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# Conceptualizing Computer Science Education Content Knowledge for the Classroom

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## ABSTRACT
Researchers have found that instructors' Pedagogical Content Knowledge (PCK) is a significant predictor of student achievement across a wide range of topic areas in the classroom. The study of PCK in the field of computer science (CS) is, however, still in its infancy. Therefore, we are developing a theoretical framework for PCK in CS that draws from the existing literature and is supported by actual evidence. To that end, we have created a classification scheme based on a body of literature spanning both broad-scope teaching and the study of education in specific fields. We have also contrasted the results of this method with those of a previous poll of educators regarding class planning. We are currently implementing the Critical Incident Technique to expert interviews and labeling all German teacher education courses with this categorization system.

**Keywords;** Educator Expertise, a Review of Related Literature, and Confirmation from the Field.

## 1. INTRODUCTION

Recent initiatives in a number of nations have sparked optimism that computer science (CS) will become a standard curriculum item in classrooms (for examples, see [39]). Nevertheless, much educational research is needed to bring this subject up to the level that mathematics, physics, foreign languages, and history have accomplished, building on many decades of teaching. This is true whether one considers computer science to be a "new" or "emerging" field. The issue of what variables influence a student's ability to learn is a central one in the field of education studies. Hattie [13] recently demonstrated that instructors' skills, expertise, and views are among the most important of these elements.

According to Shulman [36], a teacher's necessary knowledge includes both topic knowledge and educational knowledge, or what is commonly referred to as educational topic Knowledge. (PCK). Recent studies in subject-matter didactics have focused on the latter, particularly in fields like mathematics [21], physics [29], and computer science [30].

KUI (Competencies for Teaching Computer Science; translated by the writers) is a German cooperation initiative with the stated goal of determining what skillsets are necessary for effective CS education. KUI is developed at the Technische Universität München, the University of Paderborn (led by Nikolas Schaper, the project's supervisor, and Johannes Magenheim), and the University of Siegen (led by Sigrid Schubert). (Peter Hubwieser). The German Federal Ministry of Education and Research provides the funding for this project.

The purpose of this project is to create reliable competency models and valid tools for assessing teachers' abilities in three key areas: (1) subject matter content knowledge; (2) instructional content knowledge; and (3) non-cognitive skills and beliefs. The second area is the primary emphasis of this article.

Competencies, as described by Weinert [41], consist of a number of parts, one of which is a body of specialized knowledge. Therefore, since knowledge plays such an undeniably crucial part, our primary objective is to pinpoint the knowledge components of the appropriate instructional skills.

We are currently carrying out the following procedures in order to obtain the required PCK for CS education:

1. a review of the computer science school programs in Germany,
2. Critical Incident Technique [11] expert talks
3. model-based skill creation and
4. creation of new gauging tools.

We started by searching the webpages of all German colleges for teacher education programs that included the teaching topic Informatics (used herein interchangeably with computer science) and found 43 different programs.

In order to find teaching skills that would be handled as instructional objectives, a qualitative content analysis of those courses will be conducted using the approach suggested by Mayring [25]. various coders would produce various categorization systems if inductive coding were used, making it more challenging to merge them. That's why we chose to ground our research in a shared theoretical framework. The realization that it is not feasible to merely move one of the new conceptualizations of PCK (in general or for several other school courses) to computer science was reached after examining and contrasting a number of such conceptualizations. According to the particular perspective that instructors have on the learning process and from specific teaching components like tasks and tests, it was found that views of PCK for mathematics and physics were fundamentally very distinct from each other. However, the previously given PCK ideas for CS were limited to programming and thus unsuitable for our needs (see, for example, [30], [20]).



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Therefore, we chose to conduct a literature survey of the analyzed sources in addition to the most pertinent papers referenced by those, in order to identify PCK conceptualizations that could serve as building blocks for our desired classification scheme. We gathered a text collection from various sources (described in Section 3), such as pre-specialized but still "general" periodicals.

papers from the field of computer science and engineering, such as [10], [14], and more contemporary findings from other fields (mathematics, physics, biology, languages). After that, we applied Mayring's [24] suggested approach to conduct a qualitative content analysis "through the lens of CS" on this collection. This literature review yielded a two-dimensional categorization system (see section 4) that demonstrated significant similarities to but also divergences from the conceptualizations of other educational topics.

Please note that while we intended to create a categorization system that could be used as a baseline for the curricular labeling, we did not anticipate that this would be fully formed at the time. We were sure that the system would develop and become functional by the time the entire plan was finished because there would be several more actual working stages.

To obtain a first empirical confirmation, we contrasted the results of this approach with those of 11 conversations we had done with working teachers in 2010 to learn about their methods and techniques for class planning. Those conversations can be seen as preliminary proof of concept because we adhered carefully to the CIT's recommendations in conducting them. It came out that the knowledge components discussed by the educators in those conversations aligned closely with our understanding of PCK. In addition to this unexpected turn of events, contrary to our assumptions, while writing the

43 programs in teacher training, each of which was completed several days ahead of the due date for this paper, the initial system's top two tiers did not require any additional categories.

We were encouraged to share our model in its current, early form by these findings, which show that our system is quite comprehensive at least in terms of the existing instructional practice. In this article, we show the resulting categorization scheme from the literature survey and provide the first confirmation of the resulting idea of PCK by relating it to the findings from the teacher interviews conducted in 2010. Future papers will discuss the findings from the review of teacher preparation programs.

## 2. METHODOLOGY

Domain-specific competency models (and knowledge conceptualizations as components of those) can be derived using a variety of methods, including (1) inductive versus logical and (2) observational versus normative approaches, as described, for example, by Schaper [31]. But if you examine carefully, you'll notice that they have strong bilateral relationships. On the one hand, inductive derivations are intrinsically linked to empirical approaches because they must be performed using such techniques. Deductive methods would begin with preexisting conceptualizations that are based on theoretical models or assumptions, while normative approaches allude to postulations or concepts that are grounded in theory or pragmatism. The connection between theory and ethical approaches is thus made clear. (see [32]). The bottom line is that we can either take an empirical/inductive strategy or a normative/deductive one. Schaper contends that both options would have benefits and drawbacks. However, educational objectives need to be established in a normative manner to promote changes or evolutions, and a strictly observational method would represent only the "existing" practice. Competencies or knowledge components drawn normatively from first principles would be disconnected from real-world context. The best approach will likely combine elements from both of these schools of thought, such as using books to derive a working idea that can then be tested and refined using empirical-inductive techniques. This is the precise approach we are taking in our work. (see steps 1-4 in section 1 above).

### 2.1 Deductive Text Analysis

The inductive portion of the work began with the gathering of a library of periodicals that we've determined are pertinent to the topic at hand. Section 3 provides a thorough breakdown of the final text collection. Motivated by the following questions: (1) "Which PCK is needed to teach CS in schools successfully according to the state of research?" we conducted a qualitative content analysis. and (2) "What kinds of critical incidents would be most useful to present in expert interviews using the Critical Incident Technique?" (see step 2 in section 1).

Mayring [24] argues that condensing, explaining, and organizing are the primary methods of qualitative content analysis. To "summarize" means to reduce the amount of writing to its essentials. The term "explication" refers to the linking of supplementary readings with problematic sections in the main text. Finally, the goal of "structuring" is to develop an appropriate classification scheme. In [22], we present a concrete example of this approach in action. Using MaxQDA (www.maxqda.com), we created a classification scheme from the text data in this manner. included 377 distinct types. After this was done, we had in-depth conversations about those categories and introduced new, more abstract categories to further strengthen our system. We arrived at a two-dimensional system that mirrored the educational domains and planned crucial circumstances on the first dimension, and the important features of education on the second. (see section 4). From now on, we will refer to this classification scheme as the PCK model.



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## 2.2 Empirical Research

We conducted in-depth conversations with 11 veteran educators in July 2010 as part of a massive in-service training program and evaluated the data using a set of guidelines. About 150 educators routinely attended our classes, and from among them we chose discussion partners based on our collective assessment of their level of expertise and experience. All conversations were done in German, and the writers transcribed the ensuing groups and extracts. Heimann [15] and Uljens [40] suggested and explained the Berlin Model in English to serve as a framework for the conversations. This framework is a taxonomy of the critical features of instructional layout. It differentiates between (1) the circumstances under which learning can occur, (2) the four choice domains of learning (e.g., learning goals, learning targets, learning material, instruction and learning techniques, and media), and (3) the outcomes of a given learning scenario. Both the causes and effects can be broken down further into environmental and sociocultural categories. In [5], we detail how we've used this approach in faculty development.

Critical incidents, as defined by the Critical Incident Technique (CIT), are events or problems that prompt or require action on the part of the respondent [7], [9]. Interviews typically follow the following steps: (1) greeting the interviewee and explaining the method being used; (2) presenting a critical incident and asking the interviewee to describe how he or she attempted to solve it; and (3) conducting the interview by asking follow-up questions to ensure both parties have a thorough understanding of the issues at hand. (see [7], [22]). Our recommended first query for interviewees is an open one about preparing for computer science classes: "In a typical situation, how would you go about preparing for a CS class? What sorts of challenges might you run into? What kinds of solutions might you propose?"Interviewers should only provide a corresponding stimulus if teachers fail to bring up one or more of the Berlin Model's main categories, such as the following: the lesson's context, learning objectives, content, teaching methods, media, assessments, sources of information, and teacher collaboration.

The conversations were captured on the interviewees' smartphones. Eleven conversations ranging from 20 to 35 minutes were gathered in the end, with 4 female and 7 male educators participating. Two writers used qualitative content analysis [24] to record and inductively organize the conversations. The resulting taxonomy of categories mirrored the perspectives of the questioned educators on what was most important when organizing CS classes.

### Comparison of Results

We compared the 2010 survey data to our PCK model based on the literature to see if it adequately captured the decision-making in computer science education. To this end, we made an effort to integrate the interview-derived groups into the PCK model. We are fully cognizant of the fact that this in no way represents a scientific poll. However, we think the survey data is a good starting point for validating the categorization system we suggest for PCK in CS. Section 4 presents and discusses the findings in depth.

## THE TEXT CORPUS

Since the primary goal of our project KUI (described in Section 1) is the creation of German-language models and tools, we focused our search on papers written in German. We regret that many references to German periodicals were necessary and offer our apologies to our English-speaking users. However, in the interest of scholarly honesty, we must list here all papers that were reviewed.

We searched for potential conceptualizations that could be applicable to PCK as we worked to create a categorization system that would serve as a beginning point for writing the courses. We did this by compiling scholarly works from various disciplines:- overarching, cross-disciplinary frameworks for understanding PCK,

CS-specific PCK meanings and conceptualizations, - PCK definitions and conceptualizations for other topics,- requirements for training educators,- categorizations of CS education studies,Books and articles on computer science pedagogy.Our goal in doing so was to tackle the issue from a variety of angles.

## 3.1 Subject-independent Publications

We started at Shulman's famous proposals for definition and scope of *Pedagogical Content Knowledge* and *Curricular Knowledge* [36], [37]. Based on Shulmans proposal, Carlsen [6] rearranged the knowledge components in order to adapt it to the required knowledge of science teachers, dividing Shulmans
„curricular knowledge" in a subject specific and an interdisciplinary component.



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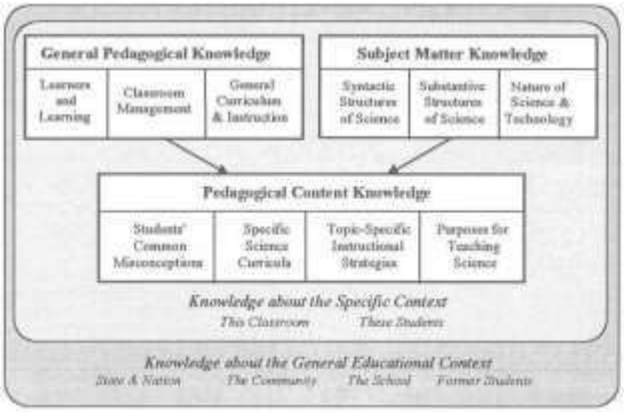


**Figure 1: Carlsen's domains of teacher knowledge [6]**

By this way, he was able to separate the three knowledge areas *Pedagogical Knowledge* (PK), *Subject Matter Knowledge* (SMK) und *Pedagogical Content Knowledge* (PCK). Starting from this

point, we focused on PCK, which was structured by Carlsen as follows: *Students' Common Misconceptions*, *Specific Science Curricula*,*Topic-Specific Instructional Strategies* and *Purposes for Teaching Science* (see figure 1).

Oser's [26] paper on PCK was a major resource for us in our joint attempt to find CS teaching skills. Terhart [38] created a second set of standards.

Like the individual states in the United States, Germany's 16 federal states control their own education funds and policies. In the Federal Republic of Germany, the Standing Conference of the Ministers for Education and Cultural Affairs of the Länder is in charge of coordinating federal legislation with the individual states. (KMK). The 2004 report from the working group this KMK created per Oser and Terhart's [35] recommendations was also included in our corpus.

## Other Subjects

Based on Shulman, the so called Michigan Group has proposed a subject specific knowledge framework for mathematics (see figure2).

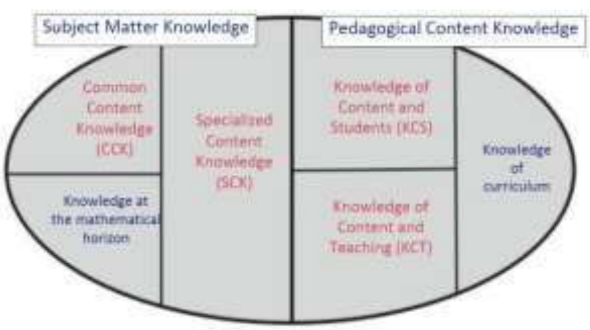


**Figure 2. "Mathematical Knowledge for Teaching" [2], [21].**

In Germany over the past decade, two major, high-quality studies, COACTIV and MT21, have looked into the impacts of the cognitive aspects of mathematics instructors on their instructional effectiveness. Each of these works has introduced a unique PCK framework (for examples, see [3], [4]). Finally, Lindmeier [21] gave a very thorough paper on PCK in mathematics. She has provided a neat little summary of current PCK knowledge in figure 2. Magnusson et al. [23] have given a detailed model for physics educators' PCK. In addition, Riese recently defended his thesis, which centered on PCK in physics [28]. The text collection now includes his theory (p. Schmelzing [33] has created a new classification system for biology; for more information, see [1]. In order to conduct a detailed study of English language instructors' PCK, Grossman (1989) has presented a series of queries on the topic of English language.

## Computer Science

As was stated above, we find the current status of PCK study for CS to be rather incipient. Nonetheless, there are a number of specific conceptualizations of teacher knowledge that could serve as a jumping-off point, such as those provided by Saeli [30] and Koppelman [20].



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In 2008, the KMK (refer to section 3.1) agreed on nationwide minimum requirements for teacher preparation programs across all 16 German states. The texts that make up Informatik (a field of study often translated as "computer science") were also included in our database. The

The Darmstadt Model, conceived of by a working group at the 2011 ACM ITiCSE meeting held in Darmstadt [17], was the next idea we incorporated. Since the initial query that prompted the development of these categories was "which factors are relevant for computer science education in schools?" we assumed that this finding would be applicable to instructors' subject-matter expertise as well.

Based on the model presented in [18], Diethelm et al. [8] have created a model for the pedagogical rebuilding of classes. Since this is such a crucial component of a teacher's job, we argue that those areas of expertise should be included in their professional content knowledge (PCK).

Since we believe that educators ought to be trained as scholars as well, we have sought out classifications of CSE studies. Two of them appeared to have potential for PCK. The first was Fincher and Petre's [10] collection of headings. Kinnunen [19] introduced the second, and Randolph et al. [27] later returned to it.

Finally, we compared and contrasted four of the most influential computer science texts in Germany: [14] (Israel), [16] (Germany), [34] (Germany), and [12] (Germany). (Switzerland). No new category was needed on the top two tiers because those volumes were already so extensive; this indicated that the category system was nearing saturation.

## 4. THE RESULTING MODEL OF PCK

An intensive discussion among the involved researchers and a subsequent process of aggregation led to a two-dimensional category system with 18 categories on the first level of the dimensions and a substantially lager number of subcategories on the lower levels, representing the deductive part of the work.

As stated in Section 2.1, we discovered that three of the top-level groups are perpendicular to the remaining fifteen. They appeared to be linked to the other 15 in some way, and on the one hand could be seen as educational processes that correlate to certain phases of a training process. We do this by conceptualizing the model as a matrix, with the three Fields of Pedagogical Operation (FPO; see Section 4.1) serving as the columns and the fifteen Aspects of Teaching and Learning (ATL; see Section 4.2) serving as the rows.

**Table 1. The two dimensional model of PCK (see 4.1. and 4.2)**

| | FPO 1 | FPO 2 | FPO 3 |
|---|---|---|---|
| ATL 1 | | | |
| ATL 2 | | | |
| … | … | … | … |
| ATL 15 | | | |

Future studies will examine the connections between the Pedagogical Operation Fields and the Teaching and Learning Aspects, and may identify knowledge components that are pertinent to both the column and the row. The first step in validating our model was comparing it to data from instructor interviews conducted in 2010 (see Section 2.3).

## THE EMPIRICAL RESULTS

In this section we will present the outcomes of the teacher interviews from 2010. The comparison with our literature-based PCK model (see section 4) will follow in section 6.

The interviews were coded by two of the authors who compared, discussed and matched their codings and categories straight after the interviews. This way, we developed the following category system that was based on 598 codings:

1) **Conditions**: preconditions, frame conditions

2) **Goals**

3) **Approach**: example driven, time planning, programming,writing outline, writing script, planning homework, identifying difficulties, by own mistakes



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4) **Sources**: textbook, curriculum, additional material, internet, teacher training, books/journals from subject-matter , colleagues, existing knowledge, material from own studies, pre-planned lessons
5) **Collaboration**: in school, with other departments, between schools
6) **Time planning**
7) **Methods and organizational arrangements**: individual learning, student activity, presentation, classroom teaching, teacher-class dialog, worksheet, entry in exercise book, project work, file, repetition, group work, differentiation, talkby students
8) **Media**: beamer, blackboard, moodle, computer, software, overhead projection, textbook, whiteboard, illustrations
9) **Problems**: technical difficulties, too much content, room, ensuring learning, standards, pre-requisite knowledge, official support, class size
10) **Assessment**: written, oral, project, not graded
11) **Evaluation**.

## 5. COMPARISON

Two people examined the coded text sections of the categories and attempted to use the 2010 version of the category system (see section 5) in the PCK model based on the literature. (see section 4). Surprisingly, we were able to incorporate all of the questioning system's divisions. This implies that our first PCK model, which was grounded in the academic literature, already handled all of the concerns raised by the educators.

You can see how frequently these overarching groups were brought up in the conversations by looking at table 4. It should be noted that the writers themselves transcribed the German quotes.

However, we also had to acknowledge that several of the theory model's top-level categories were not alluded to by the instructors, as the empirical model lacked equivalent categories. Only the item "Reacting on student demands during teaching processes" was absent from the FPO component. (FPO 2). This problem, which will arise primarily during the classes, was not addressed, which seemed quite fair given that we had inquired how the instructors would organize their lessons.

Extracurricular activities (ATL 5), science (ATL 6), and school improvement were not addressed at all on the second dimension. (ATL 14). Teachers' potential ignorance of students' participation in recreational activities during the interview is reasonable, given that such activities may not fall within the scope of their regular lesson plans. Nonetheless, there are times when it's beneficial for educators to make reference to recreational activities, such as when prepping students for extensive software projects with a visit to the industry or when urging talented students to compete in events like the International Olympiad in Informatics. Despite the obvious relevance of science findings and techniques to the classroom, many educators appear to be missing the point. Therefore, as proposed for instance by Hazzan et al. [14], this should be the primary focus of teacher training. In our nation, education improvement is left to the most experienced educators. Therefore, it's possible that not all educators consistently keep this in mind. However, this is an extremely important consideration for CS educators in especially. Ultimately, for significant educational reform, our field needs to advance and gain prominence.

It seems that all of the questioned instructors should have discussed a number of components of the PCK paradigm. The interrogator is obligated to press for an answer on this point in accordance with the rules of the discussions. All Berlin Model-related groups (and their respective subsets) fell into this category, as did Information sources (media), and Collaboration. Therefore, we could infer that all educators would have referenced the aforementioned groups, whether explicitly or tangentially. Heterogeneity in the context of subject-specific learning (ATL 11, addressed via Students' preconditions), which was absent from 5 interviews despite being explicitly stimulated, and Objectives of lessons (ATL 4), which was absent from 1 interview. It's likely that educators' limited grasp of the aforementioned groups contributed to these findings. The trigger did not elicit a response that could be used for encoding. Again, this could be interpreted as a call for more training in those areas for educators. However, in terms of the cues, we need not presuppose that any given educator will bring up the other groups. Table 5 shows the non-stimulated areas that were still discussed.

**Table 5. Addressed categories that were not stimulated**



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| *Cat. No.* | *Category* | *Coded interviews* |
|---|---|---|
| ATL 12 | Student cognition | 11 |
| ATL 9 | Specific teaching elements | 10 |
| ATL 3 | Curricula and standards | 9 |
| ATL 8 | Subject-specific teaching concepts | 5 |
| ATL 15 | Educational system | 4 |
| ATL 2 | Subject | 1 |

This shows that the teachers were well aware of the importance ofstudent cognition and specific teaching elements, fortunately.

## 6. CONCLUSION AND FUTURE WORK

We have categorized 43 CS teacher education courses in use across the 16 German states to better understand which skills might correlate to the defined knowledge components and to further expand and verify our categorization system. The initial findings show that these don't deal with any gaps in information that our hypothetically derived model would be unable to accommodate. We are currently trying to fill in the columns of table 1 by assessing the connections between the components on our PCK model's two dimensions.

To further develop, investigate, refine, and verify our categorization system and to determine the skills that correlate to our knowledge components, we are planning a second set of interviews, among specialists (teacher educators, teacher trainers, and managers). Once again, we'll use the Critical Incident Technique (CIT) [7], [9].

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