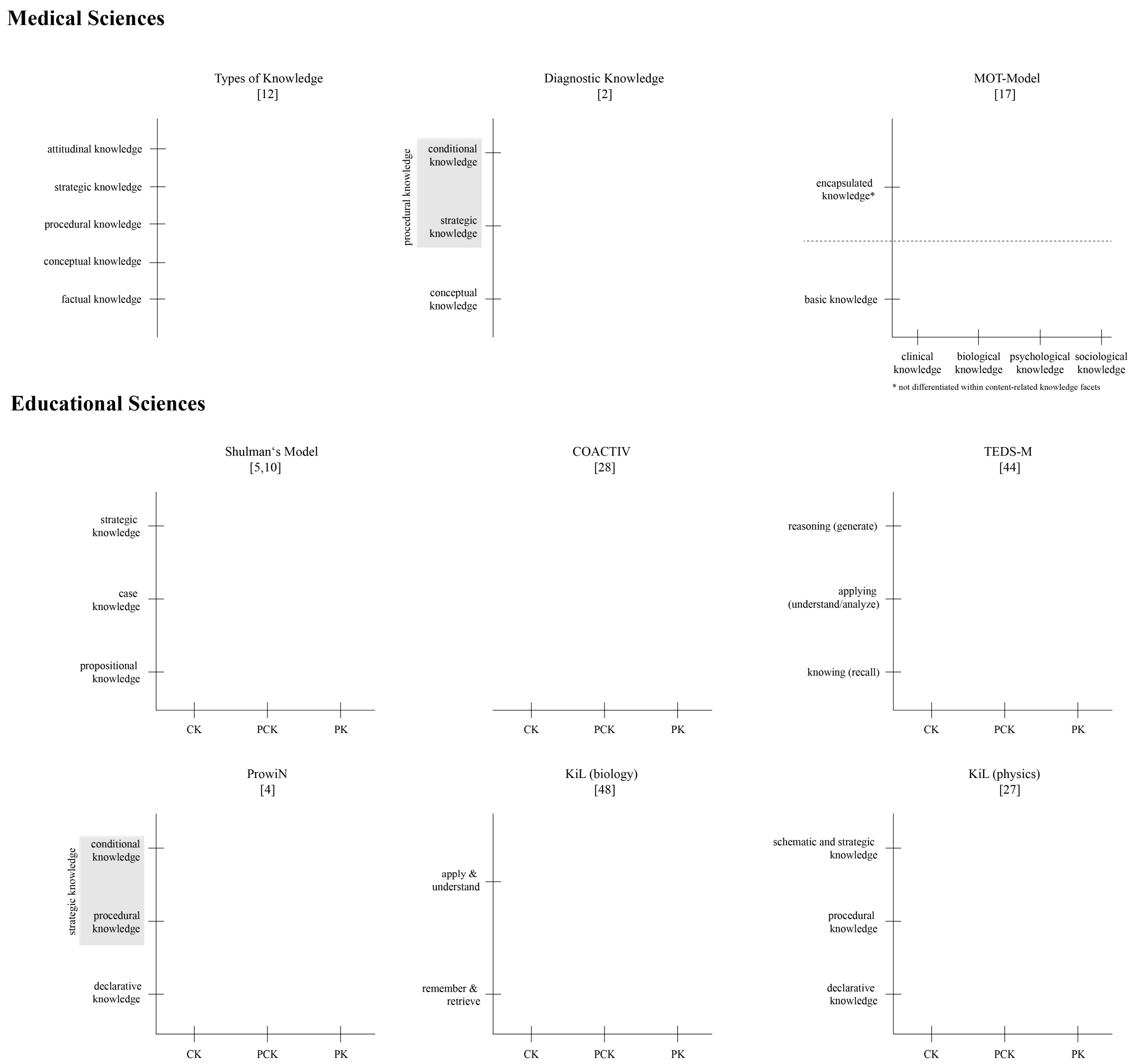

Figure 1. Models of professional knowledge in medical and educational sciences.

3. A Synthesis

The review of the models above highlights that there are substantial differences in the way different facets and types of professional knowledge are described within and across the two selected domains and that there is a considerable number of different terms that are currently being used. This is problematic, both for disciplinary and interdisciplinary research as it complicates the comparison of studies and results and by that, hinders the cumulative acquisition of knowledge.

In a comparative analysis, Hargreaves has already made a first attempt to describe a *generic model of professional knowledge* for medical doctors and teachers [52]. This model includes four different aspects: *Declarative knowledge* or "knowing that", *scientific knowledge* as a distinctive form of codified declarative knowledge, *procedural knowledge* or "knowing how", and *personal knowledge* that is built up based on experience and "seeks to integrate a professional knowledge-base and develop expert professional judgement" [52] (p. 233).

Although Hargreaves' model appears to include several important aspects, which are also included in most of the models above, the four aspects he mentions seem rather disparate and not coherently linked to state-of-the-art conceptions used in current research approaches. Whereas declarative and procedural knowledge appear to distinguish different *types* of knowledge, personal knowledge rather refers to how knowledge *developed* through expertise and relates in part to the quality of knowledge. Finally, scientific knowledge relates to the way knowledge is *created within a discipline*, but appears to be unconnected to a personal development or different types of knowledge. Therefore, as a further advancement, we propose to integrate current approaches in a new two-dimensional model that incorporates previous models and approaches being currently used.

3.1. Commonalities Between the Different Models Leading to a Two-dimensional Model

In this paper, a two-dimensional model of professional knowledge that introduces a coherent terminology for knowledge facets and types in two professional domains, namely medical doctors and teachers, is proposed and a framework that allows for further investigation of the role of professional knowledge for actions in these two domains.

First, professional knowledge can be distinguished into different content-related facets of knowledge (dimension 1). Whereas there is no widely accepted classifications for this in medicine, models for teacher's professional knowledge are mostly based on the classification proposed by Shulman [5,10], which is often focused on CK, PCK, and PK as the three most important content-related facets of knowledge.

Second, professional knowledge can be distinguished with regard to the type of knowledge (dimension 2). Models from both domains appear to agree that there is a type of knowledge that is related to facts and individual, rather decontextualized information. In contrast, there are also two more "action-related" types of knowledge, one focusing on how processes are carried out, the other focusing on when and why they are carried out.

Merging these insights into one model results in a two-dimensional structure representing the types of knowledge as one dimension and the different content-related knowledge facets as the other dimension (see Figure 2). Within the content-related differentiation, three facets of professional knowledge are distinguished: *content knowledge* (CK), *pedagogical content knowledge* (PCK), and *pedagogical-psychological knowledge* (PK). These have so far mainly been used in educational sciences (cf. Reference [4,21,26–28]). However, in medical education, these content-related facets can also be identified and distinguished, for example in the context of medical ward rounds (cf. Reference [53]; see example on medical ward round in the next section). CK comprises all domain-specific knowledge that is explicitly related to medical sciences, complemented by domain-specific knowledge that is related to medical sciences from referential sciences such as natural and life sciences or medical sociology. PCK in medicine can be understood as the content-specific knowledge that is necessary for sharing information and negotiating about the related consequences with patients, their relatives, and other collaborating health professionals. PK, in addition, covers domain-general knowledge, such as models of communication like participatory decision-making or behavioral change like coping and compliance that are important in various areas of medicine.

As regards the dimension type of knowledge, three types have emerged from the existing models: *knowing that* (KT), *knowing how* (KH), and *knowing when and why* (KW). These are mainly in line with models from medical sciences (e.g., Reference [2]) and recent two-dimensional models from educational sciences [4,21,44,48]. For the model proposed in this paper, there was a deliberate effort to refrain from using the terms declarative, procedural, strategic, and conditional knowledge, as these have differing meanings in several research fields. For example, in medical sciences and educational sciences, procedural knowledge is described as the knowledge about procedures, for example, how to manage the sequence of diagnostic tests for a patient or apply methods of patient education in medicine, how to solve a quadratic equation in mathematics, or how to use a model in instruction in biology. It, thus, only describes knowledge about how to execute specific actions [2,4] but is not directly connected to how well or easily this action can be performed. In contrast, in cognitive psychology, procedural knowledge is often associated with automatized knowledge that does not require working memory for its execution [54]. Further, Schmidmaier et al. used procedural knowledge as the umbrella term for strategic and conditional knowledge [2], whereas Tepner et al. used strategic knowledge as the umbrella term for procedural and conditional knowledge [4]. To avoid these kinds of misunderstanding, we instead used (a) knowing that (KT) referring to a network of facts, concepts, and principles, (b) knowing how (KH) referring to knowledge about actions, procedures, or manipulations, and (c) knowing when and why (KW) referring to knowledge about when and why to apply both other knowledge types (cf. Reference [47]). In some models from medical and educational sciences, the attempt was made to *summarize knowing how and knowing when and why* in the sense of *action-related knowledge* that is needed to successfully act in various situations. However, both strategic, as well as procedural knowledge, have been used as terms for this kind of knowledge [2,21,36].

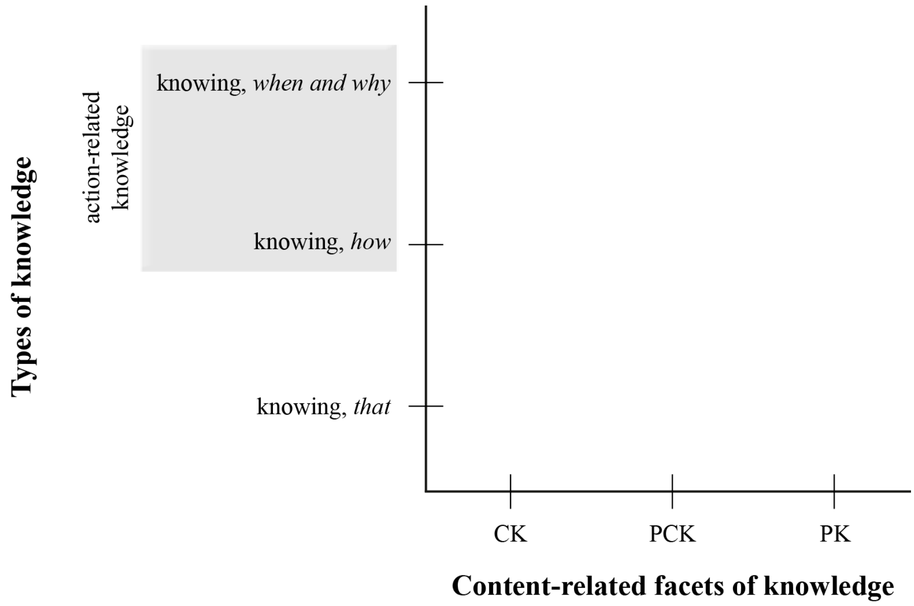

Figure 2. Two-dimensional model of professional knowledge.

Including and at the same time distinguishing both dimensions in the model does not only yield connectivity to prior research in medical and educational sciences but also affords the possibility for a more fine-grained differentiation and analysis of professional knowledge. Based on the two dimensions, the proposed model includes nine substantially different aspects of professional knowledge. These aspects can form the basis for empirical investigations within medical and educational sciences and allow comparability within interdisciplinary research. Of course, the general illustrating descriptions of the knowledge aspects (see Table 1) have to be adopted and operationalized specifically for each domain, to ensure a valid measurement that fits each domain's specific requirements. Examples of such a specific differentiation for the domains medicine, mathematics, and biology are described in the following section. Still, as the basic conceptualization of knowledge types and content-related facets of knowledge stays the same over different domains, this interdisciplinary two-dimensional model of professional knowledge allows systematic and comparable empirical investigations of different applications of knowledge in several professional situations.

Table 1. Interdisciplinary description of knowledge aspects underlying diagnostic competencies.

		Content-Related Facets of Knowledge		
		CK	**PCK**	**PK**
Types of knowledge	**knowing** *when and why*	Knowing, when and why subject-specific actions are executed. (KW-CK)	Knowing, when and why subject-specific instructional strategies are executed and knowing, when and why students' errors within a certain topic are dealt with (KW-PCK)	Knowing, when and why subject-independent instructional strategies and the diagnostic process are executed (KW-PK)
	knowing *how*	Knowing, how subject-specific actions are executed (KH-CK)	Knowing, how subject-specific instructional strategies are executed and knowing, how students' errors within a certain topic are dealt with (KH-PCK)	Knowing, how subject-independent instructional strategies and the diagnostic process are executed (KH-PK)
	knowing *that*	Knowledge about subject-specific terms, concepts, facts, and principles (KT-CK)	Knowledge about subject-specific instructional strategies and students' errors within a certain topic (KT-PCK)	Knowledge about subject-independent instructional strategies and the diagnostic process (KT-PK)

3.2. Domain-Specific Applications in the Context of Diagnosis

To illustrate the applicability and the domain-specific operationalization of the two-dimensional model laid out above, generic diagnostic settings from medical doctors as well as mathematics and biology teachers were examined as two distinct domains from teacher education. The diagnostic settings highlight that although models between medical and educational sciences have been differing so far, the proposed model allows a purposeful description of the knowledge facets needed in both areas. In particular, it shows the applicability of the three content-related CK, PK, and PCK facets, which have so far not been used in medical sciences.

3.2.1. Medicine: Diagnosing Collaboratively During an Interprofessional Medical Ward Round

The daily interprofessional ward round is the backbone of inpatient medical care and a key competence of each participating team member (cf. Reference [53]). Patients´ conditions are repeatedly assessed from all perspectives on a daily basis to decide on further diagnostic and therapeutic steps during the hospital stay. For example, the ward round team visits a patient with community-acquired pneumonia that is treated with antibiotics for three days. The team members know about the predictors for favorable and unfavorable outcomes of pneumonia in general and within their own profession (KT-CK). They also know about techniques and assessments that are needed to detect possible complications of pneumonia (e.g., low oxygen saturation, dull percussion of the chest) (KH-CK). Based on the interprofessional assessment, hypotheses that make further diagnostic or therapeutic actions necessary (e.g., computed tomography imaging of the chest or breathing therapy) (KW-CK) are raised and critically discussed. In the case of recurrent pneumonia in a patient with tobacco abuse, the team attributes smoking as a risk factor (KT-CK). All team members know about typical psychological phenomena in smokers like cognitive dissonance (KT-PCK) and about different evidence-based anti-smoking programs (KH-PCK). They can decide as a team about the necessity and the kind of counselling and education that is needed for the individual smoker (KH-PCK). The team is aware of the general six-stage model of coping with a disease (KT-PK). Before the different members of the team contact the patient, they recapitalize the principles of doctor/therapist/nurse-patient interaction (KH-PK) and are able to apply an adequate communication strategy within an individual contextual situation (KW-PK).

3.2.2. Mathematics: Diagnosing Individual Student's Misconceptions Regarding Decimal Fractions

A key activity of a teacher is to constantly diagnose and monitor each student's learning process. This may be done using written tests or by observing a student's progress in individual tasks during, in, or outside regular lessons. For example, to diagnose a student's misconceptions regarding decimal fractions (KT-PCK), the teacher may give the student particularly well-suited tasks (e.g., multiple decimal fraction comparison tasks) that allow to identify whether the student has some specific misconception, for example, that longer decimal fractions are greater (KT-PCK). The student is then diagnosed by repeatedly observing his solution process and constantly checking the correctness of the solution (KT-CK and KW-CK), the correct application of algebraic manipulations (KH-CK), and trying to match a student's errors with known student misconceptions (KT-PCK). In case of a misconception, the teacher may intervene, using his knowledge about when and why (KW-PCK) to apply certain strategies to counter common student misconceptions. For this, the teacher may contrast the student's solution process using the misconception (KH-PCK) and the mathematically correct way of solving the task (KH-CK). Keeping in mind that the teacher has more than one student and needs to watch over, support, and diagnose all or, at least, as many students as possible, the teacher has to apply his knowledge about different instructional and classroom-monitoring techniques (KT-PK) and purposefully use them (KH-PK and KW-PK) to keep the whole class on track and working so that he can focus on individual student's diagnosis in the meantime. Finally, the teacher will also continuously monitor students' motivation and react, before it would reach unintended levels.

3.2.3. Biology: Diagnosing the Situation within Whole Class Lesson Settings

During classroom interaction, teachers not only have to focus on single students but also have to monitor the situation within the whole class (cf. Reference [55]). In such a situation, a teacher is exposed to multiple stimuli. Generally, as a basis for effective learning, teachers have to ensure a productive learning environment. For example, teachers have to know indicators of good classroom management or a supportive learning climate (KT-PK). These have to be purposefully used in certain situations. For example, depending on different classroom disruptions, teachers have to apply different techniques (KH-PK) at the correct moment (KW-PK) to avoid these disruptions or decrease their impact on the class. Besides dealing with subject-independent instructional strategies, teachers of a specific domain have to teach their students specific content, such as components of the human skin, correctly (KT-CK) as well as methods of the domain, such as how to use a microscope (KH-CK and KW-CK). Additionally, teachers have to check the correctness of students' answers and procedures (KT-CK). To make such content accessible for students, several subject-specific instructional strategies are used during instruction. Therefore, teachers have to know instructional strategies like using experiments or a skin-model (KT-PCK) and teachers have to know how to implement these (KH-PCK) with a particular goal (KW-PCK). Furthermore, they require knowledge about common student misconceptions (KT-PCK). For example, during classroom discussion, teachers have to diagnose individual misconceptions based on students' errors (KT-CK and KT-PCK) and then apply specific strategies (KH-PCK) adapted to the specific misconception to ensure biology learning (KW-PCK).

4. Concluding Discussion and Outlook

The model brought forward as an interdisciplinary model for professional knowledge is based on prior research in multiple domains and can be purposefully applied in diagnostic situations in medicine, education, and possibly also in many other domains and settings, which will have to be further analyzed. The different knowledge facets and types of the model can help to distinguish different aspects of professional knowledge required in certain settings or for specific actions and may be a valuable scaffold to guide the future assessment of these. Moreover, the unified terminology can help researchers from both domains to compare research results, to pursue shared research endeavors, and to create shared knowledge, both in theoretical and empirical regards. Still, the shared terminology should not lead to the impression that knowledge in medical sciences and educational sciences are identical. It should rather be interpreted in such a way that the overall structure of professional knowledge in both domains can be regarded as similar, without making any claims about the specific description, operationalization, and assessment of these aspects in a narrower sense.

Based on this description, the model appears to be both suitable and effective and, therefore, profitable for future (interdisciplinary) research. Still, there are a couple of issues that can and should be discussed as well as be further researched in future.

4.1. Role of the Knowledge Facets for Competent Acting and Transferability Between Domains

The two-dimensional model provides nine different knowledge aspects. As knowledge is described as an important starting point for the development of competence (e.g., References [56,57]), questions arise such as, 'which knowledge aspects are needed to what extent for competent acting?'. First, this question is discussed based on current results from the area of educational sciences. Second, the possible transferability of these results to medical sciences is discussed and third, issues that are based on current research in medical sciences, which may be of interest for educational sciences, are highlighted.

Concerning the content-related distinction in CK, PCK, and PK, in educational sciences, there is already some consensus about the importance of all three knowledge facets. Studies have shown that these three knowledge facets can be measured separately (e.g., References [23,48,58,59]). Yet, results concerning the knowledge structure indicate that both teachers' CK and PK are correlated with their PCK, however, CK and PK are less correlated (e.g., References [48,60]). Additionally, empirical results further indicate that teachers require CK (e.g., Reference [61]), PCK (e.g., References [3,62]), as well as PK (e.g., Reference [63]) to successfully act in classrooms. However, it is currently unknown which of these facets are needed for specific professional actions. There are indications that PCK is a stronger direct predictor for the success of teachers' acting when compared to CK [61,62]. Additionally, it is assumed that CK may not be sufficient for effective teaching [64] but may be a prerequisite for developing PCK [59,61]. With regard to PK, it seems that these generic knowledge aspects are more strongly related to providing a positive learning atmosphere and classroom management and in the long-run prevent burn-out and emotional distress during a teacher's career [65–67].

In contrast, in medical sciences, a content-related distinction in CK, PCK, and PK has not been used before. The MOT-model made a first approach to distinguish professional knowledge based on content areas. However, this model only provides a finer sub-division of CK into different areas, whereas PCK and PK were not considered [17]. Generally, current studies in medical sciences solely focus on medical doctors' CK as a prerequisite for competent acting and diagnosing (e.g., References [2,14]). Therefore, it is still an open question for future empirical studies, if the model's three content-related facets can be measured separately in medical sciences. Research so far may lead to the impression that in medicine only CK is required for competent decision-making. However, situations that require PCK and PK to act competently can easily be described (see Section 3.2.1) based on interviews of experts in this field [53]. Still, even if these three facets could be defined and measured in medical sciences, how these facets compare with the three facets in educational sciences has to be discussed. In particular, their content-related meaning, definition, and operationalization need to be further investigated, compared, and critically reflected. Moreover, the possibility of transferring the results from educational sciences (with regard to the predictive power of different knowledge facets for successful instructional acting) to the domain of medical sciences has to be discussed. Finally, other content-related knowledge facets have been brought forward recently, for example, including technological-related facets such as technological pedagogical content knowledge (TPACK) [68] or more differentiated facets such as SRCK [49], whose importance in either domain is currently unclear. Accordingly, the strict trichotomy of CK, PCK, and PK will have to be discussed and then theoretically and empirically researched in both domains.

4.2. A Third Dimension: Links to Competence Development

Within medicine, diagnostic competencies are often defined as "the habitual and judicious use of communication, knowledge, technical skills, clinical reasoning, emotions, values, and reflections in daily practice for the benefit of the individual and community being served" [69] (p. 226). In educational sciences, however, competencies are often defined more abstractly as "the skills, knowledge, attitudes, and motivational variables that form the basis for mastery of specific [profession-related] situations" [3] (p. 807). Integrating both descriptions, the activity of diagnosing can be described as the goal-oriented collection and integration of information that is aimed at reducing uncertainty and making medical or educational decisions.

Recent conceptions of competence [70–72] and structural descriptions of competencies [1] highlight professional knowledge as a central starting point for the development of competence (see further References [56,57]). For example, in the context of diagnostic competencies, this may include knowledge about typical symptoms of a specific illness or about various student errors and misconceptions (see our examples of prototypical diagnostic settings). The professional knowledge described by the presented two-dimensional model can, thus, be regarded as a fundament for the development of professional competencies, for example, diagnostic competencies of medical doctors and teachers.

Still, how competencies actually develop out of knowledge, how these competencies develop over time, and what happens to the already existing and newly acquired knowledge over time are hitherto mostly unknown (e.g., References [73]). Additionally, as education within medical and educational sciences is often explicitly divided into different courses and areas, knowledge is mostly imparted separately. How, for example, pre-clinical knowledge of medical doctors or subject-classified knowledge of teacher students, which is acquired at the university, is integrated into a competence and how it changes over time is not clear. Therefore, a third dimension, which could be added to the two-dimensional model that describes the development of the proposed knowledge aspects over time, would be helpful to address this issue on the knowledge side. However, for this third dimension, it would be important to consider the specific knowledge acquirements of the different domains.

So far, different approaches to this issue have been taken. Within medical sciences, the term of *illness scripts* [74,75] is ubiquitous, and represents integrated models of illnesses that "encapsulate" different aspects of knowledge such as bio-medical knowledge, typical symptoms, or possible treatments [17]. These illness scripts are created, sophisticated, and differentiated over time and by experience. A similar and partially overlapping approach, which is currently discussed, has been taken by the script theory that goes back to the work of Schank [76]. It assumes the existence of specific scripts that are situation-specific memory structures that include specific enabling conditions, actions, as well as knowledge. Prototypical examples of such scripts are restaurant scripts that govern the behavior in restaurants or internal collaboration scripts [77] that structure the collaboration with others. Building on the ideas of Schank [76] and Kolodner [78], the concept of "episodic memory organization packages" (E-MOPs) has been introduced, which may be particularly well suited to address the development of professional knowledge and competence, as it explicitly includes and describes the effects of growing expertise on E-MOPs. Finally, also other schema-based theories (see Reference [79]) are currently used to describe the development of expertise and competence.

In summary, the two-dimensional model for professional knowledge is only the starting point for a more general *model for the structure and development of professional knowledge* that is able to describe the changes of medical doctors' and teachers' professional knowledge over time and with growing expertise.

4.3. Research Agenda

The constructs of professional knowledge and professional competence are ubiquitous in research and practice and apply to a multitude of domains, areas, and professions. As each of these differs, an identical, fine-grained description of professional knowledge and competence throughout these cannot be expected. Still, the fundamental categories and processes can be assumed to be similar over professions and domains, as the terms in the end describe analogous learning processes and aspects of professional knowledge. Thus, an overarching model and terminology, enriched by domain-specific operationalizations, may prove helpful to describe and compare knowledge across domains. It is, therefore, a challenge for research to find the suitable level of detailedness to describe these processes on an interdisciplinary basis, to understand the according processes, and to offer a shared framework for future research on professional knowledge and competencies. In this contribution, we presented an attempt to describe an interdisciplinary model of professional knowledge that appears to be suitable for medical doctors and teachers and is detailed enough for fine-grained analyses of the multiple different knowledge aspects. In the next step, the model can be used to categorize knowledge tests according to measured knowledge types and facets in various projects in educational and medical contexts.

Still, the proposed model is rather the starting point for a research agenda than a conclusion or outcome. It will be up to future research to empirically determine how the individual aspects of knowledge can be validly assessed, whether they can be empirically separated, and what their influence in different areas will be. The consideration of medical sciences that have not used the concepts of CK, PCK, and PK so far, reminds us that there is so far only emerging, limited evidence about their influence on acting in educational sciences and that an equivalent impact of all three facets is rather unlikely. Thus, the outcomes of according research may also be highly valuable for the future training of teachers. Equally important for the education and training of future professionals will be an empirically tested, thorough description of the development of (professional) competencies that allows for the understanding of the underlying mechanisms and the changes that may occur in the underlying professional knowledge.

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