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A Conceptual Model for Knowledge Dimensions and Processes in Design and Technology Projects

Ari Alamäki

Haaga-Helia University of Applied Sciences, Helsinki, Finland

ari.alamaki@haaga-helia.fi

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Abstract

The present study sheds new light on the knowledge dimensions and processes that occur when designing new concepts and prototypes in higher education. In particular, this study aims to develop the conceptual understanding of activities and processes that help students to gain new knowledge and understanding while designing new products and services. I employed two data collection phases among undergraduate students with qualitative abductive data analyses in order to create a conceptual framework for understanding how new knowledge is created and managed in students' social interactions. This framework also enables us to distinguish the user, business, technological and methodological knowledge dimensions that constitute the elemental perspectives for design processes. This study emphasises the need for students to use diverse methods to gain new knowledge for inventing and designing new technological solutions.

Keywords: Knowledge, Design activity, Higher education, Curriculum

Introduction

Technological knowledge, including knowledge utilised in design processes, plays a crucial role in the development of companies, industries and societies. During the past decade in particular, technological advancements have significantly influenced product and service features, and new technological knowledge and its utilisation in technological activities has sped up the design and development processes for all industrial sectors. For example, wireless sensors possessing artificial intelligence are radically influencing transportation, healthcare, housing and numerous other industrial sectors (Porter and Heppelmann 2015; Botta et al. 2016). Similarly, social computing has changed the way that people communicate (Guesalaga 2016) and advanced big data analytics have changed market forecasting and the modelling of human behaviour (Gandomi and Haider 2015). All of these advancements are outputs of technological activity within the context of modern society due to society's enormous increase in technological knowledge over recent decades. As a result, employers in companies and public organisations now require educational goals to respond to these changing industry demands (Chung, Yeh and Chen 2015; Soitinaho and Palviainen 2015; Kolmos, Hadgraft and Holgaard 2016).

The speed of technology diffusion has also increased. New innovations are spreading across the globe much more quickly than ever before (Downes and Nunes 2014), which is an entirely new situation for new product and service development processes. For example, the latest digital games, such as Niantic's Pokémon Go, Rovio's Angry Birds and Supercell's Clash of Clans, have attracted millions of users within mere weeks, whereas other physical innovations have spread across continents and countries much more slowly. Traditional innovation diffusion models, such as the one designed by Rogers (1994), now seem dated (Downes and Nunes 2014); the early adapters and pioneers created the first markets, and the second user group pragmatists followed them after months and years. Thus, the diffusions and life cycles of innovations, such as physical artefacts, took years to run their course compared to the digitally produced innovations. All of these changes in engineering, economy and society should therefore influence the engineering and technology education that we offer students in this modern world.

The essence of technology in this study follows the definition of social sciences, which sees human beings as actors in technological activity, thus belonging to the realm of technology. Human needs and desires play an increasingly crucial role in today's technological development. For example, the role of customers in value co-creation processes has significantly increased due to service business breakthroughs in the industry (Grönroos and Voima 2013). Several practical design models also emphasise the key role that customers play in design and development processes (Alamäki and Dirin 2015; Blank 2007; Ries 2010), given that new commercial and industrial innovations should be economically profitable. The importance of user understanding has long been designers' main priority (e.g. Gould and Lewis 1985; Norman 1986), but the customer-centric focus now places greater emphasis on the designed service being profitable and scalable from the customers' perspective. The world has changed, and today it leans more towards service businesses where products enable value production through services for users (Vargo and Lusch 2016). Therefore, products and services are far more interrelated than ever before, while value creation today moves towards social interaction and service exchange situations increasingly occur through digital channels or automated transactions.

Technology as a human generative activity creates a unique methodological and pedagogical approach for design and technology education from elementary to engineering education (e.g. Järvinen 1998; Alamäki 1999; Rasinen 2003; Estévez-Ayres et al. 2015). The act of teaching and learning technology does not rely purely on lecturing, memorising and applying existing technological knowledge; instead, it involves inventing, designing and developing new technological solutions for the humans' potential use. However, more research is needed in order to more deeply understand knowledge dimensions and processes as a part of design and development activities creating new ideas, solution proposals, products and services. Student projects in higher education should reflect the design processes that take place in modern industry. The user, business and technological points of view should form part of the design processes, though more research is needed regarding how new knowledge is created. This article will review the knowledge generation process in the context of technological design activities in higher education. The following research questions guide this study:

- What knowledge dimensions are identified in the students' design process?
- What knowledge processes are identified in the students' design process?
- What knowledge processes are used in connection with each knowledge dimension?

This study ultimately aims to construct a pedagogical framework combining user-, business-, technology- and methodology-related knowledge in the knowledge-generation processes that occur within the design processes.

The role of knowledge in design and technology

The well-known Platonic interpretation defines knowledge as 'justified true belief', and although there are writings (e.g. Gettier 1963) identifying weaknesses in this definition, they fail to offer any widely accepted alternative definitions. Unlike information, knowledge is cognitively observed and constructed, a process that is primarily performed by humans, though nowadays this is also done by artificial intelligences in some special cases (see e.g. High 2012). Spender (1996) states that knowledge is a contentious concept. Specifically, knowledge is a multidimensional concept involving several forms and dimensions, such as the tacit or explicit nature of knowledge (Nonaka and Takeuchi 1995), the hierarchical levels of cognitive processes (Anderson et al. 2001; Krathwohl 2002), knowledge boundaries that enable or resist communication between parties (Carlile 2002) and activities for generating new knowledge (Carlile 2002; Vincenti 1990). Vargo and Lusch (2016) describe knowledge exchange as a key element of the value co-creation process. Thus, most industrial processes and continuous development require the application and creation of new knowledge rather than the exchange and sharing of instrumental or technical knowledge. In addition, new knowledge and its meanings and interests to the practices of individuals and institutions are constructed through social interaction rather than being mechanically transferred from human to human; thus, knowledge exchange involves both situational and learning psychological features (e.g. Piaget 1985; Vygotsky 1978). For example, prior knowledge influences to ability to learn new technological knowledge (Yu, Lin and Fan 2015).

According to Vincenti (1990), knowledge activities or processes include: invention, transfers from science, theoretical and experimental research, design practice, production, and direct trials. Vries (2003) states that technological knowledge is not purely applied science, and thus cannot be classified as 'justified true belief', which is the traditional definition of knowledge. Technology creates its own knowledge base in many cases, as much technological knowledge was created through and within practical activities where a proper way of working or doing was discovered without scientific explanation. Technological knowledge consists of many knowledge types (Vincenti 1990; Mitcham 1994; Vries 2003), such as concepts, principles, theories and rules. Vries (2005) emphasises that teaching technological knowledge should include teaching its normative components. This does not apply to just descriptive knowledge, but to norms, rules, standards and other normatively determined issues as well. Additionally, the design context also influences designers' knowledge base (Haupt 2015).

Mitcham (1994) states that design, production and use are generative processes in the realm of technology. Thus, the design process aims to create something new by solving either predefined or ill-defined design problems. Knowledge is a crucial factor for successful design activity, and a significant part of the knowledge applied by designers is tacit (Chen et al. 2013) and procedural (McCormick 2004; Pirttimaa, Husu and Metsärinne 2015) in nature. Designers also need to use a larger knowledge base in the actual design phase than when producing a single artefact (e.g. Nemoto et al. 2014). This implies that the designed product or service should not only solve initial 'technical' problems, but it should also pay attention to the cognitive, emotional, behavioural and social needs of users and business owners. For example, the users and customers may have symbolic and status-related goals or needs for using the product or service. What's more, design is an intentional, goal oriented and systematic activity (Chandrasegaran et al. 2013), unlike pure inventing, and this underpins its role as a knowledge intensive activity. Design as a knowledge intensive activity does not, however, neglect inventing and creativity (e.g. Atkinson and Sandwith 2014). For example, Esjeholm (2015) found that inventing and creativity take place more effectively in tasks where students solve ill-defined problems.

Knowledge is one of the four dimensions of the realm of technology (Mitcham 1994). In fact, knowledge is the fundamental source of competitive advantage and is an essential success factor for operant resources in product and service design and production (see e.g. Kindström 2010; Vargo and Lush 2016). As a result, the ability to manage and create new knowledge is becoming an increasingly important basic skill for business professionals and even people in almost all industrial sectors. Managing knowledge has played a pivotal role in the concept of value creation ever since industries transformed to become knowledge-intensive companies. Furthermore, generating, managing and exchanging knowledge has become the critical competitive success factor for firms in today's global economy. Thus, more research is needed to answer the growing need for a deeper understanding of knowledge-generating processes where new values and solution propositions are applied and generated.

Design and technology as a generative activity

When reviewing technology within an educational context, it is important to note that technology is not a product of modern society. Rather, it is as old as humankind. Mitcham states (1994) that virtually all historians use the word technology to refer to both ancient and modern—and primitive and advanced—production activities, as well as to refer to the knowledge of how to make and use artefacts or even the artefacts themselves. He continues by claiming that the definition of technology roughly corresponds to the ways in which it is used by two major professional groups: engineers and social scientists. The humanities' view of technology is more relevant for this study, as the success of engineering's end-products is increasingly dependent on understanding the behaviour of end-users and paying customers. The definitions of technology in this approach show that the users and customers play a crucial role in the concept. Mitcham (1994) considers technology to be a practice or activity that involves making and using artefacts, but he adds to his definition of technology both artefacts and technological volition. Thus, technology is the study of our human-created world that starts with human wants and needs and ends in the satisfaction of those wants and needs (Heidegger 1977; Dugger 1993, 1997). Technology is dependent on social interaction and humans' ability to socially define and solve the needs and wants of end-users.

Technological development is not a straightforward linear process. Instead, it requires several iterative experiments before final productising and commercialisation. Blank (2012) believes that discovering users' real problems and needs is the most important factor for creating new and financially valuable solutions. Blank also states that in the iterative development model, going backwards is a natural and valuable part of learning and discovery, whereas the traditional linear product development model views going backwards as a failure or a waste. Finding the right users, customers and markets is often unpredictable, and designers and developers need to fail several times before they succeed (Blank 2007; Ries 2010). Therefore, understanding the role that users and customers play is critical for successful design activities (Norman 1986). Yang et al. (2013) pointed out that product design knowledge is often complex, multidimensional and unstructured. Furthermore, Alamäki et al. (2016) found in their case study that not all ideas or concepts can be tested with screenshots, mock-ups or minimum viable products, as there are features that require building a functional prototype for testing purposes.

The role of users and customers in design activity

Norman (1986) emphasises understanding users' mental models when designing new products and services. In fact, users will be the consumers and customers of the design processes' final outcomes while they are using and consuming new artefacts to solve their daily needs and to satisfy human wants. The users' experience directly associates with the success of a new artefact because the value is created through the usage processes (e.g. Grönroos and Voima 2013). Thus, users constitute the key target group when designing new products and services, as the designed product's or service's value proposition is actually realised while they are used in various situations or contexts.

Holopainen and Helminen (2011) show that having users participate in the actual innovation process generates user knowledge more effectively than traditional data-collection methods. The participation methods of users, such as the service design approach, bring value through integrating the different stakeholders and their needs with the design processes in several phases (Cook et al. 2002). The users' participation in the design process also ensures that their human needs and wants are carefully reviewed and tested, especially from the viewpoints of the customers' journey and service touch points (Zomerdijk and Voss 2010). The user experience influences both the success of technological artefacts and their commercial potential, which has become one of the most significant and critical success factors in today's modern industry. For example, the most important factor for the technology acceptance model is usefulness, which indicates the users' subjective experiences of the perceived benefits of technological products or services (e.g. Davis, Bagozzi and Warshaw 1989). Thus, users should be the key stakeholders at various design and development stages; developers need to continuously involve users in the design process and to refine the design concept into a serviceable system based on their feedback (Gould 1985). In addition to the service design approach, the user-centred design method also emphasises the importance of users participating in the design processes. Furthermore, design methods should also pay special attention to the business benefits of this design method, as this ensures that end-users are involved in the same processes as the business owners (Kaski, Alamäki and Moisio 2014).

Research methodology

This study aimed to qualitatively analyse knowledge generation processes during design activity in order to understand what types of knowledge processes take place and what kinds of knowledge dimensions exist in student-designers' technological inventing and design activity. This study has two phases; the first data collection phase consists of action research aiming to increase understanding of knowledge processes and dimensions during design work, and the second phase focuses on the structured interview with the aim of strengthening the conceptual development of the drafted conceptual framework.

The first data collection phase

For its research method, the first phase employed a case study (Eisenhardt 1989) accomplished as action research (Brydon-Miller, Greenwood and Maguire 2003) where the researcher worked as an instructor in the innovation and design course and, during his teaching work, collected data for the study. A total of 20 undergraduate students (N=20) from a university level Business Information Technology degree programme participated. Nineteen were male and one was female. The course took place during one semester lasting from January to May of 2016. The data collection involved several qualitative methods in order to provide an overall understanding of knowledge processes and how the students solved the design tasks. The researcher collected data by writing field notes from the seven practical design work sessions, by observing and participating in the design work of four student groups, by deploying a semi-structured questionnaire among 14 students, and by leading four group discussions among 18 students concerning their experiences with the design project. The goal of their design projects was to create a conceptual plan, sketches of a digital service and an architectural description of how sensor data could be utilised in the context of an outdoor tourism activity. The primary assignment for four student groups was to ideate how tourists and travellers could utilise sensor data in outdoor tourism activities, what value it provides for end-users and what kinds of business benefits exist for tourism service providers. The technical starting point was an Internet of Things sensor device (Thingsee) designed for the outdoor environment. To begin, the instructor introduced a brainstorming method, the students used a reframing web-tool for idea framing, IoT-device videos were presented and the assignment and the structure of the design process (need, approach and benefits) was explained to the students. After the orientation, the students began working in teams. In the middle of the design process, five potential end-users (experts in outdoor tourism activities) participated in the design process during one lesson and met each student group to evaluate and comment on their concept plans. Each student team also presented their results to the other students, faculty and company visitors at a special event. The assignment came from an EU-funded project with a goal of producing solution proposals that benefit from IoT-type devices and data in tourism.

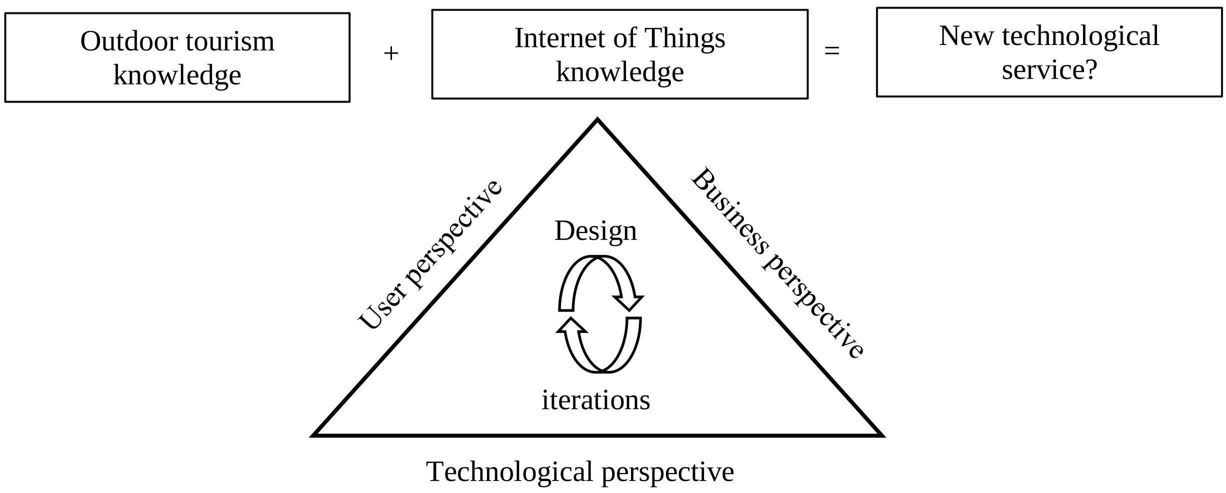

Figure 1. The conceptual model adapted for the action research from Alamäki and Dirin’s (2015) key stakeholders of the design process model

The second data collection phase

The second phase employed a structured interview as its research method. In this interview, the researcher utilised the initial understanding of the knowledge processes and dimensions created in the first data collection and analysis phase. This specifically focussed on the knowledge processes and dimensions utilised by the student groups during their design work. The researcher conducted structured group interviews with 57 (N=57) students in 22 different students groups. Those 22 student groups represented 99 students, consisting of 4–5 members per group on average, 57 of which were involved in the interview sessions. Similar to the first data collection phase, they were also undergraduate students from the university level Business Information Technology degree programme, although less than 10 were studying journalism as a major. The two courses where the data were collected took place during one semester lasting from August to December of 2016, and they were similar to the courses in the first data collection phase. The project's goal in the courses was to create a conceptual plan and sketches or prototypes of a new digital service. A total of 20 student groups had the external customer while 2 student groups designed a concept and prototype for their own digital business idea. Each student group was interviewed separately. The researcher presented the blank table of knowledge processes and dimensions created as the outcome of the first research phase. The researcher then explained the meaning and details of the knowledge processes and dimensions in the table, afterwards asking the students to recall their working practices and processes during the project in order to form a common view within a group and finally to mark all knowledge dimensions that they identified. After this, the researcher asked the students to select all knowledge processes that produced new knowledge about the selected dimensions during their design work.

Data analysis

The abductive qualitative research approach (Dubois and Gadde 2002) was used to analyse the data, as it enabled the researchers to build explanations and to elaborate on the conceptual model while analysing data in an iterative manner. In the abductive research, the researcher simultaneously processed prior literature and theories along with the analysis of the data gathered through the empirical research work (Dubois and Gadde 2002). Adopting this type of iterative research process allowed for developing a deeper understanding of the empirical data being analysed while simultaneously contributing to the theory of knowledge processes and dimensions taking place in the design work. The data analyses began with the early observations of the students' knowledge processes in their design work. The observations provided insight about the different generative processes used by the students while gaining the new knowledge needed for accomplishing the design tasks. Table 1 summarises the knowledge activities that the researcher identified from the first data collection phase. They formed several similar activities that the researcher was able to construct as a single knowledge process. The prior understanding of knowledge generation processes gathered from the existing literature (Vicenti 1990; Vries 2003) provided guidelines for the observations and further analyses. The researcher constantly revised his theoretical understanding of the empirical observations and findings. When analysing the data from the first data collection phase, the focus was on replies, notes, actions or comments indicating knowledge processes and dimensions and showing the creation of new knowledge that helped the students to proceed in the project work. According to qualitative data analysing principles (e.g. Case and Light, 2011), the researcher organised the collected data into categories by classifying the design work activities based on their features. The data classification in the research material revealed that the design work consisted of such activities as ideating solution proposals, gaining new information, sharing and solving problems, drawing sketches or demos and evaluating others' suggestions or comments. In addition, the data were analysed by utilising the stakeholders of the design process model (Fig. 1), which consist of user, business and technological perspectives united through development iterations. The user-centred design approach also takes the key stakeholders—namely, potential users—representatives of customers and companies, experts, and co-designers as knowledge sources. The model shows that involving stakeholders in the design process as equal partners promotes rapid development and more quickly integrates business expectations, user needs and technological possibilities (Alamäki and Dirin 2015). When analysing the data from the second data collection phase, the researcher totalled the marks of knowledge processes and dimensions from the interview notes, which he collected while interviewing student groups, and transformed the resulting totals into percentages (Table 2). The conceptual model (Fig. 2) presented in this study was completed during the analysis of the research data, and it will be applied to the pedagogical purpose at the end of this research paper. The researcher used several methods to improve the findings' trustworthiness, as qualitative analysis could include weaknesses in interpretations and observations (Eisenhardt and Graebner 2007). The classification, interpretation and categorisation in the analysis was based on the prior literature and theoretical understanding, and the findings were reflected in the interrelationship of empirical data and prior theoretical and empirical literature. Furthermore, using two data collection phases increased the data's trustworthiness because the second data collection was arranged to confirm and deepen the findings of the first research phase.

Findings

User knowledge

The findings of the first data collection phase show that the students typically discussed user perspectives by utilising or referring to their personal experiences of outdoor activities in the ideating and concept planning phases. Thus, tacit knowledge of prior personal user experiences was applied to the design processes. The user perspective was evaluated by presenting concepts and product drafts to the five experts who visited during the course. This process represents an experimental knowledge activity, as the expert users commented on the drafts and plans presented to them. The researcher classified this process as apprenticeship knowledge creation, which contains elements of the experimental knowledge process (user test). The visitors brought their expertise and insight to the design team; they not only shared their opinions, but they actually advised and coached students to add their understanding of users and business perspectives to the concept plans and prototypes. The students viewed the experts' visit as extremely useful, as it provided them with a great deal of fresh and trustworthy knowledge. Although the instructor also advised and coached students, this could not be classified as an apprenticeship as the instructor did not represent the voice of potential users or business owners. The students also collected user feedback at an exhibition type of event in which other students from different courses, faculty and some visitors from external companies and public organisations participated. That knowledge process represented research-oriented knowledge creation, as the students interviewed potential users while presenting their concepts and prototypes at their stand. The notes from the discussions with the students show that the students gained user understanding from the research-oriented knowledge creation event.

The findings of the second data collection phase (Table 2) reveal that students gained user knowledge primarily from their own prior experiences (73%), followed by social co-creation in teams (59%), experiments (59%) and user research (55%). All design projects focussed on designing and sketching digital services, and evidently, all students have their own personal experiences as users of those services. Thus, the utilisation of prior experiences seems to be the logical knowledge source. Overall, the findings of the second data collection phase supports the observations and analyses of the first research phase where data were collected using several data sources and methods.

Table 1. The recognised activities of knowledge generation processes in the students' design work.

Examples of students' working practices	**Knowledge-generation activities**	**Knowledge-generation process**
Students are directly applying knowledge that a teacher is teaching to them or they are reading instructional material, web sites or instructions for learning how to solve different tasks or questions.	Applying explicit knowledge (lecturing, documents, reports, instructions, etc.)	Utilisation of formal learning
Students are recalling and reflecting on their personal experiences regarding the design problem or they are applying their prior knowledge to the new design problem.	Applying tacit knowledge (prior experiences, beliefs, stories, etc.)	Utilisation of prior experience
Students are collaboratively brainstorming, discussing and sharing knowledge with each other to solve design problems or to create new ideas and plans.	Socio-constructive knowledge creation (collaboration, sharing, co-design, teamwork, etc.)	Co-creation in teams
Students are working for external clients or are meeting with external experts to discuss and evaluate ideas, requirements and solution propositions, and are receiving reflective and constructive feedback regarding their progress and results.	Apprenticeship knowledge creation (external expertise, advice, mentoring, coaching, etc.)	Interaction with external clients or experts
Students are planning and arranging short trials, experiments or testing sessions to gain direct feedback without involving users or they are testing their initial idea or solution proposition to gain instant feedback on how to improve or redesign it.	Experimental knowledge creation (trials, tests, rapid prototyping, monitoring, etc.)	Experimenting or testing
Students are planning and arranging formal sessions where they meet with potential users or customers or they can study the success of	Research-oriented knowledge creation (interviews, surveys, observations, etc.)	Executing user research

their ideas or solution propositions with potential users or customers. Feedback is collected, documented and analysed.		

Business knowledge

The findings of the first data collection phase reveal that the students had difficulties in reviewing the concept proposal from the business point of view during the concept planning phase. The final concept plan contains examples concerning business owner benefits, such as collecting data from the most-used routes and utilisation rates. The field notes and questionnaire show that little prior experiences, socio-constructive conversations, experiments or research work focussed on the business perspective. Although the user or technology point of view was often argued, the students could not create a link to the business perspectives. The visiting experts noticed that the business perspective was the weakest element of all the teams' concept plans. Hence, they discussed that perspective with students by representing the apprenticeship knowledge creation. The inventing and designing of new technologically-enabled services should deal with the business perspective if the goal is to teach students to meet the needs of design tasks in industry. In fact, it does not make sense to design products and services that cannot bring value for potential customers or business owners in the industry. The value needs to be recognised during the design process, as it should be a starting point for investments in the industrial design and development processes. More methodological knowledge and tools are also needed for promoting the business dimension in higher education design projects. That goal could be realised by designing solutions for real-life needs with potential users and business owners.

The findings of the second data collection phase indicate that interaction with external experts or clients was the primary (72%) activity for creating new knowledge for the business knowledge dimension. Only every third student group (27–36%) used other knowledge generation processes for gaining business knowledge. Interaction with external experts or clients is a natural source for learning about business knowledge. The findings reveal that other processes can also produce new knowledge in this dimension, but they do not differ from each other in the student groups that participated in this case study.

Technological knowledge

The findings of the first data collection phase show that the student groups created new understanding through socio-constructive conversations where they evaluated various technological alternatives (e.g. for the navigation structures or the key features of applications). For example, experimental knowledge creation took place in one student group that tested and demonstrated alternatives by using the Thingsee-cloud configurator as the demonstration platform. In this case, the cloud software worked as a testing tool for ideas, as the idea needed to deploy data configuration settings. The open question in the questionnaire—'What prior knowledge and skills have you been able to apply in developing the concept?'—revealed that prior tacit knowledge, i.e. prior experience, was the most common knowledge source, although the instructor presented the IoT-device and its cloud systems in the orientation lessons. The notes from the group discussion support this finding. The lecturing or formal teaching represents explicit knowledge sharing, which is a method typically employed in instructor-led teaching sessions. The field notes also show that students gained explicit technological knowledge by reading documents and watching videos on the Internet. They even stated in the group discussion that technological issues were emphasised more than user- and business-oriented topics in the group discussions.

The second data collection phase shows that the students perceived the utilisation of prior experiences to provide the most technological knowledge (77%), whereas only one student group stated that they also gained technological knowledge from their user research. Half of the groups (50 %) said that formal instruction produced useful technological knowledge for their design project.

Table 2. The knowledge dimensions and processes and their appearance in 22 students' design groups.

	User knowledge	**Business knowledge**	**Technological knowledge**	**Methodological knowledge**
Utilisation of formal learning: Applying explicit knowledge	8 (36 %)	7 (32 %)	11 (50 %)	19 (86 %)
Utilisation of prior experiences: Applying tacit knowledge	16 (73 %)	8 (36 %)	17 (77 %)	10 (46 %)
Co-creation in teams: Socio-constructive knowledge creation	13 (59 %)	8 (36 %)	9 (41 %)	15 (68 %)
Interaction with external experts or clients: Apprenticeship-type knowledge creation	9 (41 %)	16 (72 %)	4 (18 %)	3 (14 %)
Experiment or testing: Experimental knowledge creation	13 (59 %)	6 (27 %)	7 (32 %)	8 (36 %)
Executing user research: Research-oriented knowledge creation	12 (55 %)	6 (27 %)	1 (5 %)	7 (32 %)

Iterative design process and methodological knowledge

The most challenging issue during the design process was to develop a satisfactory solution to the problem. The notes from the group discussions show that producing an idea and a conceptual approach took a great deal of time and effort at the start of the design process. In addition to the field notes from working in the classroom, this finding was also revealed in the semi-structured questionnaire from the open question, ‘What has been most challenging in developing an innovative idea?’. Combining technological knowledge with tourism knowledge was a challenging task in the design process. Although almost all students had personal experiences of hiking, kayaking, camping or walking, they struggled to find an easy way to solve problem. The question ‘what issues have helped you to invent good ideas for the concept plan?’ shed light on this design challenge. Students responded that co-creation (the socio-constructive knowledge process) within the group helped them to formulate the idea needed to proceed in the task. In addition, experiences of IT applications (applying prior technological knowledge, i.e. tacit knowledge) or outdoor tourism (applying prior user knowledge, i.e. tacit knowledge) were also mentioned. The question ‘what prior knowledge and skills have you been able to apply in developing the concept?’ was answered with socio-constructive knowledge creation, such as group working or social skills. Furthermore, using outdoor tourism experience as a knowledge source was mentioned in addition to the technological knowledge from software tools, mobile applications and IoT-sensors. The field notes support these findings. The field notes and the data from the questionnaire indicated the need for a greater level of methodological knowledge for inventing concepts and solving problems. The students faced challenges in terms of limiting the concept, crystallising ideas and evaluating alternatives, and they lacked the tools required to evaluate and prioritise the initial concept and drafts. The question ‘how have you evaluated ideas and concepts in teams?’ supported the field notes showing that socio-constructive conversations would be an effective tool for producing knowledge for this task. However, the level of socio-constructive knowledge creation varied between the student teams. The external experts (apprenticeship knowledge creation) significantly helped students in finalising the concept plans. Thus, better knowledge of methodological opportunities would have helped them to proceed in solving the tasks. In addition, the design models that were taught (formal instruction) were probably too theoretical to apply to the given context in practice. From the pedagogical point of view, the sharing of explicit knowledge was not sufficient, but direct help from the instructors and expert users helped to manage them during the practical working periods.

The findings of the second data collection phase show that formal instruction (86 %) was the most significant knowledge source. Co-creation in teams (68 %) also produced new knowledge for this dimension, which indicates that students collaboratively discussed and planned solutions and methods for managing the design process. Furthermore, it sounds logical that only three student teams stated to gain methodological knowledge from the interaction with external experts or clients, as the external experts or clients focussed on targets and outcomes rather than methodological issues.

Discussion

The findings of this study reveal that the students in question gained new knowledge from six different knowledge generation processes, all of which concerned four different knowledge dimensions. The diversified activities of the design processes generated a larger knowledge base, which assisted students in building an integrated understanding of the user, business, technology and methodology dimensions that form the essential building blocks of product-service design projects. In addition, this study shows that the significance of knowledge processes vary between the different knowledge dimensions.

Theoretical implications

This study shows that design projects as a multi-dimensional learning environment provide several sources for new knowledge creation. Nowadays, knowledge and services play a more significant role in value creation (Kindström 2010; Vargo and Lush 2016), as the actual value of artefacts is usually realised in usage processes where several actors provide resources (e.g. Grönroos and Voima 2013). This sets new requirements for conceptualising design processes towards knowledge-intensive services consisting of user, business, technology and methodology dimensions. In modern society, the end-user or customer value is often produced by services (Vargo and Lush 2016) where technological solutions are important enablers and resources. This statement does not exclude product design, but products are increasingly becoming a part of the service ecosystem of satisfying human needs and wants. This study supports the literature by pointing out that design is a knowledge intensive, complex, iterative and multidimensional process (e.g. Norman 1986, Blank 2007; Ries 2010; Yang et al. 2013). In fact, the design process is becoming even more complex and iterative as designers begin to focus more on the user and business perspectives. At the same time, the technological knowledge-base is rapidly changing. Inventing and designing product-enabled services requires user, business and methodological knowledge in addition to technological knowledge, as evidenced in this study. This finding supports previous studies (e.g. Heidegger 1977; Vincenti 1990; Dugger 1993, 1997; Mitcham 1994; Vries 2003, 2005) that state that the essence of technology is not purely technological; it is also a human process where human volition, for example, plays an essential role. In modern society, there are business actors who design, produce, market and sell products and services to satisfy the needs of end-users, customers and consumers. Successful design activity should combine technological knowledge with user and business knowledge in solving industrial, social, economic or environmental problems whose ultimate aim is often commercial utilisation or economic improvement. This design activity is managed by utilising methodological knowledge in combining user, business and technological knowledge domains. Methodological knowledge helped the students in this study to define, find and exploit conceptual and procedural knowledge, which helped them to proceed in the design task from the beginning to the satisfactory selection, definition, draft, sketch, prototype, plans or any corresponding outcome. Christiaans and Venselaar (2003) refer to a highly similar phenomenon by using the concept of process knowledge. Technological development is primarily dependent on human cognitive capabilities, where the rapid creation of new knowledge plays an important role. This study provides a new understanding of those knowledge generation processes within the educational context.

This study revealed that design activity requires the ability to gather a range of information using different knowledge dimensions and processes. Creating something new in design processes requires higher-order thinking, which consists of critical thinking and creative problem solving rather than merely applying existing explicit or tacit knowledge. The concept of higher-order thinking (e.g. Resnick 1987) refers to those cognitive actions that occur in facilitation, creation and co-creation processes where designers and creators apply knowledge to a new situation or create new factual, conceptual or procedural technological knowledge. They are not only sharing existing knowledge with each other, they are also involving socio-constructive thinking processes with the goal of finding proper proposals for improving or renewing current solutions or artefacts.

Educational implications

Formal instruction constitutes only one of the knowledge sources available for students, as their prior experiences, co-creation in teams and external contact with clients influence learning in the design processes in higher education. In fact, in addition to utilising formal teaching and learning material (explicit knowledge) and practical experiences (tacit knowledge), in this study, co-creation in teams seemed to be the most common way for gaining new knowledge. This calls for more group work instead of individual learning tasks. In addition, the students felt that they benefited from the advice of experts and from interviewing potential users. Thus, this study reveals that socio-constructive and apprenticeship-type learning, as well as research, are knowledge processes that enrich the learning of students alongside formal teaching and the utilisation of prior practical experience. These results support the findings of Vincenti (1990) and Vries (2003), who point out that designers create new knowledge in the actual design processes by using various knowledge processes. However, unlike Vincenti (1990), this study separates experimental knowledge creation from research-oriented knowledge creation, as the students directed trials or simple practical experiments rather than experimental research in the educational context. Building and gaining feedback for sketches or prototypes is an iterative experiment without formal research arrangements.

The educational implications are summarised in Figure 2. In teaching and learning design and technology, we should place greater emphasis on knowledge concerning methodologies, as it provides tools for evaluating and selecting proper alternatives, solving ill-defined problems and creating the new knowledge needed for designing new products and services. Methodologies are not only technological principles, they are also related to user and business understandings of how ideas, concepts and prototypes could be tested against user and business benefits and value. Education should respond to the requirements of the modern industry, in which customers and businesses are some of the most significant stakeholders.

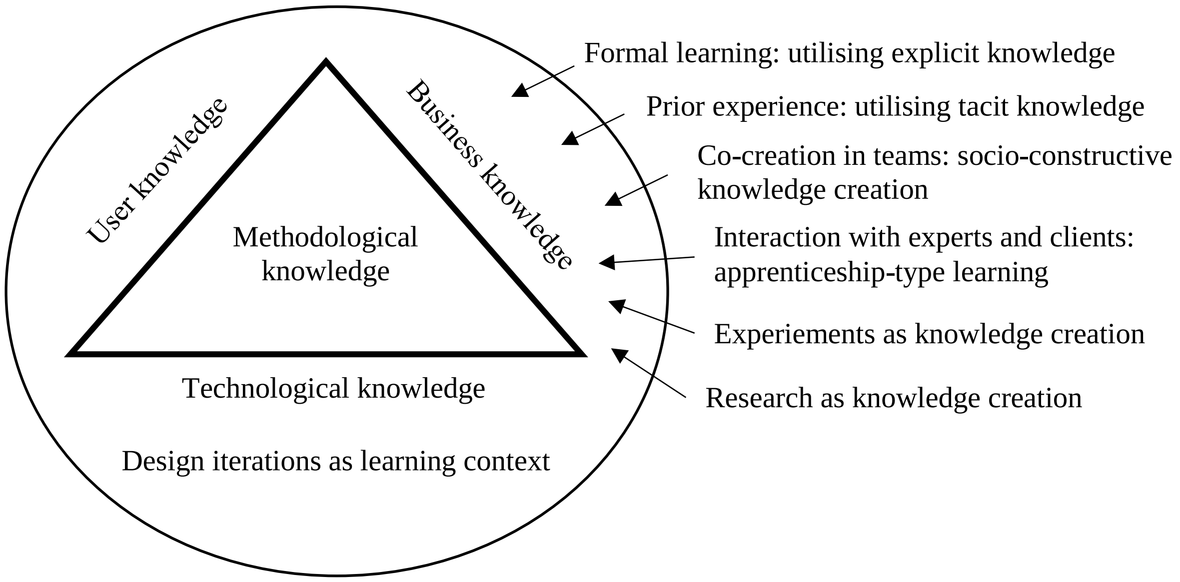

Figure 2. The knowledge dimensions and processes in the educational context where students learn by designing technological products and services.

Figure 2 shows six main processes for how students and designers can obtain new knowledge. This study supports the research of Esjeholm and Bungum (2013), which showed that design activities create several useful knowledge generation processes and provide a rich learning environment. The findings of this study show that socio-constructive knowledge co-creation plays a crucial role in the design processes. In particular, modern working life requires social co-creation skills (Soitinaho and Palviainen 2015), and co-creation as a pedagogical approach meets that educational requirement. Furthermore, understanding the user and business perspectives creates bridges to modern working life, where commercial goals are essential. The model in Figure 2 assists us in developing more collaborative and constructive pedagogical approaches that create bridges between school, business life and industry. This article shows that user experience and service orientation have become industrial standards, as these services constitute the fundamental basis of exchange between users, customers, partners and companies in modern society. Learning and teaching in technology and design education should give greater consideration to those user and customer perspectives while inventing and designing new technological solutions.

Limitations and future research work

The scientific contribution of this research is conceptual, shedding new light on the knowledge dimensions and processes in design and technology projects at the higher education level. This study does not aim to generalise its findings due to its nature as a qualitative study, where data were collected through action research and interviews and was analysed using the iterative abductive research method. Although the data were collected through several research methods, and it was analysed using the conceptual framework, there are always limitations in the findings. For instance, the deeper understanding of socio-constructive knowledge co-creation in design activities merits further examination. This study increases our basic understanding of those knowledge dimensions and processes that occur and affect the outcomes of students' design processes. The conceptual model developed in this study assists us in accomplishing further research on the levels of knowledge processes and their more detailed features. This study also encourages the researcher to pedagogically explore how students could effectively manage those knowledge processes and balance knowledge dimensions, especially user and technology perspectives. However, more research would be appropriate regarding how students more effectively learn in the context of real company-driven design projects. As the literature review shows, there are major changes occurring in the development of technological knowledge and the subsequent knowledge exchange concerning user and customer-oriented service design.

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