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PEDAGOGICAL CONTENT KNOWLEDGE IN PRODUCT DEVELOPMENT EDUCATION

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ABSTRACT
The Finnish education policy has changed in recent years and poses challenging goals for university education. In the product development domain this means that teaching needs to produce more competent practitioners for the industry than before, at reduced cost. Our long-term goal is to improve product development education, and in this paper we focus on capturing teacher knowledge that has an impact on students' learning. The purpose of this paper is to describe the first prototype of pedagogical content knowledge (PCK) in product development.
This research makes use of the educational design research (EDR) strategy. Three experienced teachers completed questionnaires and participated in discussion based on the answers. The prototype was developed jointly, and the importance of PCK in teaching was discussed. PCK as framework was seen as useful during the process, as it facilitated capturing and structuring the tacit teacher knowledge on product development. The PCK does not consider the aspects of shared knowledge of teachers or the process of continuous learning and organisational learning. We believe that in the future, the knowledge of product development teaching could be developed further in the direction of a continuous learning process by integrating PCK with processes and practices of organisational learning. The role of teachers' PCK in facilitating good learning results also needs to be studied further.

Keywords: Pedagogical content knowledge, product development education, students' misconceptions, evaluation methods.

1 INTRODUCTION

In the Nordic countries, most universities are funded by the government. In Finland, the total investment level has been around EUR 1,900 million per year since 2011. Although there has been no significant change in investment, the Ministry of Education has changed the expectation level during these years. University staff need to produce more high-quality research papers, and more students need to move into employment within a year of graduation than before. The metrics set by the government also place increased pressure on engineering education. We need novel and innovative approaches to increase the efficiency of teaching and learning. Engineering education began in Finland in the 1930s, and there are currently four universities that offer engineering education. Each university has its own approach to product development, and there is no common, nationwide classification system for product development knowledge, skills, habits or attitudes. Our understanding is that the situation is the same in other Nordic countries. From our perspective, the purpose of product development education is to teach people abilities that allow them to create new solutions for products and services, thus creating value in the contexts of economic, social and sustainable development. We believe that teacher knowledge has a major impact on the efficiency of teaching and learning. Our long-term goal is to define these skills and also to determine what kind of teacher knowledge is required in product development nationwide. This study focuses on the knowledge that a teacher has available when making decisions regarding his or her actions. Our approach is to apply the concept of pedagogical content knowledge, which originates from various educational disciplines, to the area of product development education. It provides a classification of the knowledge types we need to capture.

2 PEDAGOGICAL CONTENT KNOWLEDGE

Research from the 1990s argues that product development education still lacks scientific principles (1) and is practised on the basis of empiricism, intuition and experience (2). One can argue that the research is over twenty years old and that the situation has changed. On the basis of our literature review, product development education still lacks a shared and common understanding of the subject matter content. Some nations and communities have succeeded in defining this. For example, the CDIO framework was created to fill this gap (3) and is used in some universities. It describes on general level a variety of necessary skills. The German VDI community has been developing design process descriptions since the 1980s (4). The role of the teacher and supervision have been studied in the context of Design Based Learning (5). Earlier studies on supervision have identified the following types of activity: a) formulating questions to facilitate an understanding of design tasks (6), b) providing feedback on technical design progress (7), and c) explicating the rationale for technical design, procedures or processes (8). The Engineering, Design and Communication approach identifies stages in design processes and corresponding tools and techniques for students to learn (9). In an attempt to enhance the efficiency and quality of product development education, we study the potential nature of teachers' pedagogical content knowledge in our domain. There are currently no holistic approaches adopting a teacher knowledge viewpoint that explain how to teach this subject and why certain teaching approaches produce more viable learning results than others.
Our aim is to develop teaching and education in the area of product development education. This research focuses on the concept of pedagogical content knowledge in the domain of product development education. Theory-building of pedagogical content knowledge has taken place in the field of teacher professionalism in Anglo-American research, in particular (10)(11). In Europe, the same kinds of issues concerning teachers' knowledge areas and the importance of content have been discussed in the area of *Fachdidaktik*. The aim of the research has been to describe and explain teaching but also to develop systematic, theoretical and empirical teaching research and learning in specific fields of professionalism (12). Besides these areas, *Fachdidaktik* explores the learning environment, the understanding of teaching events, the different needs of different learners, and teacher education. The development of *Fachdidaktik* is based on the understanding that academic domains represent different fields of science, which in their part may be based on various ontological and epistemological platforms (13). The understanding of the teacher knowledge field has been the subject of much discussion, especially after L. Shulman's (10) presentations on the division of teacher competence into seven fields.

Table 1. Schulman's fields of competence for teachers

Teachers' field of competence	**Description**
Content knowledge	Content knowledge, according to Shulman (1986), includes the basic concepts and principles of the discipline and the understanding of why the topics are particularly central to a discipline.
General pedagogical knowledge	General pedagogical knowledge refers to principles and strategies of classroom management and organisation.
Curricular knowledge	Curricular knowledge refers to a variety of programmes and instructional materials that are designed for the teaching of particular subjects.
Pedagogical content knowledge	The dimension of subject matter knowledge for teaching; the ways of representing and formulating the subject that make it comprehensible to others.
Knowledge of learners and their characteristics	
Knowledge of educational contexts	Groups, classrooms, the governance and financing of schools, the characteristics of educational communities.
Knowledge of educational ends, purposes, and values, and their philosophical and historical grounds	

These fields of knowledge have been regrouped by Grossman (14), who identifies content knowledge, general pedagogical knowledge and knowledge of context as separate fields, and divides pedagogical content knowledge (PCK) into four subcategories: a) conceptions of purposes for teaching subject matter, b) knowledge of students' understanding, c) curricular knowledge, and d) knowledge of instructional strategies. Our plan is to use these fields of knowledge in product development education.

3 RESEARCH STRATEGY AND METHODOLOGY

The purpose of this research is to develop an initial prototype of pedagogical content knowledge (PCK) in product development. It follows the educational design research (EDR) strategy, in which analysis, design, evaluation and revision activities are iterated until an appropriate balance between ideals and realisation has been achieved (15). The researchers act as reflective practitioners when completing the questionnaire and engage in dialogue on the topics with each other. Research data consists of the contributions of three NPD teachers at Tampere University of Technology. In total, these teachers have over fifty years of experience from different courses related to product development education. TUT has offered product development education since 1997. The teachers answered a questionnaire, and the answers were complemented by a reflective group discussion. The data was analysed by taking a theory-oriented content analysis approach. The PCK categories are based on the teachers' knowledge areas as defined by Shulman's (16) and Grossman's (14) pedagogical content knowledge (see TABLE in Chapter 2).

4 PEDAGOGICAL CONTENT KNOWLEDGE IN PRODUCT DEVELOPMENT

In this chapter, we present our view of pedagogical content knowledge (PCK) in product development. On the basis of our analysis, we divide PCK into five sub-areas (see Figure 1.)

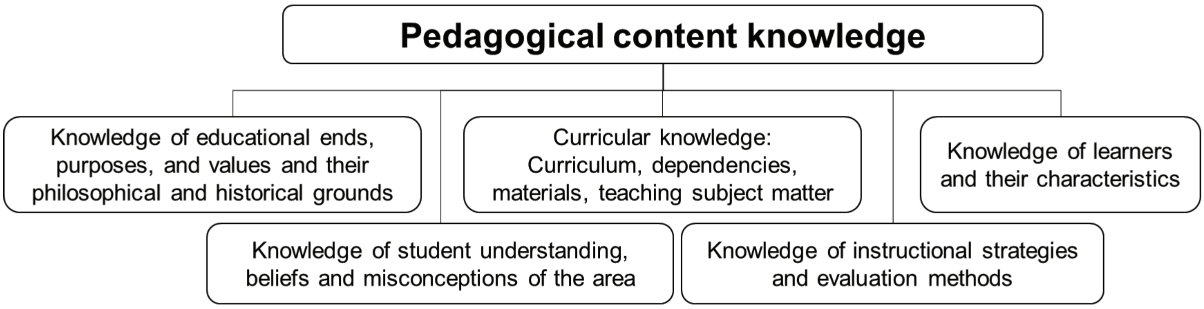

Figure 1. Pedagogical content knowledge areas in product development

When discussing **knowledge of educational ends, purposes and values, and their philosophical and historical grounds**, we discovered that the university has a long tradition of co-operation with the industrial sector. On the basis of feedback collected by the university, graduates serve the competence needs of relevant industrial operators. Based on the teachers' experiences, teaching staff are not valued as much as research staff. It should be noted that some teachers have been at the university since 1990, first as students and later as teachers and researchers.

The respondents seem to have in-depth **knowledge of students' understanding, beliefs and misconceptions of the area**. It is seen as important for a teacher to have knowledge of students' understanding, motivation, skills, habits and attitude. For example, the teachers need to be aware that some students are interested in credits or diplomas rather than skills or knowledge. When planning the courses, it also needs to be acknowledged that the students, especially first-year students, have poor self-reflection skills and that they act on the basis of the 'legacy' of high school or upper secondary school. The teachers listed some of the typical student misconceptions and beliefs: "There is only one correct answer to a question", "Creativity is a talent and, therefore, impossible to learn", "Product development begins with capturing customer requirements", "An industrial designer needs to have good drawing skills" and "Theory is something difficult and impractical, and that is why it needs to be added afterwards in the thesis. There is no need to understand the theory."

Findings related to **curricular knowledge** are linked to the product development curriculum itself, as well as horizontal and vertical dependencies within the course structure, teaching materials and conceptions of the purpose of teaching the subject matter. During the first year, students are introduced to ill-defined problems via a problem-based learning-oriented course. In the second year, students learn the basics of product development on two courses. The theme of the first course is ‘product development as a goal- and results-oriented activity’, while the second course walks the students through 35 design principles in mechanical engineering design. Third-year students also take two courses: one provides an introduction to the mind of the industrial designer, and the other focuses on module system development and product families. In the fourth year, students have one course on product development: product development project with Lean.

All the courses have a similar internal structure. The courses start with a motivational part. The content knowledge is organised visually, and the topic is introduced if necessary. Topics are usually organised in accordance with the design process. At the end of the course, a summary of the whole is presented. Each course is usually a separate module, and there are only a few commonalities between the courses. However, the skills learnt in previous years are used in later courses. Usually, the most popular textbooks on the topic are used as teaching materials. The teachers also use a lot of concrete case examples from their own research projects and industrial experience. When discussing the conceptions of purpose for teaching subject matter, the teachers emphasise that product development is a goal-oriented rather than task-oriented activity. Also, different kinds of design processes and tools are needed for a single product and module system. In this university, the flow of information and decisions are the basis for PD project management.

Knowledge of **instructional strategies** covers problem-based learning, co-creation in teams, learning logs, mini-exams, simulation games and demonstrations. The teachers have also adopted the so-called Stanford approach, which refers to lecturing with a textbook. The teachers listed exams, homework, portfolios, peer evaluation, self-evaluation, feedback from the industrial sector and project team competition as **evaluation methods** that they have knowledge of.

Additionally, pedagogical content knowledge on **knowledge of learners and their characteristics** was identified during discussion. Most students graduate from high school without any experience of design or product development. Some have very little experience of technical systems. As a result, the challenge is meeting the students on their level of understanding and comprehension. They typically do not have tools or methods for solving open questions or ‘wicked, ill-defined problems’. As laymen, they come up with an idea and then they try to make it work. They are not skilled at creating other ideas and do not know how to avoid getting stuck on the first idea. They suffer from design fixation and they are unfamiliar with self-managing groups of 6–9 people.

5 OTHER FIELDS OF TEACHER KNOWLEDGE

In this chapter we discuss the findings from the other fields of teacher knowledge: content knowledge, general pedagogical knowledge and knowledge of educational contexts. The main point in the teachers’ discussions on **content knowledge** was the challenge of teaching design processes. The best textbooks describe the process and tools for each phase, but there is a lack of elaboration on why a certain tool is used in each case, how the tools interact and what their interdependencies are. On university-level, we should be able to explain the reasoning behind the use of a certain development process and particular tools and approaches. This would enable students to better modify and implement these processes in real-life cases. While wondering how to foster creative designers, the **conceptions and beliefs of learning** were mentioned. The teachers reported the use of behavioural and constructive approaches, as well as the application of experiential learning on the courses.

When teachers guide students, their **conceptions and beliefs of teaching** and awareness of different approaches have an effect on their behaviour. The teachers discussed several methods and approaches, such as coaching, facilitating, scaffolding, situational leadership, and the zone of proximal development. Additionally, planning, execution and evaluation in teaching were mentioned as themes relevant to this topic.

The discussion on conceptions and beliefs about the curriculum had an effect on the development of the curriculum. The professor identified underlying guiding principles and beliefs that guide curriculum development. When discussing the **knowledge of teaching methods**, the teachers mentioned lecturing, problem-based learning, project-based learning, design-based learning, pre-structures for content knowledge, and educational design research. Krathwohl’s revised taxonomy of learning goals (17) is also used in the planning of product development course content. Knowledge of **educational contexts** was also discussed, and the teachers pointed out that most of the students will be employed by industrial and government organisations. It was seen as very important that we educate skilled practitioners with valuable competencies.

6 DISCUSSION

During the research and on the basis of the review comments, we noticed that the maturity of product development education differs between nations, Nordic countries and even within a single nation. When we compare the product development domain to teacher education, for example, we see that our domain is lacking a nationwide curriculum. Each university and department has different conceptions of what skills and knowledge the product development engineers need. It also seems that the nature of the work is such that it is very challenging to measure or evaluate whether a student has the required skills.

We became more aware of the clear distinction between our domain and some social science domains. In some areas, the goal is to understand the phenomena and the situation, but in our domain this is not sufficient. Our students need to understand and improve the situation, have a can-do attitude, and be resilient. The nature of product development requires the capability to deal with ambiguity and uncertainty. In terms of skills, we discussed reframing skills, cause-effect modelling, and abstract thinking. Nowadays Lean and flow thinking and cross-disciplinary and self-reflection skills are vital, as the products are based on many technologies and the time to market is constantly becoming shorter.

The process revealed where our focus currently lies and which knowledge fields have not been central. It was also successful in making tacit knowledge and conceptions explicit during the discussion. The model served as a boundary object for sense-making and negotiation on which fields of knowledge need more focus in the near future. We also realised that product development professionals require some skills in at least one engineering discipline. Currently, most students major in an engineering discipline, and product development is included in their minor studies. The discussion on general pedagogical knowledge resulted in the conclusion that it is useful to apply a mixture of behavioural, constructive and socio-constructive learning approaches in our domain. From a certain perspective, one could claim that product development is an active learning process.

This cycle of the research process provided us with valuable knowledge of teaching PD, and the reflective discussions during the data collection served the research goals. After the analysis and the results, we have been able to determine the next steps in the further development of this knowledge of product development teaching. Even though we concentrated on the pedagogical content knowledge of teachers, the data also clarifies what kind of teacher knowledge there is in the field of product development.

The theoretical framework of pedagogical content knowledge originates from the 1980s and 1990s, and we find that it lacks the aspects of teachers' shared knowledge as well as the process of continuous learning and organisational learning. PCK provided a structure and many aspects for identifying teacher knowledge, and with the help of interviews and discussions, it also facilitated the generation of explicit knowledge on the subject matter knowledge.

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