Typifying Informatics Teachers' PCK of Designing Digital Artefacts in Dutch Upper Secondary Education

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Abstract. This paper reports on the results of the first phase of an ongoing research project in design-oriented education in informatics in Dutch upper secondary education. Our study focused on eliciting and categorizing the pedagogical content knowledge (PCK) with respect to design of digital artefacts of the informatics teachers participating in the research project. Our results suggest that teachers' PCK on design can be typified in terms of two aspects, namely (i) teachers' knowledge about objectives and goals of designing digital artefacts by students, and (ii) teachers' knowledge about ways to assess students' understanding and performance. As to (i), we distinguish an orientation towards more conceptual objectives, and one towards more practical objectives. Also with respect to (ii), we found two types of teachers' knowledge, one focused on process-based assessment and another on product-based assessment.

Keywords: Pedagogical content knowledge · Informatics education · Design education · Secondary education

1 Introduction

Design-oriented education is a well-established instructional approach to teaching informatics in secondary education in the Netherlands. As a general approach, informatics teachers define and follow different sorts of individual or group-based projects for designing and developing digital artefacts in different forms including software applications, algorithms, web sites, games, videos, podcasts, etc. [4,18]. These design projects are meant to act as a vehicle for learning, by providing opportunities for application, making errors, iteration, testing, revising and refining of newly developing conceptions and solutions, reflection, communication, representation, decision making and collaboration [13].

Design-oriented education in informatics has several theoretical and practical underpinnings. From the theoretical perspective, the learning implications

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and advantages of designing has been widely recognized. Design activities and challenges might lead to the creation and establishment of a participatory and collaborative learning environment around the under construction projects [2]. Through the lens of the constructionist learning theory [17], these "participatory learning environments support learners" building of understanding through the collaborative construction of an artefact and sharable product' [2] (p. 77). It is also known that design education can contribute to the understanding of scientific concepts [13], but this side of design education is hardly exploited. From a practical perspective, the learning-by-making strategy is consistent with the epistemological view of informatics as an engineering discipline [6].

This study is a part of a three-year research project called *Formative assessment of conceptual development in design education* in the context of Dutch secondary education. This project has been inspired by the new chemistry and informatics curricula in secondary education in the Netherlands [1,5] both stressing conceptual learning and design. In this project teachers and researchers from informatics and chemistry participate and collaborate in a joint research. The rationale behind combining informatics and chemistry is to support cross-fertilization of the design-based and conceptual learning approaches which seem to form the core educational activities in these subjects, respectively. The participants in the project include four researchers from Radboud University (responsible for the informatics part) and Delft University of Technology (responsible for the chemistry part), and a consortium of 12 schools/teachers (6 teachers for each part). The main purpose of this joint project is to develop appropriate assessment instruments to monitor the conceptual development of students during design activities, and to investigate the teacher knowledge required to implement design education for conceptual learning. To this end, during this project design-oriented teaching and test materials for authentic design scenarios in both chemistry and informatics will be developed and tested. The development process of these materials is combined with an investigation of the development of the teachers' PCK on the concepts to be learned and the PCK on designing digital artefacts (hereafter referred to as PCK on design).

As the first step in this joint project, we captured, described and typified the informatics teachers' PCK on design. We will use the results of this study to construct an analytical framework meant to scrutinize the design practices of the participants in the next phases of the project. Also, the results will direct the required professional development plans for the participants.

2 Pedagogical Content Knowledge (PCK)

The PCK concept has been introduced by Shulman [21] and refers to "the ways of representing and formulating the subject that make it comprehensible to others" (p. 9). A critical feature of teachers' PCK is their strategic knowledge or 'pedagogical know-how'. This strategic knowledge describes the processes that teachers follow and employ in response to the challenges of teaching specific subjects to particular learners in specific settings [22]. From a socio-cultural perspective, PCK embodies a type of teachers' professional knowledge focusing on effective and flexible transformation of subject-matter knowledge in the communication process between teachers and learners during classroom practices. PCK is integrally and inherently situated in the everyday practices of teachers and not only residing in individuals but also is distributed in their surrounding environment including books, tools, and their communities [8,10].

Capturing PCK from teachers is a difficult and challenging task. One reason for this stems from the complex nature of PCK and ways it develops. Indeed, PCK represents a personal and often tacit knowledge seldom explicitly shared between teachers [3,15] and developed and shaped after years of experience in teaching a topic [21]. The development of PCK proceeds through a non-linear, iterative and constructive process where new information is integrated with prior experiences, knowledge and beliefs captured from various domains, practices, and interactions [10].

Several models and instruments have been proposed for investigating teachers' PCK of a specific topic including: the PCK model of Magnusson et al. [16], the Content Representation (CoRe) instrument [14], the reformulation of PCK by Grossman [9], and the teacher professional knowledge and skill model [7]. Following [16], we consider four elements of teacher's PCK on a given topic: knowledge about learning goals and objectives connected to the topic (M1), knowledge about students' understanding (M2), knowledge about instructional strategies (M3), and knowledge about ways to assess students' understanding of the specific topic (M4). The Content Representation (CoRe) instrument [14] captures the key ideas connected to a specific topic, and elicits the teachers' knowledge about each idea through 8 questions. These questions cover the above four aspects of PCK. Grossman's reformulation of PCK relates it to these key questions: why to teach a specific topic? what to teach? learning difficulties associated to the topic? and how to teach the topic? The teacher professional knowledge and skill model [7] introduces amplifiers and filters to the PCK model as influential factors in amplifying or filtering teacher's learning and practice. Teacher beliefs, orientation, prior knowledge or experience, and contextual variables might serve as amplifier or filter for teacher's learning [7].

Traditionally, the PCK concept has been introduced and investigated mainly by scholars and practitioners in the context of science education. Using PCK for eliciting and portraying teachers' knowledge in computer science is an upcoming approach (e.g., [3,11,19,20]). The results of these few studies emphasize the fruitfulness of the PCK approach to investigate professional knowledge of informatics teachers [3]. In this study we aim to use the PCK concept to investigate the nature of knowledge the informatics teachers hold and utilize to support their students in their design projects. Although, the focus of the PCK concept is on capturing teachers' pedagogical knowledge in a specific topic, however, we argue that the nature of design-supporting knowledge held by teachers is a practical knowledge in a specific domain and can be captured using the PCK approach.

3 The Study Setting

The participants of this study were a group of six enthusiastic and experienced informatics teachers participating in the informatics part of the "formative assessment in design education" project. Table 1 gives the relevant information about the participants.

Table 1. The informatics teachers participating in the research

Teacher	Gender (age)	Education	Teaching (subject: duration) and other relevant experience
1	F (44)	Informatics (MSc), physics (BA)	Informatics: 8 years, Software engineer
2	M (62)	Informatics (BA), primary education (BA)	Informatics: 12 years, Dutch language: 20 years
3	M (48)	Informatics (MSc)	CS and mathematics: 20 years, university lecturer
4	M (59)	Language	Language (Dutch, English): 18 years, Informatics: 18 years, Developing help files for companies, chess player
5	M (60)	Sport	Sport, math, economics: 18 years, Informatics: 16 years, Network building experience
6	F (56)	Language	Language, Informatics

Two below research questions directed this study:

Q1: How can informatics teachers' PCK on design be described?
Q2: Which parameters could be used to categorize informatics teachers' PCK on design?

Due to the exploratory nature of this study, we chose qualitative research methods for data collection and analysis. Given its in-depth and exploratory approach, we selected the interview as the main method to collect data (cf. [10,15]). We used the four constituting elements of PCK (i.e., M1, M2, M3, M4) [16] together with a combination of CoRe questions [14] and Grossman's [9] questions to construct a set of interview questions to elicit teachers' PCK on design, see Table 2.

Six individual semi-structured interviews were conducted with the participants. Five of the interviews were conducted in the participants' schools and one interview took place at Radboud University. Each interview lasted about two hours. All interviews were recorded using a voice recorder for further analysis. The collected data then were analyzed by the research team. The analysis procedure included transcribing audio data verbatim, coding data, reading the

Table 2. The interview questions for eliciting informatics teachers' PCK on design

PCK elements ([16])	*Questions about CS design projects (adapted from [14] and [9])*
M1. Knowledge of goals and objectives	1. Why do you ask your students to do software projects in your CS courses?
	2. What do you like/not like about software development projects by your students?
M2. Knowledge of students' understanding and practices	3. What sorts of skills do students need to acquire in order to be able to develop software?
	4. What are the learning difficulties/problems concerned with the software development projects in your classrooms?
	5. What do students actually learn from their software development projects?
M3. Knowledge about instructional strategies	6. What to teach students to achieve the project development objectives?
	7. How to teach students to achieve the project development objectives?
	8. What are the teaching difficulties/problems concerned with the software development projects in your classrooms?
	9. What technological tools do you use in your classrooms?
M4. Knowledge about ways to assess students' understanding	10. How do you assess your students' learning and achievement during their project development experiences?

transcripts organized by codes, writing memos, recoding and merging similar codes as necessary, grouping codes into categories, reviewing and confirming codes by all the research members, and writing up conclusions.

We used the teacher professional knowledge and skill model [7] in addition to the four PCK elements [16] as the analytical framework for coding the data and investigation the relationship between the emerged codes. Furthermore, to code the technology knowledge of the participants we borrowed some codes from the Technological Pedagogical and Content Knowledge (TPACK) model [12].

4 Results

In this section we use the processed data to answer the first research question and describe the informatics teachers' PCK on design and its amplifiers and filters.

Knowledge About Goals and Objectives (M1). We concluded that the informatics teachers' knowledge about objectives of design contains 10 objectives that can be divided into three main categories:

(i) *Conceptual objectives:* this category of objectives emphasize the importance of developing digital artefacts as a means for learning and understanding computer science (CS) concepts. The identified conceptual objectives for design projects include: *learning CS concepts*, *realizing students' knowledge gap*, *acquiring programming knowledge and skills*, and *incorporating theory and practice* (emphasized mainly by the teachers 1, 2, 3, 4).

(ii) *Motivational objectives*: this category emphasizes the 'fun' and motivational aspects of design practices to trigger students' learning and engagement. This category consists of three objectives, namely: *recognizing and addressing students' differentiation*, *motivation and preparing students for ICT-based jobs and subjects*, and *making a workable product (mainly for real customers) as a means for making students learning tangible and also touch their feeling of accomplishment, ownership, and sharing* (asserted by all participants).

(iii) *Practical objectives:* the focus of this category is mainly on the practical benefits and advantages of developing digital artefacts. It involves three objectives: *acquiring soft and design skills* (i.e. problem solving, communication, collaboration, design thinking, etc.); *experiencing real world problems, challenges, and way of thinking*; *becoming an independent learner*; and *learning about the latest ICT developments and trends* (emphasized mainly by the teachers 4, 5, 6).

Knowledge About Students' Understanding and Performance (M2). We divided teachers' knowledge about students' understanding and practice that influences teacher's instruction into eight categories as follows:

(i) *Students' faced problems:* according to the interviewees, students experience different sorts of problems during their design practices, including: group issues (i.e., free riding, peer assessment), technical problems, orientation/planning problems, difficulty in finding real case projects, superficial/ shallow learning mainly due to following a non-reflective approach to designing by students, difficulty in understanding the semantic of a problem, inability to transfer their theoretical knowledge into action to solve real problems (i.e. inability to breakdown a problem and using CS concepts such as loop to solve it or difficulty in generating appropriate algorithms). Addressing these problems significantly shape and influence the participants' instruction.

(ii) *Development of students' soft and design skills:*referring to teacher's knowledge and understanding of the level and development of soft and design skills in students.

> *"In a game making project, my students experienced several problems about social skills and customer relationship. Accordingly, I decided to*

change my plan for projects to define two extra roles in our project, being: manager (undertaken by the teacher) and customer to help students to learn appropriate social skills by observing the manager (teacher) communication by the customers" (Teacher 3).

(iii) *Students' learning process:* representing teachers' knowledge of the specifications of students' learning process including their learning and design goals, planning, activities, intermediate products, faced problems, taken solutions, revisions, etc. (remarked by the teachers 2, 3, 4). To capture this type of knowledge (M4), the participants use different approaches such as tracing and analyzing students' log book Teacher 4), observing students' practices, or using SCRUM methodology (Teacher 2).

(iv) *Students' understanding of their projects' structure:* referring to the teachers' knowledge about students' understanding of their projects' purposes, structure, content, and concepts underpinning their products.

(v) *Development of students' conceptual understanding:* meaning teachers' knowledge and awareness on students' conceptual knowledge and knowledge gaps. This type of M2 knowledge has an inviable position in shaping and influencing participants' instructional activities (M3), as expressed by one of the teachers:

"After analyzing their log files, I realized many students cannot calculate the average of a list of numbers in SQL. Thus, I decided to adjust my teaching materials and teach lessons about AVG and other mathematical functions in SQL" (Teacher 2).

(vi) *Students' reaction and perception:* entailing teachers' knowledge and awareness of students' reaction on and perception of design projects. The influence of this understanding on teachers' instruction (M3) is shown below:

"As an educational system you have to compete with other systems that make learning fun for children. The social components of classrooms are the most competitive advantage and favourite part of the school activities for students. We should invest on these social components to make schools fun and meaningful for students" (Teacher 5).

(vii) *Students' preferences and orientation:* referring to teachers' knowledge of students learning preferences and orientations. Capturing this type of knowledge is essential for recognizing and addressing differentiation between students (M3) as a educational principle promoted by many schools:

"When I started introducing and using Appinventor in my course, there were a lot of students who liked to be hacker and know about cyber security. Accordingly, we made some different modules where they could choose what they liked to learn" (Teacher 5).

(viii) *Students' level of performance in their projects:* referring to teachers' knowledge about the activeness of students in their group projects. Teachers use this type of knowledge to grade, trigger and encourage students to actively participate in their group projects. The participants mentioned different approaches to achieve this knowledge ranging from direct observation of students working (the teachers 1, 2, 4, 5, 6) to asking students themselves to rank their peers' level of performance and activeness (Teacher 3).

Knowledge About Instructional Strategies (M3). We identified and divided the teachers' knowledge about instructional strategies associated with conducting design projects into 8 categories as described below:

(i) *Project development and management:* referring to teachers' knowledge about shaping the students' activities according to the respective phases of software development, and teachers' skill and ability to manage and scaffold students to construct their projects and achieve their project's objectives.
(ii) *Linking conceptual content:* meaning teachers' knowledge and skills to evaluate, develop and update content required by individual students for developing their projects.
(iii) *Digital resources:* implying teachers' knowledge and ability to use technology to provide new ways of teaching CS concepts. For example, Teacher 1 uses the `code.org` service to teach complex CS and programming concepts through providing simple examples.
(iv) *Digital tools:* referring to teachers' knowledge about the affordances and constraints of technology as an enabler of different teaching approaches, that is, technology enhanced learning. For example, Teacher 4 uses the *itslearning* learning management system to log, monitor and trace the learning process of students.
(v) *Stimulating student-centric, flexible, differentiated and collaborative learning:* referring to teachers' knowledge and ability to implement and support student-centric, differentiated and collaborative learning scenarios. This sort of knowledge is embodied in different instructional activities of the participants including involving students in choosing their project subjects, implementing peer review activities, asking and encouraging students to participate in generating teaching materials and even defining final exams' questions (Teacher 5), supporting flexible learning by providing students with learning choices and allowing them what, when, where and how to learn (the teachers 1, 4), promoting differentiated learning through teaching various content and providing separate assignments for different students (Teacher 1), encouraging students to reflect on the structure of their projects and their individual and group performance (the teachers 2, 3, 6).
(vi) *SCRUM-based project development:* referring to teachers' knowledge and ability to implement SCRUM methodology in their classrooms (Teacher 2).
(vii) *Customer-students relationship management:* referring to teachers' knowledge about the management of relationship between customers and developers of projects.
(viii) *Drama:* referring to teachers' knowledge and ability to implement drama in their classrooms to ease teaching CS concepts (Teacher 3).

Knowledge About Ways to Assess Students' Learning and Performance (M4). We described teachers' knowledge about ways to assess students' understanding and performance using these codes: *final and intermediate design products*, *presentations*, *tests* (traditional or automated tests), *short quizzes*, *daily check questions*, *assignments*, *customers' feedback on developed products*, *peer assessment*, *students' reports*, *students' log book*, *teacher's observation*, *discussion*. Among these assessment tools, customer's feedback represents a new approach being used by the teachers 2, 3, 4, 5. Diverse approaches have been followed by these teachers to choose projects' customers, including: defining real customers (by the teachers 2 and 4), defining another teacher to play the role of customer (Teacher 3), and playing the role of customer by teacher himself (Teacher 5). Interestingly, while four teachers see significant learning benefits in customer's feedback, Teacher 6 does not follow this approach as she believes finding appropriate customers with realistic expectations consistent with students' knowledge and level of expertise is difficult.

5 Elaboration

In this section we elaborate on the aforementioned results to find parameters that can be used to categorize informatics teachers' PCK on design. Two highlights of informatics teachers' PCK on design can be inferred from the results. First, with regard to teachers' knowledge about objectives and goals of design, a diverse set of objectives have been identified that direct the design-based instruction of the participants. These objectives form a continuum, shown in Fig. 1, consisting of 10 objectives ranging from more conceptual objectives on one side to more practical objectives on the other side.

One reason for this diversity in objectives stems from the flexible, less structured and teacher-dependent characteristics of informatics education in the

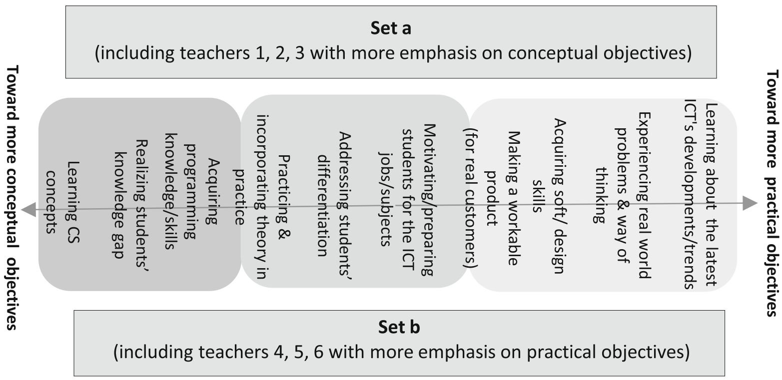

Fig. 1. The continuum of teachers' knowledge of objectives and goals of design projects

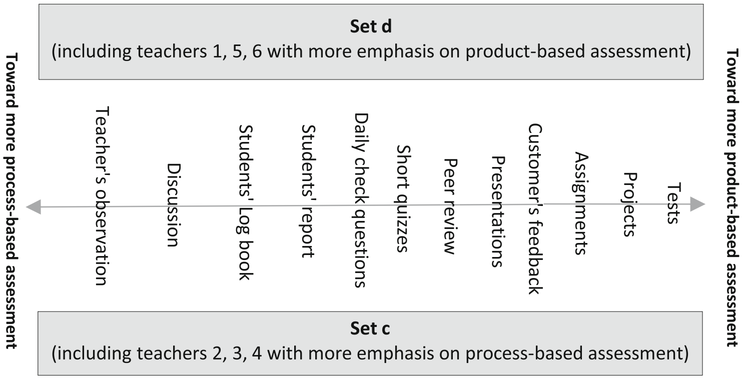

Fig. 2. Ways used by participants to assess students' understanding and performance

Netherlands. This categorization has led to the emergence of two sets of teachers, namely a set **a** consisting of the teachers 1, 2, 3 with more emphasis on conceptual objectives, and a set **b** of the teachers 4, 5, 6 with more emphasis on practical objectives. Interestingly, as described in Table 1, the teachers in set **a** have an informatics related educational background, while the teachers in set **b** have a non-informatics related educational background. This relation resembles the observations by Barendsen et al. concerning the perceived learning objectives of programming between teachers with informatics-related education and other teachers [3].

The second highlight of the teachers' PCK on design concerns the teachers' knowledge of ways to assess students' understanding and performance. As described earlier, the participants have knowledge about diverse ways to assess their students' learning and performance. These ways form a continuum ranging from more process-based assessment (i.e. observation and discussion) on one end to more product-based assessment (i.e. final products, assignments, tests) on the other end, as shown in Fig. 2.

Two sets of teachers can be discerned on the basis of this continuum: set **c** involving the teachers 2, 3, 4 with more emphasis on process-based assessment, and set **d** consisting of the teachers 1, 5, 6 with more emphasis on product-based assessment.

Based on these two PCK elements, we can typify teachers' PCK on design. Combining the elements M1 and M4 results in the identification of four types of informatics teachers' PCK, as shown in Fig. 3, namely: conceptual-product-based PCK (mainly held by Teacher 1), conceptual-process-based PCK (mainly held by the teachers 2 and 3), practical-product-based PCK (mainly held by the teachers 5 and 6), and practical-process-based PCK (mainly held by Teacher 4). These four types of teachers' PCK can be understood as representing teachers' individual orientation toward design-based education in informatics that support or shape their design-based instruction:

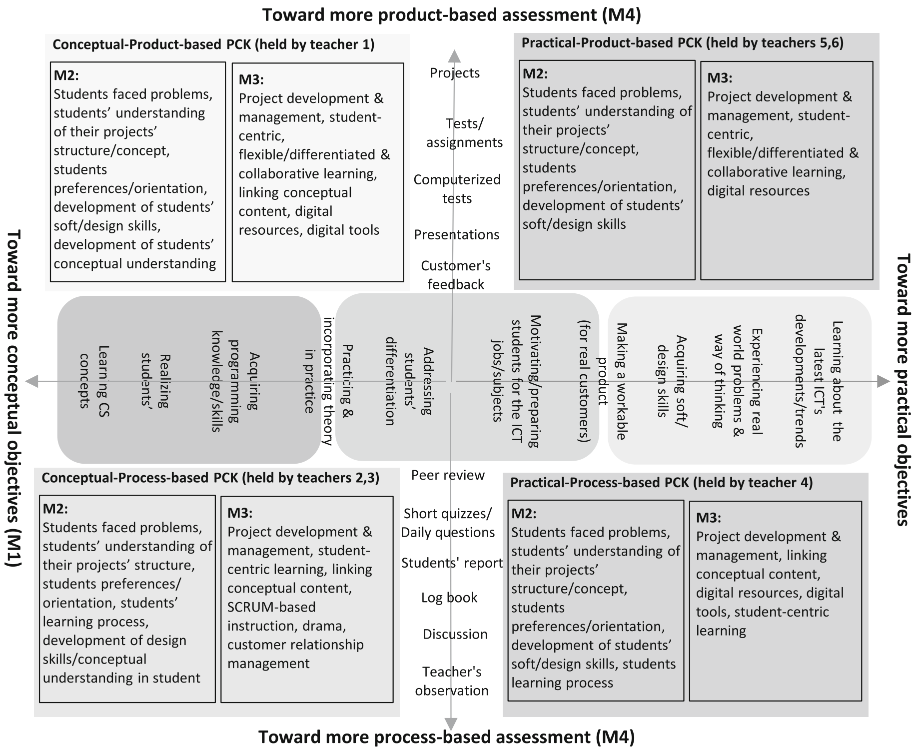

Fig. 3. A model to categorize informatics teachers' PCK on design

- *Conceptual-product-based PCK* represents teacher's orientation toward: recognizing and fulfilling more conceptual objectives for design projects (element M1) and understanding students' development of conceptual learning (M2) through product-based assessment approaches (M4) and linking conceptual content, digital resources, and digital tools (M3).
- *Conceptual-process-based PCK* refers to teacher's emphasis on: addressing more conceptual objectives (M1) and understanding students' development of conceptual learning (M2) through mainly process-based assessment approaches (M4) and SCRUM-based or drama instructional strategies (M3).
- *Practical-product-based PCK* represents teacher's orientation toward: fulfilling more practical objectives (M1) and understanding students' development of soft and design skills (M2) through mainly product-based assessment approaches (M4) and rich knowledge of digital resources (M3).
- *Practical-process-based PCK* refers to teacher's emphasis on: addressing more practical objectives (M1) and understanding students' development of soft and design skills (M2) through mainly process-based assessment approaches (M4) and rich knowledge about digital resources and digital tools (M3).

6 Conclusion and Discussion

In this paper we elicited and typified the PCK on design of six informatics teachers in the context of upper secondary school in the Netherlands. The results suggest that two distinguishing aspects of teachers' PCK can be used to typify informatics teachers' PCK on design, namely, their knowledge of objectives and ways of assessment. By combining these two elements, a model has been identified with four types of informatics teachers' PCK on design. This model represents teachers' orientations toward design that support or direct their design-based instruction in the classroom.

The model could serve to provide insight on knowledge patterns, themes, differences, and similarities among the informatics teachers with regard to their design-based instruction. The provided insight has a multi-folded functionality. First, it might inform the required professional development plans for the participating teachers. Moreover, the typified knowledge might be used as an analytical and planning framework to analyse, scrutinize, and prescribe the design practices of the teachers. Finally, we expect the results to provide us with good practices and evidence of empirical and contextualized design principles, leading to a model needed to direct the development of the course and test materials in our joint project.

The small number of participants can be seen as a limitation of the study. However, the diversity among our teachers with respect to the PCK elements M1 and M4 appears to resemble the variation in the practice of Dutch informatics teachers found in a wider study with 178 informatics teachers covering 59 percent of the population of informatics teachers in the Netherlands [4]. Whether the classification into four PCK types will still hold in the larger population, is to be investigated.

It is known that amplifiers and filters influence teachers' PCK development, see Sect. 2. Our data appeared to be sufficiently rich for an in-depth analysis of these influencing factors. We will report on this in a later paper.

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