RESEARCH REPORT

A Quest for Knowledge?

Åsa Ericson
Johan Holmqvist
Christian Johansson
Johan Wenngren

LULEÅ UNIVERSITY OF TECHNOLOGY

A Quest for Knowledge?

Åsa Ericson
Johan Holmqvist
Christian Johansson
Johan Wenngren

Functional Product Development
Luleå University of Technology

Research Report
ISSN: 1402-1528
ISRN: 978-91-7439-362-0

© 2011 Ericson, Holmqvist, Johansson & Wenngren
Functional Product Development
Division of Innovation and Design
Department of Business Administration, Technology and Social Sciences
Luleå University of Technology
SE-971 87 Luleå
SWEDEN

Printed by Universitetstryckeriet 2011

Information is not knowledge,
Knowledge is not wisdom,
Wisdom is not truth,
Truth is not beauty,
Beauty is not love,
Love is not music,
Music is the best.

Frank Zappa, "Packard Goose"

Preface

In the research project called Fuel Efficient Transmission Technology Concepts: Design Methodology, in short FETT, the affiliated partner Volvo Construction Equipment AB has come up with a new technology that meet the demands of sustainability by offering a substantial saving in fuel consumption. The goal of the research project is to provide support to bring new technologies to the market as quickly as possible. Very simplified, new technologies go from ideas in R&D projects via advanced engineering projects before they end up in product development and production. Along the way, the many tests, evaluations, improvements and refinements of the product make up a knowledge base of technically related know-how, but also more human dependent knowledge. Such experiences are important for a successful result, meaning that the realization of better products does not only depend on the coordination of at least two variants of knowledge, technical and social, but also on how the knowledge is transferred to the next step in the development processes, or how it could feed input into a new project.

In parallel, the research project ProViking THINK (Teams for Heterogeneous INnovation Knowledge) deals with the goal to seek support for cross-disciplinary engineering innovation tasks. The project is divided into two specific interest areas, where this report focuses on information/knowledge in early phases. The affiliated partner for this interest area is Volvo Aero Corporation, thus also developing components of products that use fossil fuels. The aeronautical industry has agreed upon an agenda that even aims for a much lower level of emissions than is prescribed by regulations. To reach the settled goal, the ability for innovation and coming up with breakthrough solutions needs to be challenged. Also in this context, sound knowledge transfer between people and projects are vital.

Thus, in these two projects, the issue of knowledge sharing is in common. A contribution of this report is to conceptualize the many facets of engineering knowledge, and subsequently, in the research projects provide a base for the design of supportive processes, methods and tools. A key in this report is to problematize the more social aspects of engineering knowledge. The report as such is intended to serve as a trigger for discussions in industrial workshops in the related research projects.

Luleå 2011-11-03

The authors

Abstract

Today, a new knowledge economy and more service-based offerings are commonly mentioned as a challenge for manufacturing companies. This challenge addresses the companies' knowledge base and the traditional engineering expertise areas. The report starts from an assumption that there are differences in how knowledge is managed, as well as differences in the intentions to why it is managed. Based on this assumption, the purpose in the report is two-folded. First, the purpose is to conceptualize different facets of knowledge within a framework of technical product development. Second, the purpose is that the report serves as a trigger for discussions and reflections on existing practices in industrial workshops. So, despite that the report does not provide the "right" answers to these questions; they still guide the work in our research:

- What is actually managed in every-day engineering project work?
- And, for what purposes?

The work accounted for in the report comes from a literature review and our joint efforts in understanding the research area from a theoretical perspective. First general views on knowledge is presented, including its classification in different ways, compared to information and data, as well as its division into tacit and explicit knowledge, or practical skills and theoretical knowledge. Human factors, including how people search for information, is also presented. Then a more explicit focus on technical knowledge is presented, showing the shift from knowledge as an artefact to a social and personal perspective in recent years. This also encompasses discussing the capabilities and knowledge of an engineer.

A contribution of this report is the conceptualization of different facets of engineering knowledge; especially the more social aspects of engineering knowledge have been highlighted.

Contents

1 Introduction

In our area of applied technical research, an introduction starting with *"Already the ancient Greeks…"* is commonly used to make fun of writings that are perceived as too philosophical for us to grasp. For this report, that phrase could be exactly right, not that we intend to be too philosophical, but because the concept and the nature of knowledge have been an issue for a long time.

In our research we come across "*knowledge*" in many different forms. Of course we struggle with it ourselves, since research aims to build new knowledge. So, we often ponder upon questions about knowledge, ranging from philosophical to theoretical to practical topics. Knowledge is important to most firms, not to say all organizations, and its management is of utmost concern. To reflect this, the European Union set itself a goal in the Lisbon Strategy (2000), "*to become the most competitive and dynamic knowledge-based economy in the world, capable of sustainable economic growth with more and better jobs and greater social cohesion"*, thus recognizing the importance of knowledge for innovation and growth.

There are many CEO's that agree to the statement *"I wish we knew what we know"*[1]*,* because doing so would certainly contribute in becoming a world leading company. At a practical level of abstraction, the challenges of knowledge management could be summarized into these questions:

- How can we identify our knowledge assets?
- How can we capture and formalize knowledge?
- How can we disseminate and reuse the knowledge?

Donald Rumsfeld, U.S. Defence 2001-2006, has been met with sarcasm in media and at YouTube[2]. But, he highlights important aspects when he coins the terms that there are:

- things that we know and also know what it means (known knowns),
- things that we know we should have, but we know that we miss (known unknowns),
- things that is unknown to us and we do not even know that we are missing (unknown unknowns)

---

[1] A commonly cited quote from Lew Platt, chairman of Hewlett-Packard. See for example; O'Dell & Grayson Jackson (1999).

[2] http://www.youtube.com/watch?v=jtkUO8NpI84

We all feel familiar with the lack of information that Rumsfeld talks about, especially when faced with a vital decision. Hence, knowledge management could also be summarised into these questions:

- How can we know what we know?
- How can we know what we need to know?
- How can we make our knowing organizational?

The two groups of questions presented above could represent what literature describes as a first and a second wave of knowledge management (Ackerman, Pipek and Wulf, 2003). The first wave is described to have the meaning to control and monitor knowledge flows. Knowledge is in this perspective managed as if it is an object, that is, *it* can be transferred from one instance to another. Typically, facts, measures etcetera are carriers of this type of knowledge. Support systems based on this view are common in companies today. These systems can be categorized as expert/knowledge systems and offers possibilities to keep track of the knowledge and the option to follow up the status. Such systems are commonly built upon knowledge rules that need to be upgraded and refined, often by a system manager, as new knowledge emerges. This kind of knowledge management systems can be described as "*heavyweight*", due to, for example, the lack of compatibility between different companies[3] and the resources needed to maintain them.

The second wave of knowledge management is described by Ackerman et al. (2003) to have the meaning of empowering people by providing possibilities to learn. The view of knowledge is that it is subjective and socially constructed, e.g., knowledge emerges when people jointly solve a problem. Seen from this perspective, knowledge is contextually dependent and commonly explained as having a high degree of "stickiness", for instance, we recall a previous situation to compare if there are any similarities when facing a new and problematic situation (Schön, 1995). The team asks the question: "*have we done this before?*"

It has been highlighted that 80 % of organizational knowledge is stored in people's heads, 16 % is stored as unstructured data, and only 4 % is formalized in a structured form (Bell, 2006). The interest for another type of support to provide knowledge build up and expertise sharing has risen from these insights, often categorized as social media or Web 2.0. The knowledge base in social media is dynamic and the users manage the content. This kind of knowledge management systems can be described as "*lightweight*", because they do not, for example, require a particular infrastructure (except Internet) to connect companies and they are continuously maintained by those who use it.

Commonly, the first wave knowledge management is well established in manufacturing industry, for example, in Knowledge Based Engineering (KBE), Product Data Management (PDM) and Product Lifecycle Management (PLM) systems. This fact has two sides. First, knowledge management has priority; this is really good. Second, to propose complementary ways will be a hard sell, since it can be perceived as a shift in

---

[3] Note that we here delimit the argumentation and do not consider issues like security and protecting knowledge leakage.

paradigms (Kuhn, 1996). Typically, a paradigm shift challenges the established modus operandi in an area. This is a time of debate and gate keeping, until a new knowledge base is developed. Practically, the change of paradigm impacts how every-day work is approached and conducted. Today, industry has recognised that the established knowledge management approaches do not provide sufficient support for the expected future challenges. Basically, there are differences in how to approach the knowledge management quest, see Table 1.

Table 1. Differences in approaches (adapted from Huysman and de Wit, 2002)

	1st wave approach	**2nd wave approach**
Why is knowledge shared?	Managerial purposes	Daily work
When is knowledge shared?	When there is an opportunity to do so	When there is a need to do so
Where is knowledge shared?	Operational level	Organization-wide
Whose knowledge is managed?	Individual: Human Capital	Collective: Social Capital
What knowledge is shared?	Codified	Tacit and codified
How is knowledge shared?	Repository systems and electronic networks	Via personal and electronic networks

Based on the assumption of such differences, the first purpose of this report is to conceptualize different facets of knowledge within a framework of technical product development. In this report, the naming of the two categories as *first wave/heavyweight support* and *second wave/lightweight support* is done only for the possibility to separate and compare them, not to favour one or the other.

The second, more practical, purpose of this report is to serve as a trigger for discussions in industrial workshops where the idea is to reflect on the existing practices. An expected result from the report and workshops is to inspire company representatives to start reflect on two core questions related to knowledge:

- What is actually managed in every-day engineering project work?
- And, for what purposes?

This report will conceptualize the many facets of knowledge within a framework of technical product development. We will present knowledge aspects, as they are opposites, making an effort for engineers to start to compare and contrast, as we have started to do with knowledge management in this chapter. From time to time it may look like we are favouring the softer aspects, that is, the second wave knowledge management and expertise sharing. We acknowledge that both aspects are necessary in the knowledge economy. A "double" perspective is a challenge in manufacturing industry, hence also the intriguing part in our research projects. In the long run, our research projects aim to support manufacturing industry to make use of a more extensive knowledge base.

2 What is knowledge?

Product development now includes social interplay, creativity, innovation, cross-company collaboration and the integration of two separate logics, namely goods and services, just to mention a few challenges. Going deeper into the concept of knowledge might give some generic characteristics that would provide useful insights for what needs to be managed.

2.1 Data – information – knowledge

In literature on information systems (e.g., Frické, 2009) the distinction between data, information and knowledge is vital. Data is the raw material consisting of figures, letters or similar in no particular order, coming directly from an instrument (note here that a human being can be seen as an instrument) without any processing being made. For example data can be the numbers:

2 1 0 4 1 0 1 0

To achieve information out of the data a coding key is needed, in this case it is a date:

01.04.2011

And, at least in many western countries the date April 1 is known as April's fool day; so the lessons learned is to take some statements with a grain of salt[4]. A context is needed to transform the information into knowledge. Thus, knowledge is contextually dependent (Nonaka et al., 2000) and could be interpreted differently depending on its context. Consequently, what is knowledge for one person could be information for another, or even in a worst case remain as just data.

The implicit assumption is that data can be used to create information; and that information can be used to create knowledge. The DIKW pyramid (Data, Information, Knowledge and Wisdom), in Figure 1, puts the terms into a hierarchy illustrating that large amounts of data can be distilled to a smaller quantity of information. The range of information can be further distilled into a limited amount of knowledge (Hey, 2004).

[4] Note that the report is not written on April 1.

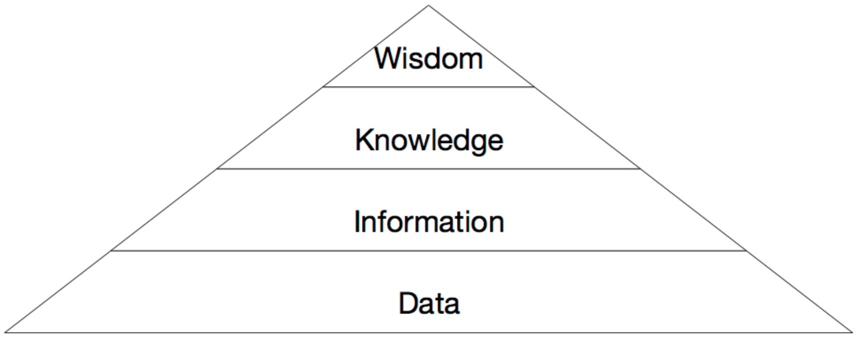

Figure 1. The DIKW pyramid (adapted from Frické, 2009)

Simplified, knowledge comes from the reflection on accumulated data and information that is put into a (new) context. In this learning process patterns can be found and, by doing *and* reflecting, experience will evolve. Data and information is about looking at the past, and could thus be gathered, stored and reused. Knowledge enables people to interpolate the data and information in order to deal with the present and make up strategies for the future.

The DIKW *pyramid* as a visual metaphor is controversial. First, the relation from knowledge to wisdom is found to be too vague. When and how does knowledge become wisdom? Second, the use of a pyramid illustrates that the higher aspects are more valuable, that knowledge is more valuable than information or data and that wisdom is well worth to strive for (Stenmark, 2001). The pyramid provides a view of a one-way direction of progress, from data to wisdom. But, there is also a feedback down the pyramid (Jennex, 2009), since our pre-existing knowledge guides which data to collect and how to measure or assess it (Tuomi, 1999). Third, the pyramid seems to assume that all knowledge is precise and always originates from data and information, i.e., it provides a too simplified picture of the relations. The pyramid visualisation disregards knowledge coming from sources like learning, experience and intuition. Making sense of data and information is a process of reflection that is formed in the mind of the interpreter (Schön, 1995; Stenmark, 2001). In industry, the work is often learned through practicing and gaining experience, and not so often through reading information sheets. It could even be that you re-invent the wheel (i.e., doing the same experiment), because the documented information is insufficient to convey the necessary knowledge.

2.2 Tacit and explicit knowledge

Basically, literature distinguishes between two broad categories of knowledge, tacit and explicit (e.g., Nonaka, 1991; Nonaka, Toyama & Konno, 2000; Holste & Fields, 2010). Tacit knowledge is more depending of a context before we can understand it, and explicit knowledge does not need that relation in the same degree. Experience is an example of tacit knowledge, i.e., we cannot readily articulate that kind of knowledge. Experiences often refer to "know-how", i.e., practical knowledge in a specific context, (Ipe, 2003) rather than "know-what", i.e., facts. Riding a bike is typically know-how and thus builds on tacit knowledge that is difficult to explain. In some cases, we do not know unless we have experienced the consequences, and sometimes we can identify the consequences beforehand. The idea of knowledge as being theoretical (erudition) or practical (skills) could be useful in parallel with this discussion of tacit and explicit. In plain language, we talk about knowing or doing and in the same vein describe a contradiction. But, knowing and doing is intertwined, and we have to apply our pre-existing knowledge as a coding key for building new knowledge (Schön, 1995).

2.2.1 Conceptual, experiential and directional knowledge

Other concepts of knowledge could be exemplified with (Johnson, 2007, pp. 17-18):

- Conceptual knowledge – theories, mental models, schema, categories, criteria, maps, heuristics, rules of thumb and recipes that are abstracted from experience. These are used as tools for understanding, for example relationship, cause and sequence. Taking lectures on car driving could exemplify this type of knowledge.
- Experiential knowledge – comes directly from doing, develops the sensitivity and skill acquired through practice, the ability to use skill with accuracy, reliability and finesse. Driving a car could exemplify this type of knowledge.
- Directional knowledge - provides the orientation for practice, includes cultural and disciplinary paradigms, social identities, stance, values, roles and motivations. Typically, directional knowledge is taken for granted. This kind of knowledge point organisations in different strategic directions.

2.3 Information in use

A more practical description of knowledge is found in the expression - *knowledge is information in use* (Turban, Aronson, 2000). The description of information as a *"flow of messages"* (Frické, 2009), also indicate that being informed does not necessarily mean that you have the capability to take actions. Product development could be described as the *"… process of gradually building up a body of information until it eventually provides a complete formula for manufacturing a new product"* (Smith & Reinertsen, 1991, p. 158). In light of a difference between information, explicit and tacit knowledge as presented in previous chapter, the missing pieces in the quote are context and someone who can make sense of the information.

2.4 The human factor

Andrew Harrison, Rolls-Royce plc. UK (2011), explained that *"The biggest problem we got is people"* when talking about knowledge management and decisions in technical product development. By that, he highlighted that the *"human factor kicks in"* and making decisions and taking actions are more complex than we first acknowledge. Knowledge management was explained as an approach that should derive incremental value from decisions informed by real operational experiences to define the operational purpose. Harrison provided an overview of how value is built up starting from experience (see Figure 2).

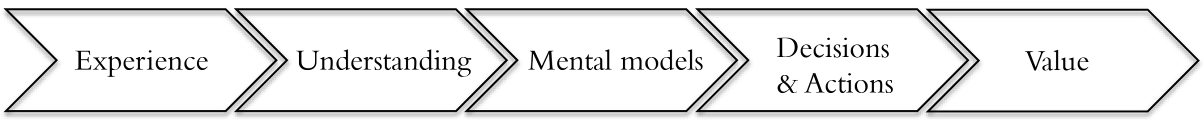

Figure 2. Incremental build up of value (source Harrison, 2011).

Based on his explanation, Harrison stressed the challenges to gain understanding, these are:

- Inaccessible – 'I can't find it when I need it'.
- Unusable – 'not in a format I can use, i.e., too detailed or too vague'.
- Unmotivated – 'I choose to ignore it, i.e., not invented here syndrome, does not fit my existing mental model'

Further, he exemplified how our experience, thinking and reasoning constrains and delimits our mental models by presenting The McGurk Effect (BBC, 2010) and The Spinning Dancer (Wikipedia, n.d.). By this he showed how our brains sometime mislead us and how the human factor kicks in when judging the knowledge/ information at hand relevant or not.

People also perceive a situation differently, thus affecting how they search for information to guide their decisions and how they gain knowledge from their doing. Mintzberg and Westley (2001) discuss three different approaches, namely thinking first, seeing first and doing first. In parallel, people make often either/or assumptions of the situation they are facing, that is, they interpret the situation as either certain or uncertain (Courtney, Kirkland & Viguerie, 1997). If the situation is perceived as certain, people tend to believe that the future is possible to predict precisely, see the left square in Figure 3. And, if the situation is perceived as uncertain people tend to consider that the future as completely unpredictable, see the right square in Figure 3. People that experiences very uncertain environments might not trust their gut-feelings and thus, suffer from decision paralysis. They focus instead on reengineering, quality management or internal cost-reduction programs instead (Courtney, Kirkland & Viguerie, 1997). The identification of a range of potential outcomes or even a discrete set of scenarios is a simple insight that is extremely powerful to determine which strategy is best (Courtney, Kirkland & Viguerie, 1997), see the two middle squares in Figure 3.

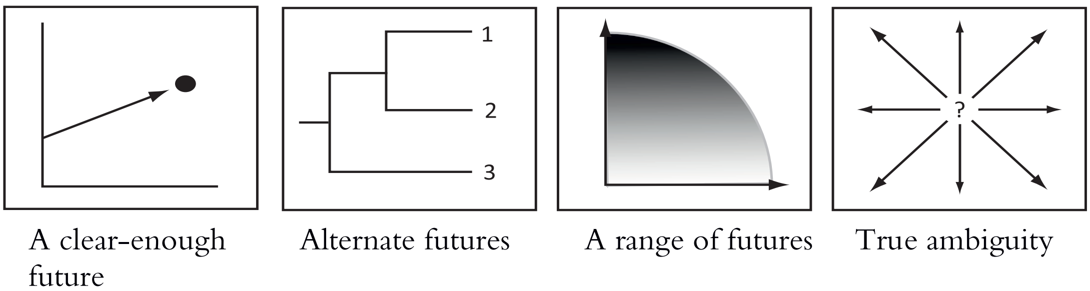

Figure 3. Decision styles (after Courtney, Kirkland & Viguerie, 1997)

3 What is technical knowledge?

Over time, the perception of what kind of knowledge that is important in a technical context has shifted. Based on the result of a search in a so-called corpus[5] we have extracted two word clouds, visualising the context that the word is being used in. Word clouds visualise the most used words by increasing the font size of the word/s. In the search we had the word knowledge as a key and queried the corpus to provide strings of text (the words before and after the keyword "knowledge") from documents containing the keyword more than 10 times. We will not claim that the corpus search has been done according to the standards of linguistic research, but the result can serve as an indication of a changing trend of engineering knowledge.

In the first word cloud the interests in academic technical journals during 1994 - 1998 are compiled, see Figure 4.

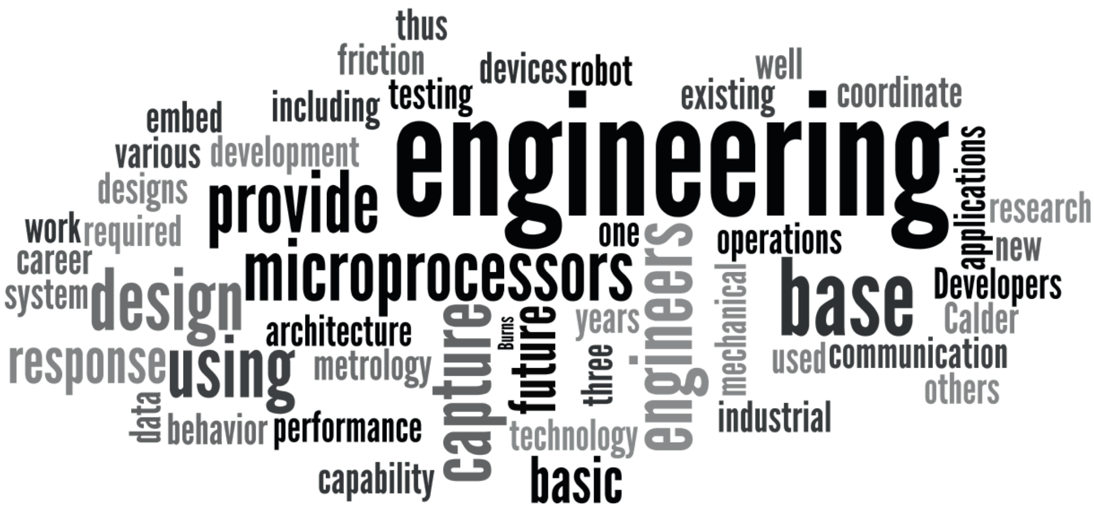

Figure 4. Word cloud, illustrating interests during 1994-1998.

In Figure 4 above, the word engineering is displayed in the largest font size and microprocessors, base, capture, design and engineers are displayed having the second largest size. The surrounding words, e.g., architecture, technology, response,

---

5 The search was performed in the Corpus of Contemporary American English, http://www.americancorpus.org, extracting text strings from sentences in Journal of Mechanical Engineering where the word, *knowledge*, is included more than 10 times in the same document. Briefly, a corpus is large and structured set of texts, today often in electronic format, and is commonly used in research about the human language.

applications, coordinate, embed, devices, and mechanical, could be thought of as a context. The word cloud illustrates the commonly used words related to "knowledge" in academic technical journals during that time, but also the relative importance among them. Based on the assumption that research published in technical journals mirrors manufacturing companies' needs, the word cloud provides some tentative indicators for the knowledge focus during the time period 1994-1998.

During this time, the computer support for technical product development was evolving fast, where a few large companies could be perceived as forerunners. For example the Boing 777 was the first commercial aircraft to be designed entirely in a computer environment (Eden, 2008; Norris and Wagner, 1999). In this project, they were pioneers using the 3D CAD software CATIA (Computer-Aided Three-dimensional Interactive Application) sourced from Dassault Systemes and IBM (Norris and Wagner, 1999). The use of software made it possible to not only assemble a virtual aircraft, but also to check for interferences and to verify proper fit of the many thousands or parts before producing any of them. The software approach not only assures a robust design, but also reduces costly rework. And, consequently, knowledge related to the development, use and impact of such support was in focus.

Figure 5. Word cloud, illustrating interests during 2007 - 2010.

The indicators of knowledge interests during the time period 2007 – 2010 are compiled in the word cloud shown in Figure 5. In this cloud, the words abilities and skills are highlighted with the largest font size. Words like engineering, engineers, understanding, and needs are displayed with a medium font size. And, the surrounding words, for example process, current, expertise, content, application and human indicate a different background than in the word cloud for 1994 – 1998. It might be possible to discern that the development and implementation of computer support for engineering tasks seem to be solved, or at least not a key concern any longer. Instead, the established support might provide possibilities for engineers to develop expertise in additional knowledge areas. The advances in information technology and the skills in developing supporting engineering software have had a beneficial impact on the product development activities. And, over time the use of engineering software systems has become an established approach. Though, based on the interest indicators in the word clouds, it might be possible to assume that the grand challenge for contemporary manufacturing companies can be found within the social and more human aspects of product development.

3.1 Capabilities of an engineer

This report, like our research perspective, originates from product development literature and our research efforts aim to contribute to the engineering area. Based on this perspective, an engineer, or a product developer, is someone who design and develop the technical solutions for a physical product, i.e., provide solutions for its function. Pugh (1991) states that "*It is an acknowledged fact that all products are manufactured…*" (p.148), and could exemplify the established and very firm relation of product development and the domain of mechanical engineering. Typically, the area of industrial design, which also is based on engineering skills and focus on product development, builds on a different type of literature. And, the industrial design engineer has in practice often a sphere of sovereignty in "giving shape" to products. So, in this report, an engineer or a product developer is a person who possesses key capabilities that relates to the development of the technical functions of a manufactured product[6].

Typically, in large manufacturing companies an engineering education is a base for different positions. For instance, engineers can work with technology development or method support, as a technical salesman, as a specialist within a certain area or as a leader of an advanced engineering project. Mechanical engineering is commonly presented as the widest and most "open" type of education for Masters of Science engineers where the students could expect to be offered a variety of positions (see for example Luleå University of Technology, Chalmers and KTH).

The underpinning idea of the mechanical engineer as the person who handles all activities in product development, from early phases of business planning and idea generation to the product launch is established in literature. The idea that engineers need to possess knowledge from outside the realm of what is commonly perceived as core engineering is established in product development literature. For example, the skills to handle customer information and innovation problems are mentioned (e.g., Ulrich & Eppinger, 2008; Ullman, 2003), but also the capability to manage the social dimensions of collaborative work is stressed from some authors (e.g., Bucciarelli, 1994; Cross, 2001).

The proposed characteristics that an engineer should possess are extensive. For example, Hubka and Eder (1996) describes what knowledge, skills, characteristics and so forth that an ideal engineer or product developer should possess, see Table 2.

[6] By this definition we delimit the perspective in the report to not include, for example, system engineers and infrastructure engineers. Though, a core message of this report is the necessity to collaborate in multi-functional or multi-disciplinary teams.

Table 2. Characteristics of an ideal engineer, Hubka & Eder 1986.

Knowledge, Understanding	Abilities, skills, faculties	Personal characteristics, attitudes
General knowledge	Memory	Productivity
Languages	Logical thinking	Perseverance
Literature	Synthesis ability	Willpower
History	Cost awareness	Honesty
etc.	Visualization abilities	Responsibility
Mathematics	Combination gift	Duty awareness
Geometry	Creativity	Openness
Physics	Mental flexibility	Thoroughness
Chemistry	Methodical working mode	Conscientiousness
etc.	Information procuring	Care
Technical branch knowledge	Decision ability	Contact readiness
Basic	Representation ability	Broad horizons
Specialized	Concentration ability	Objectivity
Design	Punctuality	Critical attitude (including self-criticism)
Manufacturing	Leadership	Self-confidence
Materials	Organization	Enthusiasm, delight in designing
etc.	Orderliness	Readiness for cooperation
National economics	Personal bearing	Constant study
Legal knowledge	Precise expression	Fairness
Psychology	Persuasive power	Psychological typology
Ergonomics	*etc.*	Psychic stability
etc.		*etc.*

Rolls-Royce states in an advertisement (Rolls-Royce, 2008) a more contemporary view on the attributes they expect of all their employees; of which a lion part actually are engineers. They expect (quote from webpage):

- *"Courage and integrity – people should demonstrate the drive, commitment and courage to, in an ethical and professional manner, contribute to the company objectives."*
- *"Judgement – to draw accurate conclusions, people should be able to analyse a variety of information and be able to use sound reasoning."*
- *"Breadth and business understanding – to develop products, services and strategies people should apply business knowledge and awareness."*
- *"Influence and working together – recognizing that people influence each other, effective communication and adapt behaviour appropriately is a key."*
- *"Delivering and managing work – people impact positively on business performance through decisions and actions that deliver results."*

Such a wide range of social and human knowledge is not a core part of the engineering educational programmes, but could be discerned as being part of the last year of the programmes (see for example Luleå University of Technology, Chalmers and KTH). Hence, it can be assumed that the main part of such skills is developed in practice when solving technical problems, e.g., becoming an experienced engineer.

3.2 The shape of technical knowledge?

Given that the range and variety of skills and knowledge are so wide and encompassing, every assignment has to be delimited in some way. Also, the physical product is itself in a state of flux (Andreasen & Hein, 1987). That is, things happen during the way from idea to product launch, which often calls for additional expertise areas than what was originally planned for. For instance, the idea of Tiger Teams (Ashley, 1992), a team that dedicates all of their efforts to solve a specific development problem to assure that the whole process is not delayed, is one approach to manage the need of expertise in development projects.

The ability to conceptualize the dynamics of a development process is an important quality for an engineer, i.e., to reflect on the situation at hand and be able to reframe the activities (Schön, 1995) in order coordinate and adapt the original plan. Also, this is important since the real and actual situation is different from the company's description of its development process (Engwall, Kling & Werr, 2005). So, the paradox of converging information and preserving ambiguity throughout the development process is part and parcel of engineering activities. By this, it can be assumed that the "shape" of technical knowledge changes in the stages from idea to product launch.

For the purpose to provide a research focus, Edeholt (2004) discusses how knowledge areas could be delimited. He proposes four different shapes, which all cover the same area. The two first shapes, from the left in Figure 6, focus on the widest possible breadth or on the maximum depth. This aligns with the discussions about staff as being generalist or specialist, which flourished in Sweden during the 1980's – 1990's. Further, Edeholt draws on how research is evaluated and concludes that depth usually represents knowledge (e.g., being a specialist of a small area) and width represent lack of knowledge (e.g., possessing shallow information of several areas). He asks the provocative question: *"Why not perceive the deep specialisation as bigotry and the shallow breadth as being broadminded?"* (Edeholt, 2004). The last two shapes at the right in Figure 6, illustrate a T-shaped volume of knowledge (e.g., possessing a broad understanding of several areas and a deep analytical expertise in one of them) and a squared shape covering equal breadth and depth (e.g., possessing expertise and understanding of a specific area).

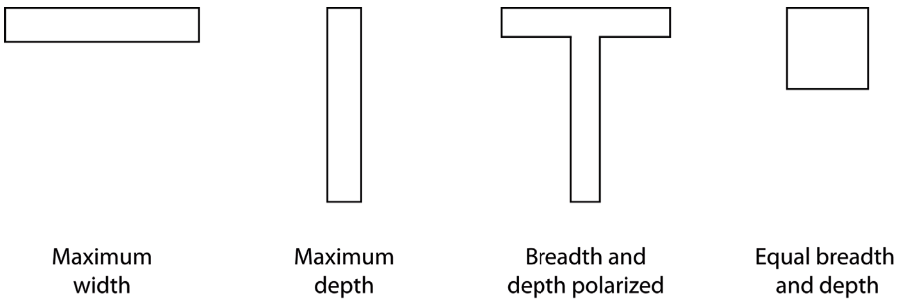

Figure 6. Different shapes of knowledge, all figures have the same area (adapted from Edeholt, 2004)

Being skilful could be described as having deep familiarity within a discipline and the capability to search for the unexpected. Such a stance usually leads to *"…results, products and performances that can unsettle and even surpass the status quo."* (Johnson, 2007, p.13).

3.3 T-shaped people's knowledge

In recent time, the engineers' broader capabilities have gained interest from other perspectives than what is commonly defined as core engineering. The basic idea that engineers should deal with the whole range from customer information via problem definition to problem solving is not new, already over 40 years ago the issue was addressed by Robert McKim, at the time head of Stanford University's product design program (Patnaik & Becker, 1999). This school of thoughts origin from traditional product development literature, and could be described as ranging from Engineering Design (for example Hyman, 2003) to Design Thinking (for example Brown, 2008). Hyman (2008) coined the metaphor of a design swamp to describe the ambiguous aspects of engineering practice and research, i.e., that engineering design to a large extent does not depend on universally applicable laws of nature. Design thinking is a stance that builds on other capabilities than seemingly does not directly bear on engineering design, for example (Brown, 2008, p. 87):

- *Empathy* – capabilities to apply multiple perspectives, i.e., to view the situation from the point of view of, e.g., colleagues, clients, users and customers (current and prospective). Practically, this means to always take a 'people first' approach to observe, identify and meet human needs.
- *Integrative thinking* – capabilities to see all of the salient aspects of a problematic situation and not relying on either/or choices. Practically, this skill is needed to go beyond existing alternatives.
- *Optimism* - believing that at least one potential solution is better than the existing alternatives. Practically, this capability transforms the challenging constraints of a given problem into opportunities.
- *Experimentalism* – posing questions and explore the situation in creative ways. Since innovation does not come from incremental tweaks, this capability offers practical skills to find solutions that go into entirely new directions.
- *Collaboration* – being enthusiastic interdisciplinary collaborators with significant experiences in more than one discipline.

Basically, the extension of the engineer's skills and capabilities could be visualised as T-shaped knowledge (Winograd, 2008). People that possess T-shaped knowledge and capabilities *"… maintain the depth and focus of a single discipline while adding a "crossbar" of design thinking that drives the integration of multiple perspectives into solving real problems."* (Winograd, 2008).

3.4 A modern engineer?

The vision of new businesses based on services and knowledge intensive work (Tukker & Tischner, 2006; Drucker, 1998) could be a prelude for a paradigm shift for manufacturing companies. Meaning that new arguments and directions of interest will challenge the existing domains of knowledge. The pillar of products as being tangible, goods or manufactured things is the inherent viewpoint for engineers and, subsequently perceived as the core of engineering knowledge. But, the new business will surely challenge that posture since services and knowledge are by nature intangible and human dependent. Already today, industry representatives perceives that 80 % of work is spent to figure out how to collaborate, how to frame and approach the development task, i.e., only 20 % is spent on what is described as typical engineering work.

Shifting perspectives that challenge the established ones is "natural" and also the engineering community have experienced such shifts. Looking back to the beginning of 1900 in Sweden, two conflicting engineering ideals could be seen, namely one advocating a firm technical competence and one suggesting an extension towards also economical and organisational knowledge areas (Sundin, 1981). This situation could also be described as a clash between a focus on knowledge areas for, on one side, theory and science and on the other practice and industry. The spokesmen[7] for the latter perspective stated that the engineers' most important task was to balance the economical, organisational and the technical considerations, and they questioned the minimal training in those subjects that was provided in education during that time. So far, the inspiration for progress in the engineering education and practice came from Germany. Around 1910, F.W. Taylor and his "Scientific Management" (commonly mentioned as Taylorism) had an impact on the Swedish community of engineers (Sundin, 1981). Scientific Management offered an association between economics and organisation that fitted the more traditional engineering perspective of technical knowledge. In the same vein, it offered a solution for how to bridge the two strands and ended the debate. Though, the pillars of Taylorism, e.g., specialization, standardization, mass-production, controls on the working force and increased intensity of work, had the same impact on the knowledge domains of engineering. Over time the engineer became just a cog in the machinery, e.g., solved specified problems, and the years in the midst of 1900 did foster such an approach (Sundin, 2006).

Again, the vision of a knowledge economy, with all the facets of collaboration and globalization, challenge the management of engineering knowledge. Today, with all the advances in technology and support, knowledge management can provide solutions. Knowledge management can in its widest description be *"…a formal, directed process of determining what information a company has that could benefit others in the company and then devising ways to making it easily available."* (Liss, 1999, p. 1). Hence, it is a key to understand what is the practical "engineering knowledge" that is set into actions in real-life product development projects before suggesting the third wave of knowledge management. A core questions is: *What is typical engineering knowledge today?*

[7] Yes, they were all men. Greta Woxén graduated 1928 at KTH and become the first civil engineer in Sweden (Wikipedia).

References

Ackerman, M., Pipek, V. and Wulf, V. (Eds.). (2003). *Sharing Expertise: Beyond Knowledge Management,* MIT Press, Cambridge, MA, USA.

Andreasen, M. M., Hein, L. (1987). *Integrated Product Development,* Springer-Verlag, UK.

Ashley, S. (1992). Initiative in concurrent engineering. DARPA, Defence Advanced Research Projects Agency. *Mechanical Engineering-CIME*, April 01, 1992.

Bell, S. (2006). *Lean enterprise systems: using IT for continuous improvement*. John Wiley & Sons, Hoboken.

Brown, T. (2008). Design Thinking. *Harvard Business Review*, June: 85-92.

Bucciarelli, L. (1994). *Designing Engineers,* MIT Press

Chalmers (2011). In Swedish: http://www.chalmers.se/sv/utbildning/program-pa-grundniva/Sidor/Maskinteknik.aspx, accessed 2011-11-01.

Courtney, H., Kirkland, J., Viguerie, P. (1997). Strategy under uncertainty, *Harvard Business Review*, November-December: 67-79.

Cross, N (2001). Designerly ways of knowing: design discipline versus design science. *Design Issues,* 17(3): 49–55.

Drucker, P. F. (1998). The Discipline of Innovation, *Harvard Business Review*, November-December: 149-157.

Edeholt, H. (2004). Doctorial Thesis: *Design, Innovation och andra Paradoxer - om förändring satt i system* (In Swedish). Chalmers University of Technology, Göteborg, Sweden.

Eden, Paul, ed (2008). *Civil Aircraft Today: The World's Most Successful Commercial Aircraft*. London: Amber Books Ltd. ISBN 1-84509-324-0.

Engwall, M., Kling, R. and Werr, A. (2005). Models in action: how management models are interpreted in new product development. *R&D Management*, 35: 427-439.

Frické, M., (2009). The knowledge pyramid: a critique of the DIKW hierarchy. *Journal of Information Systems* 35(2): 131-142.

Harrison, A. (2011). *Keynote speech*, CIRP IPS2 Conference in Braunschweig, May 5, 2011.

Hubka, V., Eder. E. (1996). *Design Science: introduction to the needs, scope and organization of engineering design knowledge,* Springer Verlag, London.

Holste, J., Fields, D. (2010). Trust and tacit knowledge sharing and use. *Journal of Knowledge Management,* 14**:** 128-140.

Huysman, M.H., D de Wit (2002). *Knowledge Sharing in Practice,* Dordrecht: Kluwer Academics Publishers.

Hyman, B. (2003). *Fundamentals of Engineering Design*. 2nd edition. Prentice-Hall, USA.

Ipe, M. (2003). Knowledge Sharing in Organizations: A Conceptual Framework, *Human Resource Development Review* 2(4): 337-359.

Jennex, M. E. (2009). *Re-visiting the Knowledge Pyramid*. Proceedings of the 42nd Hawaii International Conference on System Sciences.

Johnson, H. A. (2007). Artistry for the strategist, *Journal of Business Strategy*, 28(4): 13-21.

Krishnan, V., Ulrich, K.T. (2001). Product Development Decisions: A Review of the Literature, *Management Science*. 47(1): 1-21.

KTH (2011). In Swedish: http://www.kth.se/utbildning/program/civilingenjor/maskinteknik, accessed 2011-11-01.

Kuhn, T.S. (1996). 3rd edition. *The Structure of Scientific Revolutions*, University of Chicago Press, Chicago, IL.

Lisbon Strategy (2000). Accessed 2011-11-06. http://www.consilium.europa.eu/uedocs/cms_data/docs/pressdata/en/ec/00100-r1.en0.htm

Liss, K. (1999). Do we know how to do that? Understanding knowledge management, *Harvard Management Update*, February: 1-4.

Luleå University of Technology (2011). In Swedish: http://www.ltu.se/edu/program/TCMAA, accessed 2011-11-01.

Mintzberg, H., Westley, F. (2001). Decision making: it's not what you think. *MIT Sloan Management Review*, Spring: 89-93.

Nonaka, I. (1991). The knowledge-creating company, *Harvard Business Review,* November-December: 96-104

Nonaka, I., Toyama, R. and Konno N. (2000). SECI, Ba and Leadership: a Unified Model of Dynamic Knowledge Creation, *Long Range Planning*, 33(1): 5-34.

Norris, G., Wagner, M. (1999). *Modern Boeing Jetliners*. Minneapolis, Minnesota: Zenith Imprint. ISBN 0-7603-0717-2.

O'Dell, C., Grayson Jackson, C. (1999). If Only We Knew what We know: Identification and transfer of internal best practices, *California Management Review*, 40(3): 154-174

Patnaik, D., Becker, R. (1999). Needfinding: The Why and How of Uncovering People's Needs. *Design Management Journal*. 10(2): 37-43.

Pugh, S. (1991). *Total Design – integrated methods for successful product engineering*. Addison-Wesely Publishing Company. United Kingdom.

Rolls-royce, (2008). Available from: http://people.rolls-royce.com/careers/workingforus/what_we_look/ [2008-12-08]

Rumsfeld, D. YouTube: Known unknowns, 27 Nov, (2006). Available from: http://www.youtube.com/watch?v=_RpSv3HjpEw [25 Aug, 2011]

Schön, D. A. (1995). *The reflective practitioner: how professionals think in action*. Aldershot, Arena

Smith, P.G., Reinertsen, D.G. (1991). *Developing Products in Half the Time,* Van Nostrand Reinhold Book, USA.

Stenmark, D. (2001) 'The Relationship between Information and Knowledge', *Paper presented at the 24 th Information Systems Research Conference in Scandinavia, August 11-14, 2001.* Ulvik, Norway.

Sundin, B. (2006). *Den kupade handen: historien om människan och tekniken* (In Swedish). Scandbook, Stockholm.

Sundin, B. (1981). *Ingenjörsvetenskapens tidevarv* (In Swedish). Doktorsavhandling, Humanistiska fakulteten, Umeå Universitet. Sweden.

BBC, YouTube: The McGurk Effect, 10 nov, 2010. Available from: http://www.youtube.com/watch?v=G-lN8vWm3m0 [26 Aug, 2011]

Tukker, A., Tischner, U. (2006). Note from the field: Product-services as a research field: past, present and future, Reflections from a decade of research. *Journal of Cleaner Production*, 14: 1552-1556.

Tuomi, I. (1999) 'Data is More than Knowledge: Implications of the Reversed Knowledge Hierarchy for Knowledge Management and Organizational Memory', *Journal of Management Information Systems*, Vol. 16, No. 3, pp.107-121.

Turban, E., Aronson, J. E. (2000). *Decision Support Systems and Intelligent Systems,* 6th edition, International, Upper Saddle River, Pearson Education.

Ullman, D. G. (2003). *The Mechanical Design Process,* 3rd edition, McGraw-Hill, New York.

Ulrich, K.T., Eppinger, S.D. (2008). *Product design and development,* 4th edition, McGraw Hill.

Wikipedia, The spinning Dancer Illusion, (n.d.) Available from: http://upload.wikimedia.org/wikipedia/commons/2/21/Spinning_Dancer.gif [26 Aug, 2011]

Winograd, T. (2008). Design Education for Business and Engineering Management Students: A New Approach, *Key Process, Management & Organizational Interactions,* January-February 2008: 44-45.