THESIS FOR THE DEGREE OF LICENTIATE OF ENGINEERING

THE MEDIATING ROLE

OF

PRODUCT REPRESENTATIONS

A Study with Three Dimensional Textiles in Early Phases of Innovation

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CHALMERS UNIVERSITY OF TECHNOLOGY
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Cover: The illustration represents the Users and the Designers coming together in a co-design process, facilitated by textile representations.

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ABSTRACT

Smart textiles are understood as textiles, where new functions are integrated to form a textile system that can react and interact with the environment. These new textile systems place completely new demands on the actors in the development process. With smart textiles at hand, the textile sector is almost facing a paradigm shift, which requires new manufacturing techniques; new ways of working and new roles need to be developed. New collaborations across disciplinary boundaries need to be created in order to generate new innovative products.

Research state that it is of paramount importance that users are involved as early as possible in the development process of innovative products, the argument being that they possess knowledge regarding the product and its everyday use, which is lacking among designers. However, such user involvement may be limited to users acting as informants or as evaluators, but the involvement can also develop into the user becoming a member of the multidisciplinary team, a co-designer representing his/her own discipline. This is argued to facilitate the recognition of user needs and taking of them into consideration in the development process. However, such teams also face a number of challenges. One of the challenges is that the team members often lack a common language and use of terms, as they need to establish cross-disciplinary communication in order to successfully specify a common goal. Furthermore, it is necessary to convert knowledge from one area of expertise into information, which is comprehensible to someone with other experiences and skills, as this makes the knowledge valuable to a individual, who has a different background or views the problem from a different perspective.

The case presented in this study concers a project where a multidisciplinary team was gathered to explore the possibility of using three-dimensional weaving techniques combined with smart textile technology to solve a clinical problem in long-term monitoring of brain activity (EEG). In the project, textile product representations were developed iteratively in collaboration with the user of the future product.

The studied case aimed to understand how product representations can facilitate the dialogue in multidisciplinary teams in order to bridge the gap between users and designer. The analysis of the data reveals the importance of the product representations mediating the discussions and the sharing of knowledge but also that the product representations played different roles in the process. Five different roles were identified, the roles have further been categorized into two main groups: explanatory and concrete roles and more proactive roles.

The explanatory roles are defined such as;
- 'verbaliser' serving as a facilitator to fill in where words as missing or terms are not understood,
- 'demonstrator' helping to concretize questions and answers between the user and the designer.

The more proactive roles were defined as;
- 'visualisers' which denotes situations when representations support individuals to recall or evoke mental images,
- 'stimulators' that support the generation of new ideas or design solutions and the progression of new ideas and new shared knowledge in the project, and
- 'integrators' that support the integration of perspectives between different disciplines and unites different perspectives in the team.

The conclusion of this study is that the representation supports and facilitates the collaboration and communication across disciplines, bridging gaps and generating new shared knowledge.

ACKNOWLEDGEMENTS

This project has evolved into something I could not foresee, when I began my research journey, and opens new doors to how research in textile development can be pursued. I would firstly like to thank my main supervisor Professor MariAnne Karlsson, who is the foremost door opener to this research approach. She has by solid pedagogy, depth of knowledge, delightful humour and with one or two encouraging hugs shown me the path to these new and exciting research venues.

Dr. Leif Sandsjö, my advisor, who has been a remarkable support through thick and thin and without whom I had never taken me all the way to where I am today. Leif, with his mixture of humour, patience and ability to twist and turn questions such that new answers can be detected in life and research.

Professor Håkan Torstensson, my advisor and who opened the doors to The Swedish School of Textiles and generously shared his experience and guided accustomedly through the academy paths.

I would also thank the people I have been privileged to meet and work with daily during this time. All members in the case study, no one mentioned and no one forgotten, without whose contribution this research would not have been possible to carry out.

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All positive colleagues at The Swedish School of Textiles, who are always there for a textile discussion and force the textile into new adventures. I would also like thank the people in the weaving studio, Hanna Lindholm, Roger Högberg and Olle Holmudd, who always share their expertise when the threads become tangled. Dr. Tariq Bashir at the School of Engineering, who enthusiastically blended polymers to our samples, without which some experiments had never been taken place.

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Last but not least, I want to thank my family: Johanna, Dennis and Mattias, who always helps me keep my feet on the ground and put me back to reality when I presume that the world revolves only around textiles.

Stig, because you are always by my side.

Peter's café sits on a hillside in Horta, a port city on one of the Azores islands in the middle of the Atlantic Ocean. By the time you reach the docks in the harbour, you can tell that this place is special. Bright, colourful paintings of sailboats and flags line the piers—hundreds and hundreds of them, drawn by visiting captains and crew members from every corner of the globe. Horta is the one place between the Americas and Europe where world-traveling sailors stop to take a break. Some are heading toward Fiji, others to Spain. Some are on their second tour around the world; others are simply resting before the last leg to Brazil. They come from different backgrounds and cultures. And all of them converge upon the rustic-looking Peter's Café. Here they can pick up year-old letters from other world travellers or just sit and talk over a beer or a glass of Madeira. When I saw this place for the first time, I realized that the serene environment of the café actually concealed a chaotic universe. The café was filled with ideas and viewpoints from all corners of the world, and these ideas were intermingling and colliding with each other.

"Get this, they don't use hooks when fishing for marlin in Cuba," one visitor says.

"So what do they use?" another asks.

"Rags. The lure is covered in rags. When the fish strikes the rag, it wraps around the fish bill and won't let go because of the friction. The fish don't get hurt and can be released, no problem."

"That's pretty neat. Maybe we could use something like that. . . ."

The people here participate in what seems like an almost random combination of ideas. One conversation leads into another, and it is difficult to guess what idea will come up next. Peter's Café is a nexus point in the world, one of the most extreme I have ever seen. There is another place just like Peter's Café, but it is not in the Azores. It is in our minds. It is a place where different cultures, domains, and disciplines stream together toward a single point. They connect, allowing for established concepts to clash and combine, ultimately forming a multitude of new, ground-breaking ideas.

(Excerpt from The Medici Effect, Johansson, 2006).

SELECTED PUBLICATIONS

RELATED TO THE CONTENT OF THIS THESIS

Eriksson, S., Sandsjö L., Karlsson I. C. M. (2014) Mediating Co-Design a Case Study with 3D Textile. (Manuscript).

Eriksson, S., Sandsjö L., Karlsson I.C.M. (2013) Investigating the Conceptual Phase of Innovation: Communication and Collaboration in Multidisciplinary Teams. Proceedings of EIASM - 20th International product development managament conference - Re-enchanting technology, Paris, France, June 24-25.

Eriksson, S., Sandsjö, L., Guo, L., Löfhede, J., Lindholm, H., Thordstein, M. (2012) 3D Weaving Technique Applied in Long Term Monitoring of Brain Activity. Proceedings of 4^{th} World Conference on 3D Fabrics and Their Applications. Aachen, Germany, September 10^{th} – 12^{th}.

Sandsjö, L., Löfhede, J., Eriksson, S., Guo, L., Thordstein, M. (2012) EEG Measurements Using Textile Electrodes. Presented ISEK 2012 - XIX Congress of the International Society of Electrophysiology and Kinesiology, Brisbane, Australia, 19-21st July.

Eriksson,S., Berglin, L., Gunnarsson, E., Guo, L., Lindholm, H., Sandsjö, L. (2011) Three-dimensional multilayer fabric structures for interactive textiles. Proceedings of the 3rd World Conference on 3D Fabrics and Their Applications. Wuhan, P. R. China, 20-21 April.

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1. INTRODUCTION

Textiles in general, and weaving in particular, are likely to be as old as humanity itself; there are few inventions which have been more important for human evolution (Geijer, 1994), For thousands of years, humans have fabricated textiles to protect themselves from challenging conditions, such as cold, heat, rain and wind. Textiles have also played an important role in communicating a variety of messages; various religions have used them symbolically in their rituals, and in many societies textiles have been used to signify social standing and cultural identity (Geijer, 1994).

As the farmer once upon a time fabricated his own tools to suit his purposes, so too did people spin and dye their yarn to make their own textiles. The resultant textile product was designed for a specific purpose, so as to perform the intended function as well as express the desired aesthetic qualities. Those who did not have the expertise or ability to make their own clothing instead put their trust in the tailor to obtain the assistance to have their garments suit their requirements. Thus, there was a direct communication between 'designers' and 'users', and the latter were closely involved in the development of a product.

The production of textiles has over time evolved from basal techniques to skilled craftsmanship, and its evolution was one of the driving forces behind the industrialisation of modern society. The Spinning Jenny (1764) and Jacquard loom (early 19th century) are two of the most famous innovations, and are arguably responsible for the beginnings of the Industrial Revolution (Sundin, 2006).

Also today, textiles are used on a daily basis. Textile artefacts such as the clothes we wear, the curtains in our windows or the plasters protecting a scraped knee are, just as the tools we use, the furniture we rest in, and the computers we work with, artefacts with which we surround ourselves and which play a central role in the continuous development of our society. However, the big difference is that over time a gap has emerged between users and designers, and thus between users and the development process. Today users often find themselves far away from the development and production process, which results in that the user often has limited knowledge of how the products are produced today (Karlsson, 1996) and therefore have little chance of influencing the characteristics of the product.

New materials in combination with new and more advanced technologies place the textile sector almost facing a paradigm shift, which requires new manufacturing techniques, new methods and development of new roles. Many researchers have argued that collaboration and interaction across disciplines are vital in order to identify new challenges and their solutions in new, innovative products (Cooper and Kleinschmidt, 1987; Woodman et al.,1993; Ulrich and Eppinger, 2004; Johansson, 2006).

It has also been stated that it is of paramount importance that users are involved as early as possible in the development process, the argument being that they possess knowledge regarding the product and its everyday use which might be lacking among designers (Herstatt and von Hippel, 1992; Karlsson, 1996). However, such user involvement may be limited to users acting as informants or as evaluators, but the involvement can also be developed into the user becoming a member of the multidisciplinary team, a co-designer representing his/her own discipline. This is argued to facilitate the recognition of user requirements and taking them into consideration early in the development process (Herstatt and von Hippel, 1992; Veryzer and Borja de Mozota, 2005; van den Bossche et al., 2006,).

A multidisciplinary[1] team is often defined as multidisciplinary when different experts collaborate around a problem. However the definition multidisciplinary may be overlooked in constellations in activities where the user participates with his competence and represents his own profession, but this indeed forms the constellation of a multidisciplinary team.

However, even if multidisciplinary teams are considered a prerequisite for the creation of innovative products, the team also faces a number of challenges. It is well established that such teams must generate communication across disciplines in order to successfully establish a unified goal (Star and Griesemer, 1989; Leonard-Barton et al., 1994). Some of the challenges faced by multidisciplinary teams are the lack of a common language and terms as well as an understanding for one another's skills and contributions to the process (Bharadwaj and Menon, 2000; Carlile, 2002). Furthermore, in multidisciplinary teams, it is necessary to convert knowledge from one area of expertise into information which is comprehensible to someone with other experiences and skills, as this makes the knowledge valuable to someone who has a different background or views the problem from a different perspective. It is therefore crucial to support an extensive integration of different types of knowledge and skills.

Several researchers point out that to heighten the cross-boundary integration some kind of facilitating object is essential to support dialogues across disciplines (Star and Griesemer, 1989; Cook and Brown, 1999; Karlsson et al., 1999; Engelbrektsson, 2004; De Dreu, 2007).

A beloved child has many names and facilitating object are described as "boundary objects" (Star and Griesemer, 1989, Leigh Star, 2010), "mediating tools" (Carlile, 2002, Veryzer and Borja de Mozota, 2005) or "negotiation tools"(Lee, 2005). Even if there are differences between the diverse definitions, the overall common denominator is that something physical and/or visual is used to facilitate understanding and collaboration. Mediating tools[2] may generally consist of elements which invite reflection, and which may explain or add a focus to the object or process in the context (Carlile, 2004; Engelbrektsson, 2004; Leigh Star, 2010).

Product representation denotes an element, which indicates a potential design or function of the future product. Product representations may be used as mediating tools to describe problems and express properties, identify origins and affiliations, together with their possibility to invite and encourage reactions in the development of innovative products (Monö 2000). They may furthermore facilitate communication of the key principles of the future product during the development process within the product development team and help identify requirements, describe problems and evaluate solutions. In addition, they are a communication tool for the developers to communicate the progress of the new product to, for instance the company management.

Although it is argued that users' knowledge is vital to take into account in order to develop a successful product, the development involving users will face the same problems as any multidisciplinary team.

[1] Innovative products, which are often of a complicated nature, require the formation of interdisciplinary or multidisciplinary collaborations. These two terms are frequently confused and, in 2004, the Swedish Research Council issued definitions; thus, 'multidisciplinary' refers to a collaboration between disciplines which is limited to the changing of the frontiers of only the area(s) being researched, while an 'interdisciplinary' project is one which attempts to advance the frontier of research in general, in the form of a common effort between researchers from multiple disciplines and through the integration of knowledge from these various areas. In this thesis, however, collaborations of a cross-disciplinary nature will be referred to as multidisciplinary ones. This is not to say that interdisciplinary collaborations are entirely excluded from the discussion below.

[2] In this thesis "mediating tool" is used as an overall common description where "something which facilitates the collaboration" is used, but not defined in another way.

There is a need to understand each other's expertise and contribution to the development process; previous research convincingly argues that mediating tools of any kind are required to facilitate the dialogue between users and designers, in the development of innovative products (Bødker, 2000; Engelbrektsson, 2004). However, few studies go into detail as regards exactly how different mediating tools facilitate the bridging of the divide between developers and users and create the prerequisites necessary for the user to become a co-designer and thus take an active role as part of the development team.

Today, new materials and new techniques generate the opportunity to develop new advanced functional textiles. 'Smart textiles', which is the collective name in use for these textiles , interact by multiple functions, forming a textile system that can react and interact with its environment (CEN, 2011). These new textile systems pose a new range of requirements on the design of the textiles, as well as the product development processes and the development team. In this new era, the textile industry will necessitate interaction, where collaboration across disciplines is required in order to meet tomorrow´s user requirements in innovative textile products.

In this thesis a case study is presented, in which a multidisciplinary team involving users and designers gathered with the intention to examine if a problem in medicine could be addressed, using new, functional, textile materials and a novel three-dimensional weaving technique. The textile samples produced during case were used to study how product representations can facilitate the collaboration and cross-border communication in a multidisciplinary team.

1.1 AIM OF STUDY AND RESEARCH QUESTIONS

This thesis examines how product representations may function as mediating tools and intermediaries between individuals with different expertise, and how product representations may facilitate communication and collaboration in multidisciplinary teams.

This has been achieved through analysing empirical data gathered during a case study, as well as explorations of the development of the dialogue between different individuals in a multidisciplinary collaborative project. Although textile product representations play a central role in this research project, questions of a more general nature have been posed:

- How can product representations facilitate multidisciplinary co-design processes?
- What roles do the product representations play in facilitating multidisciplinary collaboration?
- What changes occur in the process, as new product representations evolve and are presented to users?

By answering these questions, a contribution is made to the discussion, which centres on product representations as mediating tools, and how they facilitate the development of a co-design process between users and designers in multidisciplinary teams during the early stages of innovative projects.

1.2 RESEARCH APPROACH

The research approach in this thesis is exploratory with a holistic and empirical perspective, while the development project has been studied using mixed research methods.

The thesis describes and discusses the study of a case, in which different textile product representations,including but not limeted to prototypes, have been developed in an iterative process. This process is described in the section 'Creating the representations'. In the process of creating the product representations, questions have been introduced about learning processes, as well as how hidden information about problems or their design solutions can be invisible and not detected and exposed until physical artifacts have brought light to them. In the design and creation of the representations, issues related to handicraft skills and their importance in the early stages of innovation has been of interest as well.

The iterative development was based on the dialogue between designers and (intended) users, in which the product representations were used as mediating tools. This is described in the section 'Using the representations'. The process, the use of the representations and the effects were studied through participant observation. The data from the meetings between designers and users has been processed using an unprejudiced, inductive method and analyzed by using qualitative content analysis (Granskär and Höglund-Nielsen, 2008).

In the observation of the project meetings, where the users met the representations, many viewpoints to base the study on can be of interest, and the learning process was observed as one of the most important in the process. But in order to learn new, communication is required on the learner's conditions.

Therefore this study focuses on how and whether the representations might facilitate the dialogue, such that the user's knowledge can be elicited and the multidisciplinary team's various skills and expertise can be developed into new common shared knowledge, with the possibility to make the user go from being an evaluator to an active co-designer in the process.

2. TEXTILES

Today´s textiles exhibit a wide variety of uses and perform a range of different functions. The textile industry is divided into three primary segments, of which the clothing industry is the largest followed by home and interior textiles, and technical textiles. One area of textile production, which is currently experiencing a rapid development, is that of technical textiles. Areas where technical textiles are found are e.g. in the agriculture and aquaculture sectors, geotextiles, personnel and property protection, and the automotive, building and construction, aerospace, medical and hygiene industries. Although technical textiles are primarily valued for their material properties over aesthetic considerations, consumer of products, such as work wear and sportswear, demand solutions that satisfy both requirements.

Technical textiles satisfy a range of functional requirements for flexibility, elasticity, absorption, weight, heat and fire resistance to mention a few. The combination of the multitude of fibres available (e.g. cotton, wool, polyester, carbon, glass, aramids) with any of a number of manufacturing methods (e.g. weaving, knitting, braiding or non-woven technique) facilitates the manufacture of advanced textiles, which are adapted to the specific needs of the end user. In 2010, the market for technical textiles was worth 120 million USD in annual sales; of this, medical technological textiles constituted 10% (Rigby, 2010).

2.1 THE MAIN TRADITIONAL TEXTILE TECHNIQUES

Traditional manufacturing techniques for textiles include weaving, knitting, and braiding.

2.1.1 WEAVING

Weaving is the most frequently utilised of the various manufacturing techniques for technical textiles (Mohamed and Stobbe, 2003).

The weaving technique is that which yields the highest levels of dimensional stability, as the yarns are structured so as to form a biaxial system consisting of two yarn systems, in which the Y-axis is the warp and the X-axis the weft. With two interweaving yarn systems, arranged perpendicularly to one another, one can achieve a near-infinite array of variations and provide the textile with different properties (Figure 1).

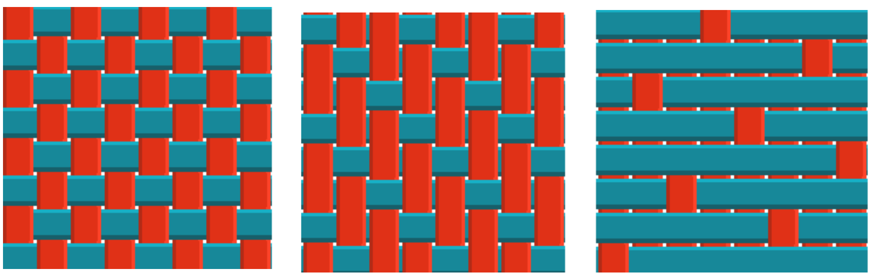

Figure 1. Plain weave, Twill weave and Satin weave (from left to right).

The most common weaving methods are plain weaving, twill, and satin, where plain weaving displays the highest dimensional stability and satin the highest inclination towards structural shearing, with twill falling in-between (Figure 1).

2.1.2 KNITTING

Knitting comprises two different methods for manufacturing textiles; common to them both are the integration of loops, which form meshes in a textile with elastic properties. The first is the so-called weft-knitting technique, where meshes are formed using one yarn system. This is used primarily by the fashion industry and allows the knitting of garments, in the so-called fully fashioned technique, wherein the different pieces which to form the garment is knitted in its final shape directly in the machine. The second technique is commonly referred to as warp-knitting and consists of two yarn systems which work together to form meshes (Figure 2). Warp-knitting is the most commonly used technique for the manufacture of technical textiles (Raz, 1987).

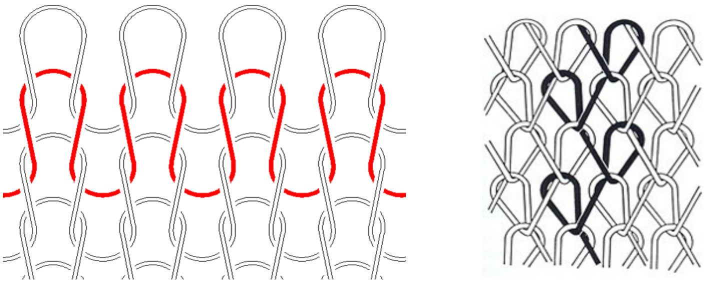

Figure 2. Weft knitting (left) and warp knitting (right). (Raz, 1987).

2.1.3 BRAIDING

Braiding, arranges yarns diagonally across each other, and allows the interlinking of multiple threads in plaiting pattern (Figure 3). It is possible to manufacture braided structures which have flat or circular shapes. In cross-sections, circular braids may consist of either a round or an oval cross section, and possible applications include for instance cords, laces, and ropes. One of the benefits of braided structures is that they have a considerably higher load capacity than structures made with other techniques. Flat braiding techniques involve diagonal interlacing of yarns, in which the cones are positioned to produce a flat structure (Ko et al., 2011).

Figure 3. A circular braiding machine with twelve cones interlacing for braiding.

2.2 THREE DIMENSIONAL TEXTILES

Three-dimensional textiles are not a new category of textiles, the concept has a rather long history. Velvet is a double-faced fabric, which is separated by a knife in the centre and thus forms a three-dimensional pile fabric. Although the earliest archaeological evidence dates to the 13th century AD, fragmentary descriptions of what are believed to be pile fabrics have been found in China and dated to 400 BC (Geijer, 1994). Even hand-knitted socks are an archaic example of three-dimensional textile, despite the fact that these techniques do not utilise the full potential of the concept (Hearle, 2011). However in the half-century since three-dimensional textile techniques were introduced into the field of technical textiles, heavy industries such as aerospace, arms and automotive industries have provided the driving force behind the development. As the production of carbon, glass fibres and high-performance aramids began in the early 1960s new opportunities for new areas of application for technical textiles emerged, and applications for three-dimensional textile composites with the aim to replace metals in load-bearing constructions with light weighted, high load capacity, composites began to evolve (Bilisik, 2011).

Initially the industry was aiming for applications of a relatively low-tech nature; textile sheets of e.g. glass or carbon fibre were produced by meter and further combined and arranged in multiple directions. Laminated together with a hardener they achieve the required high mechanical properties, and thus the process forms a three-dimensional load-bearing structure (Cho and Ko, 1989). Another example of combined textiles is textiles for ballistic applications, which are often made from high performance fibres such as aramids (Rebouillat, 2001; Sun and Chen, 2010).

These textiles have so far been arranged in multiple directions, combined through sewing or welding to create a three-dimensional material with mechanical properties to withstand a ballistic pressure wave from e.g. a bullet (Chen and Sun, 2009). However, the compound textiles have inherent limitations and do not always meet requirements for mechanical properties such as stress resistance (Mouritz et al., 1999). Although it is possible to reach a relatively optimal balance between warp and weft for biaxial woven textiles, the deformation resistance is relatively low for diagonal manipulations of the material. The anisotropic properties imply a weakening in the structure, which results in increased risk of delamination when stressed, in addition to being a resource-intensive manufacturing method (Ko and Hartman, 1986; Prichard, 2011). These manufacturing processes do not always meet the market requirements for functional strength. In addition these kinds of production methods consume vast quantities of time and resources (Mouritz et al., 1999). The limitations of traditional production processes for advanced textile applications may be circumvented by designing three-dimensional textiles with new methods, which will satisfy requirements for efficiency, functionality and environmentally friendly methods, in order to facilitate the manufacture of the high end textile products of tomorrow (Hearle, 2011).

Today's technical textiles do often consist of various materials, which are jointly assembled through different lamination and bonding processes to form a combined three-dimensional textile composite structure. At present, three-dimensional textiles are implemented in a wide range of technical applications, such as in filter, ballistic, clothing and sportswear industries, as well as healthcare applications (Hu, 2008).

In the healthcare sector, textile applications have fairly recently expanded beyond the traditional ones, such as bandage of gauze, to technical textiles with materials that can be used inside the human body (Petrulyte, 2008; Tang et al., 2012).

For instance, three-dimensional textiles are today used as cellular growth material for bone implants, as they can be designed to replace blood vessels or damaged ligaments in the body as well as for advanced wound-healing bandages (Shikinami and Kawarada, 1998; Schmitt, 1999; Moutos et al., 2007).

The use of three-dimensional technical textiles in medical technology is predicted to become even more important in the future, as new methods and functions may present medical practitioners with new and better ways of providing their patients with the care they require.

2.2.1 THE DEFINITION OF THREE DIMENSIONAL TEXTILES

Almost all textile materials have a three-dimensional structure at the micro level. The differences between two- and three-dimensional textiles are easier to identify from a macro perspective. At the world's first conference in three-dimensional textiles, held at the University of Manchester in 2008, Hearle (2008) proposed that 'three-dimensional textiles' is a collective term, describing textile products made of fibres or yarn and arranged in all three dimensions, i.e. X, Y, and Z, regardless of whether the technique used to create the textile is knitting, braiding or weaving.

Three-dimensional textiles do not represent one single manufacturing technique but encompass several different methods, which all serve to create three-dimensional textile structures. These can be manufactured in any textile techniques, which allow two or more yarn systems. The distinctive three-dimensional textiles consist of yarns that are arranged along the X- and Y- but also the vertical Z-axis in the textile in order to achieve one or more of the distinctive characteristics listed below:

- Substantial thickness through layering;
- Solid planar material with multiple layers;
- Multiple yarn systems;
- Enabling shedding and weft insertion, both horizontally and vertically;
- Creating three-dimensional woven shapes e.g. domes.

2.2.2 THREE-DIMENSIONAL WOVEN TEXTILE

Three-dimensional woven textiles are most frequently used to produce technical textiles, where multiple composite materials are required to achieve e.g. sufficient load capacity in combination with low weight. Woven structures, which have been combined in a single process, run a lower risk of delamination than materials made using other kinds of lamination techniques. In this way, it is possible to design textile structures with increased strength, better mechanical properties, higher dimensional stability and improved thermal properties, in combination with low weight compared to strength (Mansour, 2008) and at lower cost compared to laminated two-dimensional textiles (Mouritz et al., 1999; Hearle, 2008).

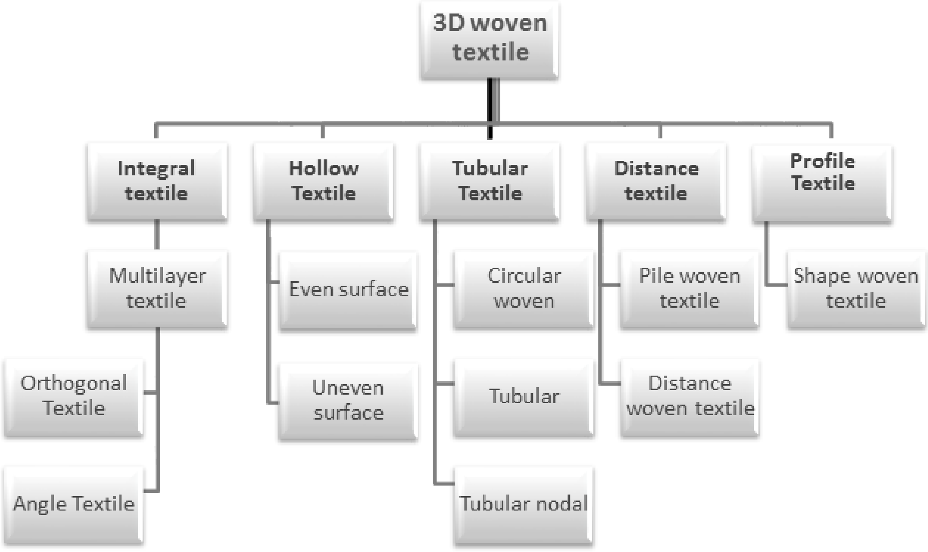

Figure 4. Three-dimensional woven textile categories (Chen, 2011; Gloy et al., 2011).

Three-dimensional woven textiles are divided into two main categories, integrated structures, in which binder yarns link one layer to another within the textile structure (Chen and Sun, 2010; Bilisik, 2011) and interlinked structures, in which binder yarns link the two surface layers top to bottom (Hu, 2008).

The main categories are further divided in several sub-categories that distinguish the textile structures from each other (Figure 4) (Chen et al., 2011; Gloy et al., 2011).

2.2.3 SUB-CATEGORIES OF THREE DIMENSIONAL WOVEN FABRICS

An integral solid woven structure is the most common three-dimensional textile. It is referred to as multi-layered textiles, which consist of two categories of bindings; the orthogonal interlocking and angular interlocking (Figure 5).

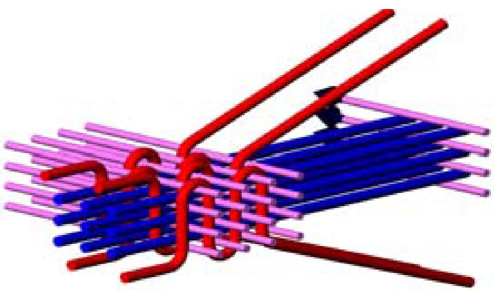

Figure 5. Orthogonal interlocking in three-dimensional weaving technique (Mansour, 2008).

The architecture of the solid structure is based on a multi-layered principle, in which multiple woven layers are stitched together during the weaving process. Textiles designed as a multi-layered textile have high stability and resistance to impact, due to the yarn being interlaced along the Z-axis, meaning that they are both resistant to diagonal deformation and providing high resistance to shearing.

A three-dimensional woven hollow structure (Figure 6) is possible to design with either a flat surface or an uneven surface. In this context, a three-dimensional hollow structure refers to tunnels which run parallel either in the weft or the warp direction, or diagonally at any level in the architecture of the textile.The hollow structure results in a textile with high energy absorption capabilities, as well as a large volume combined with low weight (Chen, 2009; Gloy et al., 2011).

Figure 6. A three-dimensional hollow woven structure with uneven surface (Chen, 2009).

The tubular woven textiles (Figure 7) are designed in the form of a tube in various dimensions and used e.g. in fire hoses to stabilise the inner structure and prevent expansion due to high pressure. The three-dimensional nodal structures are characterised by tubes, which are designed in such a way as to incorporate branching at certain points. The structure can be designed as T- branches or multiple- branching with applications such as vascular graft.
Nodal textiles are woven as biaxial two-dimensional textiles and separated after being taken out of the weaving machine.

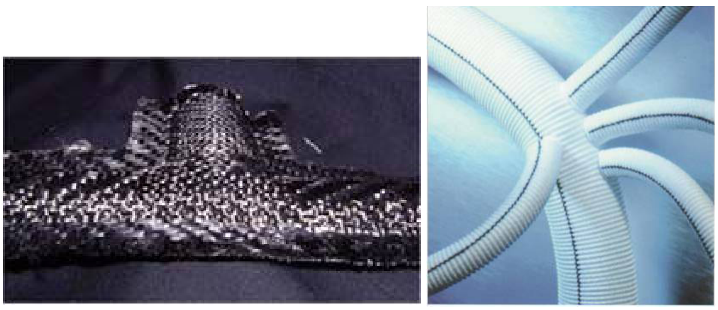

Figure 7. Three-dimensional nodal woven structures, a T-branch (Chen, 2008) and a multiple branch structure (McQuaid, 2005), respectively.

The three-dimensional distance textile (Figure 8) forms different levels in the structure and can be produced as pile textile, e.g. velvet, or woven with ligaments to form a sandwich structure. Sandwich structures are structures that can reinforce various elements, such as pressure tanks for transportation or marine industry (Torun et al., 2013)

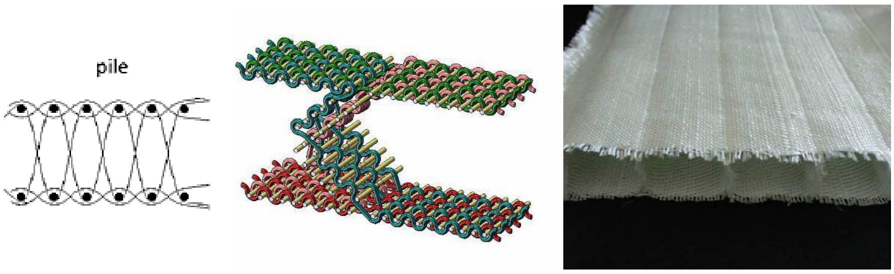

Figure 8. The left picture illustrates a traditional pile weave. The middle illustrates a CAD visualization of a woven ligament fabric. The right picture shows a ligament-woven distance textile fabric (Torun et al., 2013).

The three-dimensional shell structures (Figure 9) are designed to form the characteristic dome shape, which can be produced by different weaving methods, more specifically by weave combination, by different take-up or by moulding. The three-dimensional dome structure creates textiles with high sheerness. The dome structure differs from the general requested characteristics in three-dimensional textiles, thus here the high sheerness in the material is the requested property. Dome structures allow the fibers and yarns to support high flexibility but without losing their interrelationships. The material is characterised by very high flexibility, primarily diagonally, which stems from the flexibility of the jacquard weaving technique, in which each warp thread is arranged so that it can work individually in the Y-axis, thus forming the dome shape, and provide seamless woven reinforcement to reduce weight and increase strength (Büsgen, 2008).

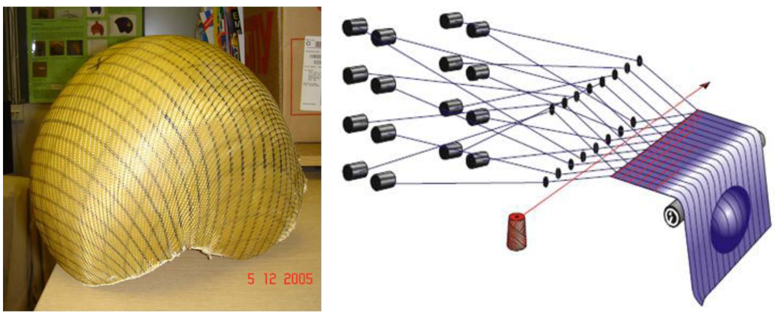

Figure 9. A dome structure (left), where the design of the textile allows the fabric to be molded in a dome shape (Chen, 2008). Right is a schematic view of the three-dimensional dome weaving technique from Büsgen (2008).

2.2.4 MANUFACTURING PROCESS FOR THREE-DIMENSIONAL WOVEN TEXTILES

Many of the three-dimensional woven textiles can be produced with conventional weaving machines using dobby or jacquard techniques. By changing the stitching points in the structures in combination with the density in the warp and weft systems, different requested characteristics can be designed into the woven textile (Chen et al., 2011). There is, however, a need for special weaving machines, which are used to create structures in another way than those mentioned earlier in order to e.g. further increase efficiency in production, as well as allow structures with particular properties or profiles to be manufactured (Figure 10). With special manufacturing machines the need for cutting or further assembling processes after the production of profile structures can be eliminated. Examples of these profiles are textile structures which form **I**, **T** or **H** profiles in the manufacturing process.

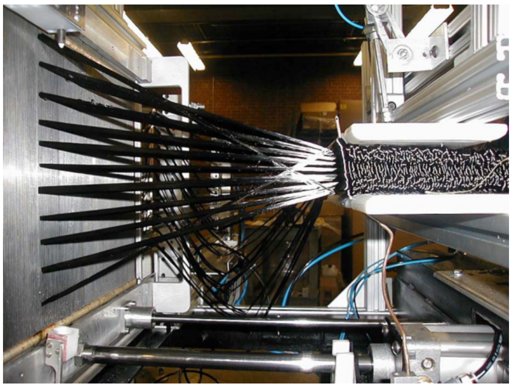

Figure 10. Special weaving machine by 3TEX Inc. for orthogonal structures with multiple (10) weft inserts to form a carbon bar (Mansour, 2008). Crossing of the Z-yarns by harness movement after beat-up.

The company 3Tex Inc. has developed specialised looms for three yarn systems (axial warp, binding warp and weft) together with multiple weft posts (Figure 10). Technologies to design cross-sectional changes to stabilize the woven material together with structures in other forms such as **I,H** or **T** have been developed by e.g. 3TEX and BITEAM AB. (BITEAM, 2014, 3TEX, 2014,)

Another example of specialized looms is the new weaving machine developed by MAGEBA, a producer of narrow fabric weaving machines. The new machine was exhibited at the ITMA trade show in Frankfurt, Germany in 2011.

> "This new shuttle loom (type SSL M) features a combination of a 4-shuttle weft insertion and a special innovative shedding. This is achieved by use of Unival 100-Jacquard, made by Stäubli. It is possible to generate several sheds at the same time, ensuring a multi-shuttle simultaneous weft insertion" (MAGEBA, 2014).

The loom facilitates the design of a new type of multi-dimensional woven structures and is able to produce three-dimensional woven textiles in advanced configurations, e.g. H-shape (Figure 11). The loom has been developed in order to expand the field of three-dimensional woven textile applications for complex design structures into areas such as multi-dimensional fabrics for profiles and near-net-shape fabrics made of carbon and glass fibres.

In 2011 MAGEBA presented another shuttle loom in Frankfurt, which is a single station loom (of the type SL MT 1/180), designed to allow flexible and economical production of versatile complex narrow fabrics for medical and technical applications. This new shuttle loom model is equipped with a two-shuttle weft insertion, and the new servo-driven, electronic dobby with 16 shafts offers an indefinite repeat length (MAGEBA, 2014).

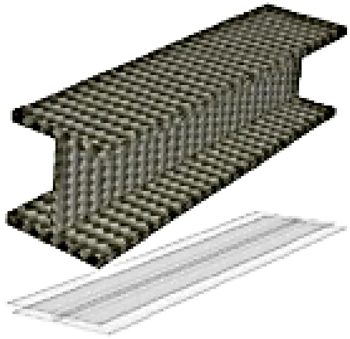

Figure 11. H-shaped carbon fabric produced in the shuttle loom type SSL M from MAGEBA.

2.2.5 OTHER TECHNIQUES FOR THREE-DIMENSIONAL TEXTILES

Knitting and braiding are besides weaving, two common techniques to produce three-dimensional textile structures. Three-dimensional knitted structures developed using a warp-knitting technique are often referred to as 'Spacer Fabrics' (Figure 12).

Figure 12. A three dimensional warp-knitted spacer fabric (Baltex, 2013).

The three-dimensional warp-knitted material consists of two surface layers and a composite layer in-between; this sandwich construction means that the material is porous, airy and light weighted, making it suitable for applications in sports, the automotive industry and healthcare (Anand, 2008). Another technique is the three dimensional weft-knitting technique, mostly used in fashion design, which knits the entire garment seamlessly in one piece.

Braiding is typologically a subcategory of knots (Ashley 1944) and forms various three-dimensional structures. Braiding technology has together with the aforementioned techniques evolved rapidly over the past decades and is today one of the most used techniques in order to create textiles that have a high resistance to external stresses and a high load capacity to weight ratio (Ko et al., 2011). An example is a hexagonal braiding technique developed by British Colombia University that increased the possibility to braid textiles in a variety of shapes and with fine dimension yarns for healthcare applications (Ko et al., 2008) (Figure 13).

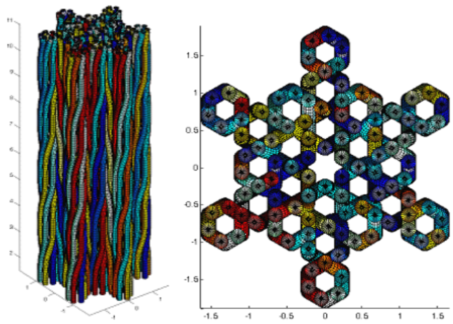

Figure 13. Braiding patterns for various three-dimensional braid shapes (Ko et al., 2011).

By using braiding techniques, it is possible to arrange the yarn cones so that yarns are interlaced diagonally and thus create a three-dimensional shape. Using an inner structure, yarns are braided to form, for example a wing in a wind turbine (Gao et al., 2013). Another area is thin blood vessels or braided structures for tissue engineering, for example used as scaffolds (Ko et al., 2008).

2.3 SMART TEXTILES

The textile industry has experienced radical changes in recent decades, and the globalisation of the manufacturing industry has led to a fiercely competitive situation for companies based in Europe and the USA; however, in the latter, the textile industry is still of great importance as regards social and economic considerations (Schwarz et al., 2010).

In order for the textile industry to maintain a dominant market position, the complexity of advanced technical solutions in the textile field has had to increase, why the (relatively) recently established research area of smart textiles is of great importance. Smart textiles are textiles with multiple functions integrated, which can generate added value and increased performance. Such textiles interact with their surrounding environment in different ways. With smart textiles, new materials and new techniques make the textile industry face a new era, in which an increased level of coordination between multidisciplinary constellations is required, as perspectives from the disparate fields of science, technology, design and the humanities are required to precipitate the development and adoption of new functions for textiles. Smart textiles appear in several segments of textiles, such as fashion, interior textiles and personal protection, and today medical applications represent an increasing driving force for the development of this new area of textiles.

2.3.1 THE DEFINITION OF SMART TEXTILE

There are several different definitions of a smart textile but essentially smart textiles are fabrics that can interact with their environment in different ways. The most commonly accepted definition reads as follows: smart textiles are intelligent materials and systems which are capable to sense and respond to the surrounding environment in a predictable and useful manner (CEN, 2011).

Through different functionalities, which are integrated in the structure, the textiles are able to sense, actuate or adapt themselves to environmental conditions or stimuli. The stimuli that trigger the response may originate from a variety of sources and can consist of light, sound, moisture, thermal conditions such as heat and cold, a chemical reaction or an electrical signal, to mention a few. The textiles that are able to adapt themselves to the environment are textiles that essentially consist of a controlling unit of any kind, like a computer and a sensing or actuating textile. The primary function of a smart material can thus be categorized as sensor, actuator, and adaptive textiles (Tao, 2001; CEN, 2011) (Figure 14).

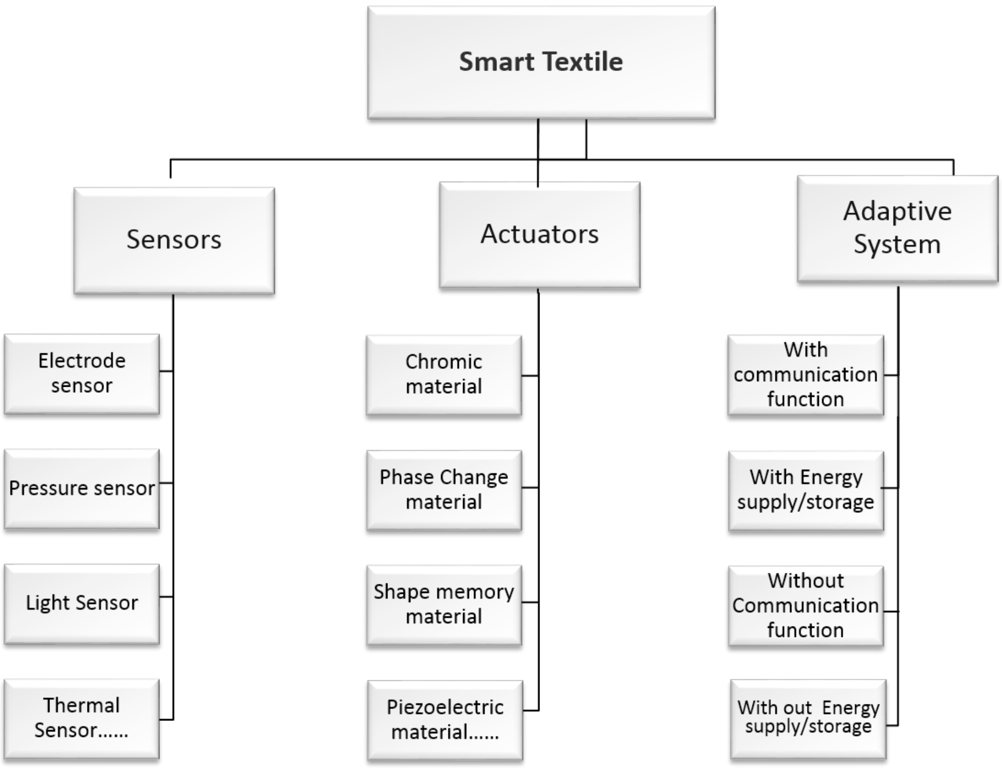

Figure 14. Smart Textiles categorization based on Tao (2001) and CEN report (2011).

2.3.2 SENSORS

A sensor has the capacity to convert a signal to another kind of signal. There are different sensing functions that enable the transformation of the signal (Addington and Schodek, 2007). Examples of sensors are;

- Electrode sensors, which can detect electrical signals;
- Thermal sensors, which detect thermal changes in the environment;
- Light sensors, which convert light energy to voltage output;
- Pressure sensors, which convert pressure to electrical signals;
- Sound sensors, which convert sound to an electrical signal

2.3.3 ACTUATORS

The task of an actuator in a smart textile is to respond to an external stimulus by creating a reaction within the material. Actuators cause objects to change by e.g. altering their colour or shape, emitting a sound, or causing a change in temperature. These changes in the material may be either mechanical or chemical. Examples of actuators are;

- Chromic materials, which react and change their visual appearance when activated by stimuli such as changes in temperature or light, or as a result of exposure to chemical or mechanical stress;

- Phase Change Materials, which are actuators that change their form, e.g. from solid to liquid, or absorb and store energy, which may then be released;

- Shape Memory Materials, which are alloys that transform, in general, through the conversion of thermal into kinetic energy and as the material cools, they regains their original shape;

- Piezoelectric materials, which have the ability to convert mechanical energy into electrical energy.

2.3.4 ADAPTIVE FUNCTION

In order for a smart textile system to function as an adaptive textile it requires more than sensing or actuating functionalities.

An adaptive textile system requires the use of one or more additional functionalities from different units, such as an energy supply or energy storage capabilities, in order to be able to function as stand-alone units, as well as data transfer and data processing devices. However, despite the development of flexible solar cells and batteries powered by the kinetic energy generated by body motions, the necessary energy is still most often provided by batteries or other forms of electrical power supply (Schwarz et al., 2010).

A smart textile also requires a control unit. The purpose of the control unit is to regulate and coordinate the functions of the other components by managing the flow of information through the processor. The communication between the various components of the textile, as well as between, say, the user and the textile is vital. Many of the techniques and material which form smart textile systems are continuously taken advances to increase the ability to be integrated in textiles. However, the data processing is still carried out by electronic devices, which at present are not feasible in textiles due to size, flexibility and washability for instance. As rapid advances in wireless technologies are however predicted to eliminate the need to carry large and often bulky devices for data collection and data processing and allow an upsurge in usage (Schwarz et al., 2010).

2.4 APPLICATIONS OF SMART TEXTILES

In recent years, a large number of projects, focused on possible applications for smart textiles, have been carried out, creating interesting scenarios, where e.g. sensors are integrated into firemen's clothes in order to increase their safety during exposure to extreme conditions.

Medical technology is another area, in which smart textiles have found potential applications and attract a great deal of interest, particularly applications concerning monitoring patients' body functions (Van Langenhove, 2007) including respiration, measuring external pressure or moisture, measuring muscle electrical activity (EMG), monitoring heart rate (ECG) or monitoring brain activity signals (EEG) (Van Langenhove et al., 2007; Paradiso and De Rossi, 2008; Coyle et al., 2010; Hui et al., 2011) have attracted attention and become the focus of research projects all over the world.

Nevertheless, despite the fact that smart textiles have been researched since the 1990s, very few products have (as yet) been introduced to the market, with most of these projects existing only in laboratory environments. There are multiple reasons for this. Schwartz et al. (2010) point out that the requirements for the integration of several different advanced textile techniques form a considerable obstacle in any attempts at scaling up production to an industrial level. A potential solution could be to exploit three-dimensional technologies (Hearle, 2009). Furthermore, for these innovative projects to reach the market, it is necessary for developers to overcome the ingrained reluctance of the textile industry to engage in multidisciplinary development of textile products. Schwarz et al. (ibid.) also highlight the need for the development of methods and standards in order for smart textiles to be developed and industrialised and for new innovations to reach society.

3. INNOVATION AND PRODUCT DEVELOPMENT

The innovation process is complex, with many parameters that influence the success of an innovative product. Even if this thesis focuses on how the dialogue between users and developers can be facilitated in the early phases of the innovation process, there is a need to introduce the reader to the process and give a glimpse of the complexity and an enhanced opportunity to understand what parameters affect the innovation process.

3.1 INNOVATION

Global challenges place demands for innovation in both products and services, and organizations continuously face new and changing customer requirements. For this reason there is considerable research interest to explore what affects the innovation process. Innovation is therefore studied from the perspective of various disciplines, such as human resources, operations management, entrepreneurship, R&D and product design (Damanpour and Schneider, 2006).

The term 'innovation' is frequently used in a wide variety of fields, including economics, technology, and the humanities, but it is difficult to find a common definition. The word itself stems from the Latin word 'novus', and the verb form 'novare', together with the prefix 'in', meaning 'to make new' (Dictionary.com, 2013, Oxford University Press, 2006).

The degree of novelty, required for a product or service to be referred to as innovation, has been debated and transformed over time. Innovation in a modern sense is divided into two main categories; incremental or radical. Incremental innovations are based on continuous improvements and gradually developed in small stages based on previous knowledge, whereas radical innovations utilise new knowledge, which deviates significantly from previously established basic principles (Remneland, 2010).

However, an intriguing idea or prototype does not make an innovation, as long as it has not reached the market or other non-commercial distribution. The path to market is not without obstacles. According to Rogers (2003), both explicit and implicit phenomena influence whether an innovation is adopted by the customer/user or not. Rogers points out that before the user adopts an innovation, it has to pass a process in which "(1) the innovation (2) is communicated through certain channels (3) over time (4) among the members of a social system". An innovation is spread and adopted by the user, if at all, at different pace and depends, according to Rogers, on whether the user sees an added value in the innovation. The innovation must furthermore be compatible with fundamental values, the complexity of the product be manageable for the user, and the user must be able to try and observe the consequence of adopting it in order to adopt the innovation. Therefore new innovative products have to be developed with thorough understanding of users and use in order to be commercially successful. This is however not an easy endeavour.

Research shows that users often modify and even redesign new products or equipment so that the products suit their requirements and needs in a more accurate way (von Hippel and Katz, 2002; von Hippel, 2005b). Griffin and Hauser (1993) point out that users can identify most of the requirements, they want the future product to respond to early in the process and suggest that, through user participation in the development process, the requirements may turn out to be clear and captured. Veryzer and Borja de Mozota (2005) argue that by placing the users and their needs in the center of a User Oriented Design Process (UOD), the user's experience can support the idea generation process, and products that meet users' needs more accurately can be developed.

Together, this leads to the argument to involve the user early in the development of innovative products in order to capture needs and requirements as early as possible in the process.

3.1.1 INNOVATORS

Innovation and development of innovative products are a result of interaction among a variety of actors (e.g. people, enterprises, universities), in which information and technology flow in a complex system to turn an idea into a product, accepted on the market (OECD, 1997; Lundvall, 2007). Research stresses that innovation is initiated to a higher degree by individuals who are more creative than others (Amabile, 1988; Amabile, 1997; Bharadwaj and Menon, 2000). In order to understand the individual process of innovators, Dyer et al. (2009) organized a study to identify what distinguishes these innovative individuals from others, how they act and, more specifically, what they do during the development process, as well as what happens when these individuals arrive at ideas which may become innovations. Dyer et al. (2009) (ibid) identified five 'discovery skills', which distinguish individuals, who initiate and develop innovative products and introduce them to the market, from those of a less inventive nature. According to their findings an innovator's DNA is designated of individuals that have the abilities to:

1. Associate - the ability to connect seemingly unrelated problems, questions or ideas;
2. Question - the ability to ask provocative questions and, like the devil's advocate, ask why, why not, and what if;
3. Observe - the ability to detect and examine common phenomena and behaviour of e.g. potential customers from an anthropological perspective;
4. Experiment - the ability to try out new ideas in active experiments and build prototypes;
5. Network - the ability to meet and network with people, who have different perspectives and ideas, with the intention of increasing the individuals own knowledge.

The networking phenomenon is commonly associated to the Medici dynasty in Florence, Italy, during the 14th century. They developed a creative arena for the artists and scientists of the Renaissance era, which in turn led to interdisciplinary encounters and the creation of new concepts. The networking phenomenon has been further explored by Johansson (2006), who stressed the importance of going outside one's normal sphere of experience.

3.1.2 INNOVATING TEAMS

Even though some innovations may occur by accident, most innovations are initiated and developed through networking and team collaboration. A team consists of individuals and may be described as "small number of people with complementary skills who are committed to a common purpose, a set of performance goals and an approach, for which they hold themselves mutually accountable" (Katzenbach and Smith, 1993). Teams consisting of individuals with different professional backgrounds, knowledge, and skills are argued to be more creative than other teams, since they bring useful and diverse perspectives to the group (Paulus, 2000; West, 2000). However a number of additional factors have been identified to affect the team's innovation process. These factors include e.g. team composition, communication, conflict resolution and trust (Paulus, 2000; van den Bossche et al., 2006; Sutton, 2010).

The ingredients of a great team performance are many. Cook and Macaulay (2013) as well as Cook and Brown (1999) defined four pillars that affect team level of (high or low) performance;

- Commitment , i.e. the willingness of an individual to commit to achieving a common goal. The common goal has to be understood by everybody.

- Communication, which is vital for the success of a team. High performance teams have a higher degree of communication both within the team and with other stakeholders. Communication is one of the most critical team processes, and team members have to feel free to express their opinion and be valued for their contribution.

- Contribution means that everyone's diverse skills and expertise have to be recognized as a valuable resource to the team, and the team members have to feel that their contribution is appreciated.

- Collaboration is the most crucial pillar and signifies that team members are co-operative rather than competitive. They support each other and work towards a common goal rather than being self-centred.

Similar arguments have been proposed by other researchers. A positive group climate was for instance identified by Lovén (2012) as a crucial factor for individuals' willingness and ability to contribute with their skills to the full. Ackerman (2007) stressed that everyone in the team needs to feel involved and to understand his/her contribution to the group in order to make success.

If Cook and Macaulay (2013) highlight the setting for collaboraion within the team West (2000, 2002) points out the influencing parameters for creativity and innovation performance in teams. West (2002) describes four different parameters that affect the creativity and innovation process;

- Task characteristics are fundamental characteristics, such as who works in the group, the structural process, the roles in the group and formulation of goals.

- Group knowledge: The team includes mixed individuals with diverse skills and different expertise, which will enhance innovative ideas, but there has to be an overlap of mental models in the group in order to communicate and collaborate effectively.

- External demands affect the group by organizational or external threats in different stages of the innovation process. In the early stage, when innovative ideas are generated, external threats can have a negative effect on the group's creativity. When the innovation is in the implementation phase they could, on the other hand, have an encouraging effect on the road to implementation.

- Integrating group processes include processes that enable the team to translate the effect of diverse knowledge as well as integration skills that West (ibid.) describes as diverse skills, such as conflict resolution and skills to recognize and discourage undesirable conflicts and employ win-win negotiation strategies in the innovation process.

Finally, there is a need for a knowledge-sharing process. This is essential in multidisciplinary teams in order to generate new solutions to a problem and has been stressed as a result in a number of studies (Knowles, 1990; Bharadwaj and Menon, 2000; Carlile, 2004; du Chatenier et al., 2009). This theme will be further described in the section 'Knowledge creation and knowledge sharing'.

3.2 PROCESSES

Innovations and new products are created through activities coordinated over time, which requires some kind of development process. The activities in the process are to result in new information, new market knowledge and new design solutions in the new product. A fundamental phenomenon in the development process is that the solution to the problem is abstract in the beginning of the process and becomes more and more concrete and finally properly defined in the later stages (Baxter, 1999; Ulrich and Eppinger, 2004).

3.2.1 LINEAR VS ITERATIVE PROCESSES

There are several different processes that companies may operate by in order to reach the market with new products. Despite the well-known complexity of the development process it is often described as a linear process, where defined methods and standardized procedures bring the process forward in a predefined manner. An example of such a standard process is the "Stage Gate Model". This process consists of a number of gates, where predetermined requirements must be met for approval by management, before the next gate opens and the project can continue (Cooper et al., 2002; Ulrich and Eppinger, 2004).

Another way of reaching the goal is using an iterative development process (Figure 15). An iterative development process stands for trying out and testing ideas at a more accelerated pace than, for example, the Stage Gate process. Unlike those more linear processes the iterative development process does not require that analysis, requirements specification and systems, etc., are completely defined in the initial iterations. Instead, iterative development can be illustrated by a spiral of repeating all the steps in the process : identify, plan, implement and review/evaluate. Tests and evaluations are performed on prototypes, and the resulting experiences are evaluated and utilized and brought back in the next loop to the development process. The iterations may have different purposes, partly design solutions are iterated within the design team and partly the aim may be to iterate with the user in order to identify and modify the solutions to reach the set target.

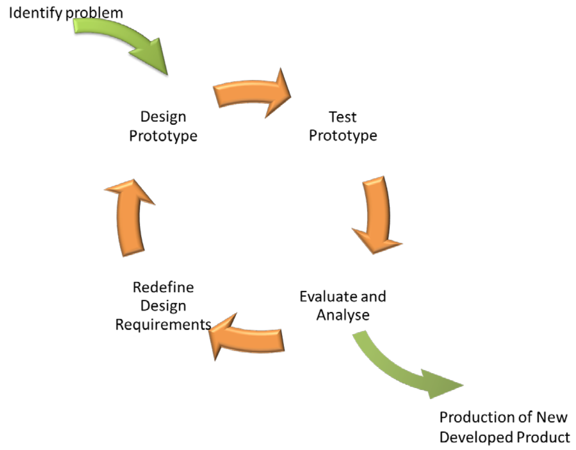

Figure 15. Iterative design processes where one design loop is illustrated by the orange arrows. This loop is repeated until satisfaction with the design has been achieved and the product can be produced.

Von Hippel (2001) describes how an iterative trial and error process can support the process of identifying what requirements the future product needs to fulfill and the design of the forthcoming product. The iterative process consists according to Hippel of four steps: (1) easily identified requirements along with all identified requirements outlined by the user in a first specification. This specification can be both incomplete and partially incorrect but serves as a first basis to the design solutions. (2) The developer responds by visualising design solutions that are partially correct due to the, so far, identified requirements. (3) The solution is tested in the user environment, and deficiencies and new potential for improvement are detected. (4) These new identified needs and solutions generate a new edition of design solutions, which are developed in a next loop, and the process is repeated several times, until the function and design are accepted by both the developer and the user. Through the iterative process, needs are identified and clarified, and information is detected of what is really needed in the next product, something that is difficult to detect initially. Different processes can also be described according to the main perspective that companies apply in the development process, for instance as manufacturer-centric or user-centric process (Urban and von Hippel, 1988; Schuler and Namioka, 1993; Kaulio, 1997; Borja de Mozota, 2003; Veryzer and Borja de Mozota, 2005; von Hippel, 2005b).

Processes can furthermore be described as prototype- or requirement-driven development processes, according to the tools used to support the identification of the needs and functions in the forthcoming product (Kaulio, 1997; Westerlund, 2009).

3.2.2 MANUFACTURER-CENTRIC VS USER-CENTRIC PROCESSES

The manufacturer-centric process is according to von Hippel (von Hippel, 2005a) the most commonly used development process (Figure 16). Essentially, companies develop new products in a relatively traditional manner, using contemporary manufacturing processes to govern the design and functions of the product. User feedback for the new product is used to a relatively limited extent; rather, standard methods such as target group analyses through e.g. questionnaires or interviews are used, in the hope that they will inform as to what the user wants from the next generation of products (von Hippel, 2005a; Ulrich and Eppinger, 2004).

According to von Hippel (2005b) the collected data passes through several stages of analysis, compiled with the aim of appealing the widest possible audience for the next product generation. The information from these surveys results in development of various conceptual elements of the new product, and the user may be invited at certain stages to evaluate already designed solutions. The result from such activities are further generalised to give a view of the average user’s needs

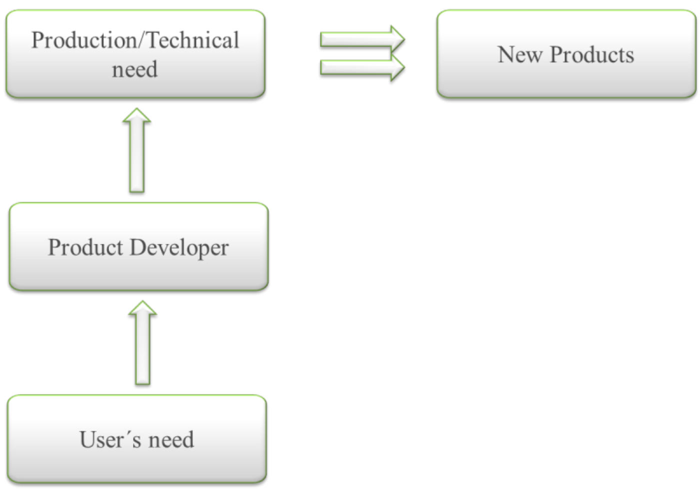

Figure 16. Manufacturer-centric process illustrating the users’ needs passing through and being interpreted at several stages in the development process.

The generalization of data and few contacts with the user during the development process entail, not without risks, that specific information about the user's needs might be weeded out, which may lead to that opportunities for new innovations are missed (von Hippel and Katz, 2002; von Hippel, 2005a).

Although product development teams often consist of individuals from within the organisation, it has been argued that customers and users may function as important sources for innovations (Herstatt and von Hippel, 1992; von Hippel, 2005a). Von Hippel (2005a) shows in his research that products do not correspond to users' needs, why as many as 40% of users make modifications to the design of the product they buy, in order for it to better suit their needs. These end-users range from e.g. wind surfers to users of more technologically advanced medical equipment. Even companies modify their newly purchased equipment so that it corresponds to their requirements in a more precise manner (de Jong and von Hippel, 2009). These modifications of products by the user are feasible, since the users have specialist knowledge of how they would like the product to operate and quickly dispatch products that do not fulfil their need (Urban and von Hippel, 1988; Shah et al.,2009). Another way to capture the users' requirements is to provide the users with a 'user toolkit' (von Hippel and Katz, 2002). With such a toolkit the user can perform modifications and changes while discovering and identifying requirements. Achieving this in the developer's environment, allowing feedback from developers, will enable the user 'speaking the language of the producer'.

This facilitates that the user's needs and requirements can be taken into consideration in the development process. Engelbrektsson and Karlsson (2004) point out that users with experience of the product in usage contribute to a greater extent and with more details on expressed needs and requirements to the developer, than users who do not have the same experience of the product in use. Moreover, according to Karlsson et al. (2011), the development of technical innovations must take a broader approach and develop new innovative products from the user perspective, with the user involved early in as well as during the development process. According to, for instance Herstatt and von Hippel (1992) the user-centric model (Figure 17) appears to be the most successful in terms of the development processes of new products. The need for and the positive effects of a user-centric process have been confirmed by researchers such as Herstatt and von Hippel (1992),Borja de Mozota (2003), and Veryzer and Borja de Mozota (2005).

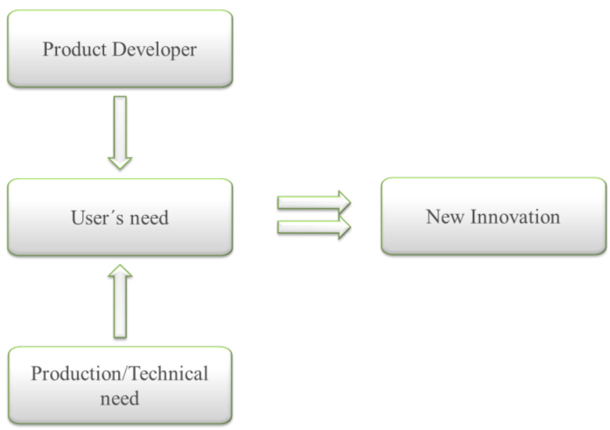

Figure 17. The User-Centric process, where the user's needs are central and the various technical parameters pass directly through the users in the process.

Unlike the manufacture-centric process, the user-centric process incorporates user input from an early stage in the product development process, and this contact is maintained until the finished project. With the user as a key resource in the product developing process the team's ability increases to obtain users' knowledge, opinions and requirements and implement them in the forthcoming product, in a manner that matches the users' needs (Herstatt and von Hippel, 1992; Griffin and Hauser, 1993; Engelbrektsson, 2004; von Hippel, 2005a).

The user-centric process offers the ability to better match the user's specific needs, and valuable information can be gathered and integrated throughout the design process. By offering the user to participate throughout the entire process of new product development the products get the opportunity to be matched more exactly to the user's specific needs.

3.2.3 SPECIFICATION-DRIVEN VS PROTOTYPE-DRIVEN DEVELOPMENT PROCESSES

Both a manufacturer-centric and a user-centric model may involve companies possessing different attitudes toward the identification and creation of detailed specifications for the product under development. One approach is described as a specification-driven process, whereby the conditions and requirements for the product are identified and codified prior to the development of the product itself (Baxter, 1999; Ulrich and Eppinger, 2004,).

Conversely, in a prototype-driven process, specifications are identified in an iterative process, and so the physical prototype embodies corporeal design solutions. Schrage (1993) argue that
"Just as managing the dialog between theory and experiment is essential to the advancement of physics, managing the dialog between specifications and prototypes are essential to the advancement of design innovation". By developing innovative new products in an iterative prototype-driven design process, new ideas and new thoughts are made visible.

Companies have different attitudes to prototype making. Some see the prototyping only as way to verify the requirements; while others treat a prototype as a functional end product. In either case, the prototype only becomes a medium which is used to convince management or point out statements in the discussion instead of being a vehicle which invites to, and creates a platform for dialogue in the design process, i.e. the prototypes are used to prove a point instead of creating a platform for the design dialogue. Used correctly, the prototype can become a medium to manage risks as well as exploring and opening for future opportunities (Schrage, 1993).

Prototypes can support the collaboration between different disciplines as it can bridge the language between disciplines or verify desired properties. Kelly (2001) argues that companies which seek to develop innovative products will have to abandon the specification-driven procedure, as it is generally retrospective in nature and reliant on pre-established solutions, and instead adopt the prototype-driven model, thus using physical conceptualisations in order to visualise the intended product and development process. This may lead to new lines of thinking and progressive ideas, and is better suited to facilitate the exploration of a variety of possibilities than the specification-driven process (Westerlund, 2009).

3.3 COMMUNICATION ACROSS DISCIPLINES

In literature regarding new product development the processes is often described as one-dimensional process, with a definite start and end. Companies are constantly searching for standardised processes and methods in order to streamline, support and manage the complex processes involved in the development of new products (Leonard-Barton et al., 1994; Ulrich and Eppinger, 2004).

However, it is also argued that the process is far more complex than this simplistic description, and that innovative products are not generated as a result of methods and standardised working processes; rather, it is through exchanges of experience and knowledge between people who work outside of their own discipline and conceptual domain that innovation occurs (West, 2002; Johansson, 2006), as was argued in the earlier section on 'Innovating teams'. This may appear obvious since the development of new complex products requires different skills from different disciplines to gather around the problem and cooperate across boundaries.

However, an equally important condition is that such multidisciplinary teams are able to communicate trans boundary such that an understanding can evolve of what the contribution of the other expertise is to the process. This is essential to the clarification of a unified perspective regarding the ultimate goal of the project and which methods and process models will most efficiently move the team towards that goal (Star and Griesemer, 1989; Carlile, 2002; Carlile, 2004; Du Chatenier et al., 2009). Obstacles for communication between disciplines, and reasons for misinterpretations, are that professions often differ from one another in terms of character (Carlile, 2004), and that language and terminology often vary between these specialised areas (Karlsson et al., 2011). Other obstacles might be that the different expertise lack knowledge and understanding what different skills and professions can actually contribute to the development process (Karlsson, 1996; van den Bossche et al., 2006; Kimble et al., 2010).

3.3.1 USER INVOLVEMENT

By discipline in the context of multi-disciplinary product development, is most often meant marketing, engineering design, and production engineering. In this thesis users are considered a discipline which contributes with diverse expertise and skills. Although the involvement of users as additional sources of knowledge early on in the development process is generally considered to be essential (Herstatt and von Hippel, 1992; von Hippel, 2005a; Veryzer and Borja de Mozota, 2005) it may also complicate communication within the development team (Star and Griesemer, 1989; Engelbrektsson, 2004). There are a number of causes for these problems and, apart from the importance of language; one of them may be that it is difficult for users to provide clear information on their needs. Some of the users' needs and requirements for the design of the product may be easy to identify and explained to the developers, but there may be aspects which prove difficult to identify and describe, as the users may not be entirely conscious of them or lack the vocabulary to fully articulate their needs.

Karlsson (1996) divides user requirements into three categories according their degree of accessibility.

- *Captured requirements* are easily identifiable, as the users are aware of and are able to verbalise them, for instance during interviews.

- *Elicited requirements* refer to requirements that require a certain effort before they are communicated. Users may no longer be aware of existing problems, as they consider the problem to be solved through their own modification of existing solutions. Certain requirements may take a disturbance, a so-called breakdown, for the user to once again become aware of the problem.

- *Emerging requirements* are those which are very difficult for users to communicate as a result of them not being aware of existing potential design solutions until they have been visualised and tested. These requirements may emerge as a consequence of new solutions being proposed.

Another reason that affects the user's ability to contribute in the development process may be that modern society has created a large gap between the user and the development processes of new products, This results in that it might be rare and unfamiliar for a user to act as an active participant and have sufficient knowledge that is sought-after in the development process; this may be why users are inexperienced at articulating their needs and transferring their knowledge to developers.

Bridging this gap requires users to understand their contributions to the process, and developers to appreciate and fully utilise the knowledge provided by users, and to help them overcome their unfamiliarity with active participation in the development process (von Hippel, 1994; Karlsson et al., 2011). This places considerable demands on the developer's ability and willingness to communicate with those outside of their own discipline. It requires terms and technological problems to be explained in a way that users with other expertise, recognise and may be accustomed to (Bødker, 1987; Carlile, 2004; Karlsson et al., 2011).

3.4 KNOWLEDGE CREATION AND KNOWLEDGE SHARING

One way of viewing product development is as a communicative and collaborative process where different knowledge – organisational and individual, explicit and implicit – needs to merge in order to create new and shared knowledge.

3.4.1 IMPLICIT AND EXPLICIT KNOWLEDGE

Implicit knowledge or tacit knowledge is originally defined by Polanyi (1962) and is knowledge difficult to explore, since it is embodied from experienced activity. Implicit knowledge often depends on the context and the individual, culture, beliefs, value and attitude (Polanyi, 1962, Polanyi, 1966). Implicit knowledge is essential to generate new knowledge, but it is often an unconscious knowledge, gained through experiences and therefore difficult to access, until 'something' unexpected occurs, which brings it to a conscious level with the possibility to externalize (Molander, 1996). Explicit knowledge, on the other hand, is formalised and codified and referred to as "know-what knowledge". The explicit knowledge can be expressed as words, numbers, mathematical or scientific formulas, as well as musical notations (Polanyi, 1962; Nonaka and Takeuchi, 1996; Cook and Brown, 1999).

Nonaka and Takeuchi (1996) argued that new knowledge is a result of interaction between implicit and explicit knowledge in a continuous process. The process is carried out in two particular social context, in which the individual exists. In the SECI model (Figure 18) (Nonaka and Takeuchi, 1996) four stages of interaction between implicit knowledge and explicit knowledge are described:

- **Socialisation** is when tacit knowledge passes through individuals, face to face, by practice, imitations or observations (tacit to tacit in model);

- **Externalisation** occurs when knowledge is codified into documents or books etc. and can be spread through an organisation or society (tacit to explicit in model);

- **Combination** is the simplest form of knowledge creation. An explicit source is combined with other explicit sources and generates new knowledge that can be explicitly described in for instance new documents (explicit to explicit in model);

- **Internalisation** is when explicit sources are used and learned and further modified and internalized to the users existing tacit knowledge (explicit to implicit in model).

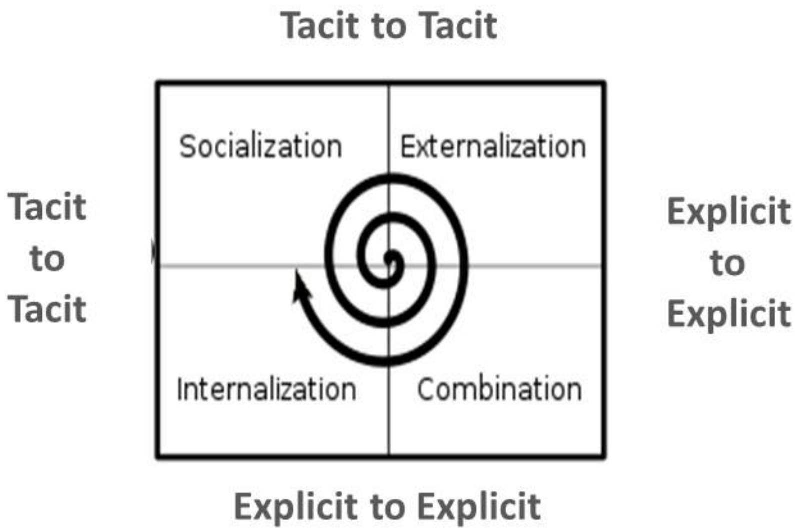

Figure 18. The SECI model (Nonaka and Takeuchi, 1996) illustrates how different knowledge moves in its context in a spiral motion through the four stages of interaction and expands over time as new knowledge is generated.

3.4.2 LEARNING BY DOING

Knowledge can also be generated by doing. Learning by doing as a knowledge generating process might be associated with poorly constructed projects, but Hoever (2012) asserts that such a methodology may also occur in structured situations, such as research projects, where an outcome or the nature of a solution is impossible to predict. Learning by doing in trial and error processes may involve that new and innovative thoughts are processes, result of solving a problem,and which may be hidden in complexity or impossible to foresee in advance (Gomaa and Scott, 1981; Schön, 1983; von Hippel and Tyre, 1995). Molander (1996) and von Hippel and Tyre (1995) argue that such situations, which may not be foreseen from the outset, will be resolved, when the solution of the probelm is developed and when they are faced. In the learning by doing process, trial and error is essential to the problem-solving process. Learning by doing comprises trial and error cycles, which often arise in the problem-solving process of new technology, and new product development processes consist of a substantial element of problem solving. Trial and error, reflect, learn, try again are vital to generate new knowledge before a new technic represent al solution is identified and can be implemented (von Hippel and Tyre, 1995).

3.5 MEDIATING KNOWLEDGE SHARING

As already emphasized, communication is essential in cross-disciplinary collaboration in order for knowledge to be transferred from one expert to another and hereby become comprehensible for team members with other experiences and skills. However, the lack of a common language for knowledge transfer has been identified as a source of mis-communication, which can serve as an obstacle to the collaborative effort between members of a product development team (Carlile, 2002; Carlile, 2004; Zárraga and Bonache, 2005; van den Bossche et al., 2006; Leigh Star, 2010; Karlsson et al., 2011).

3.5.1 MEDIATING TOOLS

Söderman (2001) claims that it is particularly important to establish good communication and mutual understanding during the early stages of a development project, in order for an exchange of ideas to take place between users and developers and between the various other disciplines of the design team. In order to generate this essentially new, shared knowledge across disciplines, researchers have argued the importance of utilising different kinds of mediating tools, which can be used as a lingua franca by all team members in order to exchange experiences and gain knowledge (Star and Griesemer, 1989; Soderman, 2001; Carlile, 2002; Engelbrektsson, 2004; Engelbrektsson et al., 2004).

Star and Griesemer (1989) argue that 'boundary objects', which are able to act as mediating tools, are the key to developing and maintaining coherence across intersecting social worlds.

> "Boundary objects are objects which are both plastic enough to adapt to local needs and constraints of the several parties employing them, yet robust enough to maintain a common identity across sites. They are weakly structured in common use, and become strongly structured in individual-site use. They may be abstract or concrete. They have different meanings in different social worlds but their structure is common enough to more than one world to make them recognizable, a means of translation. "(Star and Griesemer, 1989)

However, several other researchers consider the definition by Star and Griesemer to be too narrow, and argue in favour of a more holistic and less constrained approach to mediating tools (Carlile, 2002; Kimble and Hildreth, 2005; Lee, 2005). Other approaches, which feature broader perspectives on mediating tools, include definitions of them as objects or symbols, which may be used as a channel or facilitator in the establishment of a two-way link between the sender and the receiver, for instance between developer and user, and facilitate communication across disciplines in a development team.

In product development, different mediating tools may be employed for different purposes: a divergent purpose, such as when searching for a solution to a problem, or a convergent purpose, such as when evaluating different design solutions (Hounde, 1997; Kaulio, 1997; Söderman, 2005). Regardless of the stated purpose, a mediating tool may contribute to the cross-disciplinary dialogue and collaboration by describing problems, expressing and formulating requirements for properties, encouraging reactions and reflections, and stimulating discussions. Engelbrektsson (2004) defines a mediating tool as something that stimulates discussion, enhances the user's understanding of a product or concept and simplifies the dialogue between the user and the developer.

3.5.2 PRODUCT REPRESENTATIONS AS MEDIATING TOOLS

In product development processes, prototypes are one of the most common type of artefacts employed as mediating tools (Hounde, 1997; Rhinow et al., 2012). The role of the prototype is often described as a means for communicating progress and development to management, as it offers a physical embodiment of proposed design solutions and allows them to be evaluated (Veryzer, 1998; Ulrich and Eppinger, 2004; Rhinow et al., 2012). However prototypes can support the collaboration between different disciplines, as it can bridge the language between disciplines or verify desired properties. There is though a need for other mediating tools, which may facilitate communication between, for instance, user and developer; in particular in the early stages of development, for instance to stimulate the creation of new design solutions for the next generation of products (Karlsson et al., 1999; Engelbrektsson, 2004; Brandt, 2007).

Researchers, for instance Houde and Hill (1997), have expanded the definition of 'prototype' in stating that "prototypes are identifiable as any representation of a design idea - regardless of medium". Extending the concept 'prototype' to product representations in general would be consistent with Houde's and Hill's (1997) interpretation of the term. Product representations may thus encapsulate a wide range of concepts, such as design specifications (written or verbal), hand-drawn sketches, mood boards, CAD drawings, virtual reality (VR) representations, mock-ups or material samples.

However, according to Ben Mahmoud-Jouini et al. (2013) these artefacts need to be categorised in a hierarchic order in order to understand the different functions of the representations. In their study the artefacts were divided into three categories according to what they contribute in the process. The categories are presented as

(a) stimulators, which initiate the exploration of unfamiliar knowledge and are used before the idea generation phase;

(b) demonstrators, that create a context for reflecting on and experiencing the concepts; and

(c) prototypes, which enable testing specification and evaluating the design solutions in order meet the specifications.

These three categories were further positioned by Ben Mahmoud-Jouini et al. into two approaches regarding the way of use: (i) a chronological order, based on where in the development process the artefact is used and (ii) a functional order, based on the generated results of the artefact in the design process.

Considering also the notion of other researchers e.g (Gupta et al., 1997; Hounde, 1997; Kelley, 2001; Junginger, 2008), the main functions of a product representation are evidently representing different design incarnations of the future product and demonstrating, for instance, technology and function, size, shape, and choice of materials. The progress of the project can be demonstrated within the development team, between the user and the development team, as well as for interested stakeholders both within and outside of the company or organisation. However, product representations may also be used to identify problems and needs, confirm that the problem has been correctly understood and interpreted by all those involved, and further elicit potential solutions (Agrell, 1996; von Hippel, 2001; Carlile, 2002; Borja de Mozota, 2003). They can also function as an instrument for clarification between disciplines and individuals and decrease the level of uncertainty, which may exist when new solutions are to be identified and designed. When product representations are in a physical form and thus possible to handle and manipulate, they may serve as evidence gathering and provide practical experience of the product for both users and developers (Schrage, 1993; Béguin, 2003). There may be insights, which are difficult to come to during the development process until the product has been visualized in some way, and by using different kinds of representations, such as material samples or simple composite prototypes, the team may learn what is possible and what is not, thus contributing to increased awareness of problems and possibilities in the development process (von Hippel, 1994; Leigh Star, 2010). They may further contribute to expanding the team's knowledge regarding properties, functionalities, and production processes, and support the creation of a common arena for developers and users, thus becoming an aid in the iterative decision-making process (Schrage, 1993; Rhinow et al., 2012). Product representations can, thus, play a mediating role in different phases of the development process. Monö (1997) describes the mediating role of product representations as follows: they may help the user and developer to recognise and evaluate different phenomena, elicit ideas and images to facilitate comprehension of different scenarios in the process, and stimulate feelings and impulses, resulting in individuals coming up with new thoughts and ideas.

However, the product representation used must be chosen with care, something that is stressed by Hounde and Hill (1997), as well as by Söderman (2001) and Engelbrektsson (2004). Considerations must be made regarding what information content is possible to communicate: i.e. basic representations can answer advanced queries and vice versa. Concept sketches may be used to communicate the overall idea of a product, while a physical prototype can be used for discussing details regarding for instance size or the position of a display.

4. THE CASE

The studied case is a project, founded in an organisational setting in the form of a Triple-Helix initiative[3] in biomedical engineering. The aim of the initiative is to stimulate development of new projects, through which clinical needs or ideas (as expressed by clinical experts) can be jointly addressed by healthcare professionals, academics, and industrial partners, representing experts from various disciplines. In the current project, a multidisciplinary team was gathered to explore the possibility of using textile technology to solve a medical technological problem in healthcare of premature infants.

4.1 THE PROBLEM

Long-term monitoring of brain activity (EEG) of premature infants is at present carried out as a requisite routine in the treatment of these vulnerable patients. Today's standard method is to position electrodes for the measurement in a certain order, according to the international ten-twenty system. The ten-twenty system positions the electrodes in relation to the regions of the brain, that are to be examined (Jasper, 1957). The positioning of the electrodes on the head is currently a complicated and time-consuming process in which each electrode is placed one by one and the process requires special trained staff. Another drawback is that when the electrodes are eventually in place, there is a risk that they will move out of position as the infant moves its head. This may cause interruptions in the measurements.

There are different "cap" or "helmet" solutions available with integrated electrodes that simplify the application of all electrodes to the patient's head considerably. However, the health-care professionals have identified difficulties in executing long-term monitoring with today´s methods. In addition the existing method, besides the mentioned drawbacks, the methods often results in complications in terms of pressure damage to the skin on the infant's head. Together, these problems result in that long term recordings can only be implemented for a limited time and do not respond to the clinically motivated 24/7 EEG measurements.

4.2 CONCEIVABLE SOLUTIONS

The health-care professionals initial specified requirements for potential solutions, such as 'a soft cap including approximately twenty integrated electrodes', 'easy to assemble on the patient' and 'possible to use for uninterrupted measurements over a prolonged period'. The healthcare professionals also wanted to avoid the use of a contact gel, which is used today, as it sometimes irritates the patients' skin.

A wide range of textile materials and manufacturing techniques allow the design of soft and smooth textile systems. In this project, with reference to the healthcare professionals' initial requirements, a newly developed 3D weaving technique was identified as a potential solution to the problem at hand. The 3D weaving technique is predicted to ensure a light pressure to keep the electrodes in place and with necessary skin contact, without causing the damage that today's method does. Although the technique had not been tested in the specific context before, it was assumed that it would be possible to design a smooth textile sensor system, which would not cause pressure damage to the infant's skin. The technology also presented an opportunity to produce an electrode system, including all of the required components, in one single process, joined together so as to make the electrodes easy to assemble, increase the stability of the device, and decrease the likelihood of the infant's movements repositioning the device on the head.

[3] In 2000, the term Triple Helix was coined, which aims to describe the importance of the dynamic interaction between actors from different contexts. Triple Helix involves close collaboration between state / government, business / industry and academia, where joint learning is central and thereby also communication (forskning.se, 2014).

4.3 THE TEAM

The multidisciplinary team comprised

- a neurophysiologist as a clinical EEG expert, with specialasing in premature infants;
- two biomedical engineers, one with expertise in signal processing and one specialist in long-term monitoring of electrophysiological signals, and;
- two textile specialists, one in three-dimensional weaving and one in smart textiles engineering.

The team members came from different organisations, and the project was independent in so far as it had no set budget and no external stakeholders or internal managers, who expected results within a predetermined time frame. Also, there was no designated project manager responsible for the issues of time, cost and technology. Instead, the team members were jointly responsible for ensuring that the project progressed in a positive way.

The team may be identified as a group of individuals with different expertise gathered together to examine a medical technology problem. However, in this study the group is identified as two groups representing the 'users' of the forthcoming product and the 'designers' of the same. The users are represented by the healthcare specialists and the signal processing specialist, while the designers are represented by the textile competences and the specialist in long term monitoring of electrophysiological signals. In the following text the individuals in the team's will be defined and related to either 'users' or 'designers'.

The spoken language during meetings was English, as the group contained one non-Swedish speaking individual. This changed, however, when this team member was absent for an extended period of time, and the rest of the team talked Swedish. In addition, another member of the team (the signal processing engineer) left the project to pursue other assignments after eight months but continued to contribute with his expertise by e-mail and maintained continuous contact with the other user (neurophysiologists) (Figure 19).

4.4 THE INTERMEDIATING PROCESS

The intermediating process in this study consisted of nine meetings, (fairly) equally distributed over nine months. The meetings comprised discussions concerning issues such as user requirements as well as technical requirements and opportunities. Various product representations were iteratively developed and introduced to the users at the meetings (Table 1).

In a parallel process between the meetings, the prototypes were further developed by the designers, based on the meeting discussions, but completely new ideas or solutions could also be tried out and prepared to be presented at the next meeting. The test of each new presented solution was performed by the users and evaluated and discussed with the designers and experts at the next meeting. The results were analysed both from the users' perspective and the designers' perspectives and formed the basis for the next development loop of the product representation.

Decisions on how to proceed to the next step in the process were jointly taken by the users and the designers.

Figure 19 illustrates the process where the red dots symbolize each meeting and the intermediate development of the representations is symbolized by the grey rhombuses. The designers are shown at the top level and the users at the lower level of the picture. The whole team participated in the meetings, and between the meetings the users and the designers acted in their own environment. However at some points the user and the designers interacted between the meetings, e.g. a developer worked together with the users at tests in the users' environment.

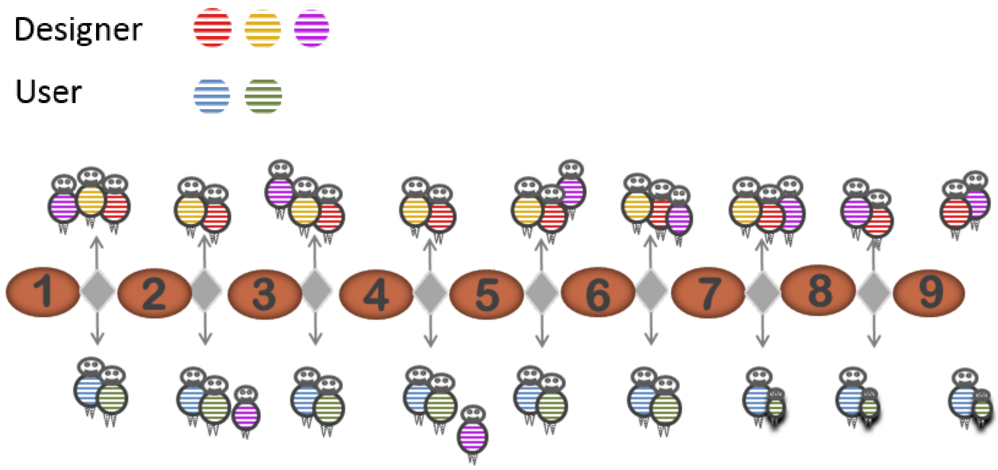

Figure 19. The intermediating team process with actors, meetings and intermediate activities.

4.5 THE PRODUCT REPRESENTATIONS

In the project various product representations played a central role in order to examine and answer the research questions. Most of the representations used were different textile artifacts, which had been produced experimentally in an iterative process. However, other representations included sketches of various kinds or commercially available products, which possessed properties that were searched for or which had properties that were to be avoided (Table 1).

Table 1. The various representations used at each meeting during the process.

Meeting	Used representation in the meeting
1 (non-recorded)	A project plan, with different scenarios for how the product's characteristics and functionality can be linked, was shown and discussed with the users. Sample material from previous projects (with other partners), such as different electrodes with snap buttons and a braided textile cable, was demonstrated to the users. Some of the materials were pre-known to users and some material was new to them.
2 (non-recorded)	The users were introduced to solitary prototypes of electrodes, which should be tested in order to define the characteristics that worked best. These prototypes were designed in a way that the users had seen and tried before in another project with other participants.
3	Electrodes in different versions with a push button as connector, a solution which was recognised to the users from previous project. A new braided cable was introduced. Sketches on whiteboard were used.
4	In this meeting the users were introduced to new kind of electrodes, where the push button was replaced by a textile braided cable, and the surface materials of the electrodes consisted of chosen materials from the previous meeting. This type of electrode was new for the users.
5	New types of cables were shown to the user, commercial as well as manufactured within the project in various editions. Sketches over the position of the electrodes were presented by the users.
6	A plastic head was used for the design of the entire prototype in an assembled form: an initial prototype with 21 electrodes and wiring attached, one half with commercial cable and the other half with textile braided cables attached to the electrodes.
7	New edition of the prototype with all components, electrodes, network systems, cabling-still content on an experimental basis assembled to examine a certain function of the electrode system.
8	New prototype - a more mature version according to the users desire (elastic material). Sketches.
9	A three dimensional woven prototype of an electrode-system integrated in a ribbon completed in one single production process.

The textile product representations were prepared by traditional textile manufacturing processes, such as weaving, knitting, embroidery, braiding, yarn-twisting, combined with stitching and bonding techniques such as lamination in a "cut and paste" method.
The creation of the product representations is presented in chapter 5.

4.6 DATA COLLECTION AND ANALYSIS

The analysis is based on participating observation in the team meetings,diary notes and the development of the representations.
All but the first two meetings were recorded, using a smart phone equipped with an external microphone. All team members were informed about the study and gave their consent to the meetings being recorded.

The recordings were transcribed in full, and a qualitative content analysis was carried out (Granskär and Höglund-Nielsen, 2008). The contents of the first two, unrecorded, meetings are included in the analysis, based on protocols, sketches and photographs. The analysis took an inductive, exploratory approach, with the intention to explore communication and cooperation in the multidisciplinary team in an innovation project's early phases. The analysis was carried out in several steps.

First, all meetings were listened through several times to get familiar with the discussion and tone of voice. In the next step the transcriptions from seven meetings were read through as a whole to get a basic understanding of all the meetings in a sequence and to get familiarised with the dialogue as a text.

The third step of the analysis focused on the content of the meetings. There were no predefined themes for the analysis, and therefore a coding system was created as the analysis proceeded. The outcome of this part of the analysis was a clear division between technical themes and dialogue of a more social character, and the different themes of the discussion were discerned. Various characters of dialogue were identified, for instance social chatter, questioning, answers, explanation and conclusion.

The social chatter was included in the analysis, despite not directly affecting the technical development, but due to the fact that it was considered a crucial part of the meetings and contributed to the users and developers coming together as a team.

At the fourth step of the analysis, questions such as 'how do the dialogue and cooperation progress within the team?'; 'do the users contribute with their own knowledge to the development process?'; 'what kind of relationship do the actors have to the product representation?'; 'does the product representation contribute to generating new knowledge/understanding in the team?'; and 'does the product representation contribute to a shared knowledge?' were used to discover and discern different themes from the transcribed dialogue to be included in the coding system.

In a further, fifth step of the analysis, different characteristics of each of the themes from the dialogue were analysed in order to discover possible themes regarding the role of the representations by examining the transcriptions with the focus on questions such as 'how was the product representation used among the individual team members?'; 'were there any particular situations, where the dialogue needed support?'; 'did the product representation invite to questioning?'; 'how did the product representations contribute to knowledge in the team?'; and 'was there any variety of roles of the product representations?'.

In order to get a better understanding of the flow of the different themes within each meeting as well as the individual contributions from each of the team members, two separate colour coding systems were used to present the dialogue in terms of themes and individual contributions.

This graphical presentation of the meetings used colour coded bars to indicate the themes and the color-coded members on a chart to visualize the flow in the dialogue. This enabled a clear overview, about not only the different themes and how they appeared during the meetings, but also the activity of each of the team members and what kind of comments they made in relation to the different themes.

All transcribed colour-coded meetings were printed out, reduced by 75% of a standard A4 size paper. Each meeting was arranged, side by side in the chronological order according to when the meeting had taken place in a long poster. Figure 20 shows examples of three such colour-coded charts arranged side by side in chronological order and a close up of a colour-coded conversation.

Figure 20. The transcribed colour-coded meetings arranged in chronological order for analysis, where the flow in the dialogue is documented (left panel). The right panel shows a section of a coded conversation in detail.

These different colour codes, along with the arrangement of transcripts, made it possible to explore and compare the contribution of the product representation and its development at an individual level but also at the level of the team as a whole and, furthermore, visualize the themes in the analysis process in a lucid way. This analysis formed the basis for the findings that are presented in the chapter 'Using the representations'.

5. CREATING AND USING THE REPRESENTATIONS

The outcome of this study is presented from two perspectives; Creating the representations and Using the representations. The section 'Creating the representations' describes how the textile product representations for long-term EEG monitoring were created, while the section 'Using the representations' describes what occurred when these representations were used in meetings between developers and users.

'Creating the representaions' presents the resulting technical textile in the form of a three-dimensional woven textile, which shows the potential benefits of integrating multiple functions in a single process in order to create a textile system. The completed product was preceded by a development process in which textile product representations were created in an experimental and conceptual process. The product representations were initially constructed as individual components; this allowed the identification of the properties and functionalities of each property respectively, prior to their being assembled to form the textile system.

In 'Using the representations', the use of the representations is analysed and described. Users participated in the process from the very beginning, offering their experiences regarding the limitations of the present solution and the new product concept in actual use, something which the designers lacked. During the project, the users were given opportunities to handle the materials, discuss them, pose questions to the designers during project meetings, and test functionalities and properties in the intended use environments; the results then formed the basis for the next iteration of the solutions.

5.1 CREATING THE REPRESENTATIONS

In the project, the three main subsystems, i.e. the electrodes, the cables, and the carrying structure, were designed as individual parts prior to being assembled to form the complete product. By creating simple and easily assembled product representations using basic, cut-and-paste methods, it was possible to quickly create representations of both high and low complexity.

5.1.1 ELECTRODES

Textile electrodes of different types were constructed in order to investigate the design of the surface, with the aim of creating a soft electrode surface with as high conductivity as these constituted the two primary requirements of the electrode subsystem.

Other properties were also investigated, such as stimulating local sweating and moisture-keeping properties to reduce the skin-to-electrode impedance.

The example below describes the first production stage, in which the designers created electrodes for the users to try out in their own environment and examine how well each product representation corresponded to the requirements.

> The conductive materials consisted of commercially available yarns which were woven and knitted into textiles of different kinds. These would, together with a knitted spacer fabric create the electrode samples. Initially, the electrodes were equipped with a push-button to enable easy connection to the measuring equipment. The push-button was placed in the spacer fabric (the white material in Figure 21), and was connected to the surface of the electrode by means of a conductive silver thread from the surface of the electrode and winded around the base of the push-button.

The placement of the push-button caused a small dent to form in the spacer fabric as it was compressed; this in turn made the electrode surface concave rather than convex, resulting in a decreased skin contact of the electrode as contact gel was not to be used. To counteract this problem, another piece of thinner spacer fabric was added to the electrode (Diary notes 2011-10-05).

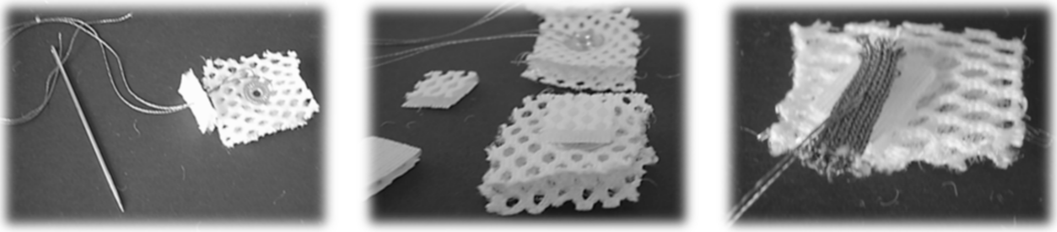

Figure 21. The first electrode prototypes are designed and crafted.

The sample electrodes were designed with different surface structures but using the same materials. Initially, prototypes were developed using either commercially available materials or ones created by the designers themselves, as was deemed necessary to match the initial specification of requirements. New combinations of materials and surface structures were developed in an iterative process, each of which was tested by the users to find the best solution.

5.1.2 CABLE SYSTEM

It was realised early on that developing a cable system was inevitable, as the standard EEG system includes around twenty electrodes, all of which require individual connecting cables. The initial solution where electrodes were connected by a push-button only worked for testing purposes in a laboratory environment. In addition to replacing the push-buttons by an integrated cable system the users also requested the used cables to be soft and flexible to prevent harming the patient's skin.

This cable requirement was in line with the designers´ requirement as it would also simplify the (future) textile production (as imagined by them) without negatively impacting on the functionality of the product. Starting with the requirements identified for the cables, the project pursued two solutions. The first solutions proposed to use commercially available cables. Initially, easily available, commercially produced standard cables were therefore investigated. These were, however, at an early stage found to be too thick and stiff, significantly affecting patient comfort; thus, they were deemed to be unfit to fulfil the specification of requirements. After searching on the market, the developers found a company that produces thin cables for medical technological products; these produced excellent test results, as regards both the level of comfort and the transmission of the signal from the electrode to the measurement system.

The second solution required an investigation into how well a braided textile cable would correspond to the requirements. Such a cable requires a conductive core to transmit the signal, which in turn necessitates a protective sheath to prevent short circuits and stop moisture from reaching the conductive core and causing interruptions.

In earlier projects, the designers had constructed textile cables using a braiding technique, and these were presented to the project team. In spite of the fact that the cable shown proved to be too thick and the material of which its core is composed has a too high electric resistance (meaning that it did not meet the requirements of the project), the cable was able to stimulate, at this early stage of the project, a discussion as to how to solve the connection issue in clinical use outside the laboratory.

The example below describes how the designers constructed the textile cable using a braiding technique.

> The identified properties guided the choice of yarns, and included a high conductivity, low moisture absorption, and a thin, soft and flexible structure. In the braiding machine, twelve yarn cones rotate individually and the yarns from them are braided at a crossing point, creating a tube. First, the correct yarn must be wound onto the twelve cones as part of a semi-manual process, in which each cone is placed on a rotating shaft in order for the yarn to be wound onto the cone while the operator uses one hand to control how tightly the yarn is wound.
>
> The conductive core is wound onto another type of cone, placed underneath the machine, and threaded up to the crossing point, where the braiding around the core takes place. The first attempt encountered a number of problems; small loops of the conductive core protruded through the protective cover, and the textile cable was too irregular and far too thick to function correctly in the intended application. In order to counteract this effect, the excenters of the machine were replaced thus the speed of the rotating cones was adjusted. These measures did not, however, fully solve the problem, as the rate at which the conductive core was fed through the machine up to the crossing point was still irregular.
>
> To solve the feed rate issue, the developers devised a simple form of resistance, consisting of a sequence of nuts through which the core travelled; this continuous resistance stabilised the feed rate and thus the quality of the cable. Another problem occurred as the conductive yarn came into contact with certain metal surfaces on the machine, which caused the safety system of the machine to trigger an emergency stop. The particular surfaces had to be covered in order to prevent the problem, and the initial solution was to put a sheet of paper over the surfaces in question; however, the paper proved to be easily dislodged, and so the surfaces were instead covered in protective tape, thus allowing the conductive yarn to pass through the machine to the crossing point, without triggering the safety shut off. Although the braiding technique resulted in a thin, fine, and pliable cable, it required another moisture barrier in addition to what the yarn and the structure itself could accomplish. Experiments were then conducted in which the textile cable was coated in polymers to prevent moisture from penetrating to the core (diary notes 2012-01-12).

Although the users' feedback for the textile cable was positive, the parallel investigation of available commercial cables also yielded a favourable result which corresponded well to the requirements for the cables. At this point, the decision was made to discontinue development so as to avoid misusing the limited time available for the development process. One uncertainty remained, however; the issue of how to process the cable in order for the connection with the electrode to be reproduced in an industrial environment. This is a common problem for smart textiles which has yet to be resolved.

5.1.3 THE CARRYING STRUCTURE FOR ELECTRODES AND CABLES

Another user requirement was that the product should be easy to apply to and easy to wear for the patient. Thus, a carrying structure for the electrodes and the cables had to be constructed to integrate the diverse components into a single unit.

Figure 22. Cut-and-paste workshop where the developers design the templates to the prototype as a whole for the first time.

A textile structure was designed and developed through multiple iterations (Figure 22). The design was tested by the users between each iteration and the designers received feedback regarding issues such as comfort, fit, adjustability, signal quality, etc., which formed a basis for the adjustments carried out prior to the users testing the next iteration. As in the process when templates for patterns to a new garment are created, the material used to create the first design was a pliable material but which did not stretch. The non-stretchable material ensured that parameters which affect fit and function were easily identifiable since these aspects do not rely on the material and changes in the design can be transferred back to the template. This also aids the process of adjusting the size of the product during the latter stages of the project.

Some requirements in the forthcoming product were identified from the users at the start of the project, for instance the conductive electrode surface, smooth surface and easy to apply.
However several requirements such as the isolation layer, prevention from evaporation, resilient and contactable and attachable to the conductive part of the electrode were initally hidden and neither the users or the developers were aware of them when the project started (Table 2). The various functional requirements which were identified in interaction between the users and the developers emerged during the development and testing of the product representations and both the users and the designer helped in this progress.

Table 2. Identified requirements in the textile system.

Electrode	Cable	Carrier
Conductive surface	Contactable and attachable to the conductive part of the electrode	Easy to apply on the patient's head
Smooth surface	Not affecting the patient's comfort	Comfortable to wear
Moisture keeping	Soft	Different sizes
Prevents evaporation of moisture	Flexible	Electrodes positioned according to the international 10-20 system
Isolation layer	Cable connection between sensor and monitor	Allow washing method which enables disinfection
Resilient layer	Attached to the electrode during textile manufacturing process	
	Protect from electrical magnetic interference	

5.1.4 THE THREE-DIMENSIONAL WOVEN RIBBON

The development process was mainly conducted using a cut-and-paste method, which informed and facilitated the construction and development of the textile system. This process further stressed the potential advantages of constructing the textile system using a three-dimensional weaving technique. This weaving process allows a product with all the identified properties to be produced in one single process, avoiding the need to manufacture individual components separately and lamination to form the complete and final design. In addition, the weaving process facilitates the selection of individual properties for materials in the weft and the warp, as well as of individual weaving patterns for each layer in the structure. Due to the flexibility of the weaving process, it is possible to select different types of yarn for different linear planes, according to user requirements, and to interlace them in order to form a unique structure. (Figure 23).

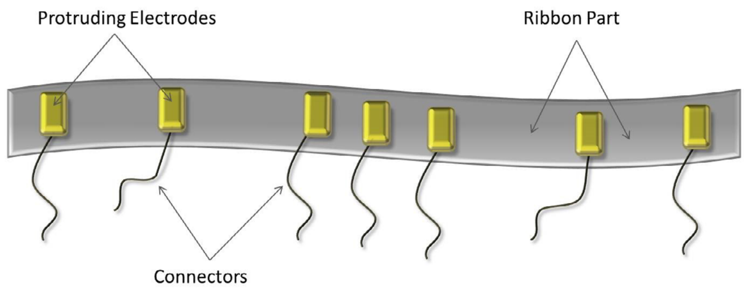

Figure 23. Illustrates the three dimensional woven ribbon with electrodes positioned due to the ten-twenty system.

The outcome at this stage of the project was a woven structure from which moisture-keeping, protruding resilient electrodes were integrated in a woven ribbon. The technique allowed each electrode to be positioned individually in the woven structure according to the international ten-twenty system for EEG signal acquisition (Jasper, 1957).

5.2 USING THE REPRESENTATIONS

This section summarises what occurred when the users and the designers met, and the roles of the different product representations. The representations supported users and designers in the process of developing an understanding between the disciplines, facilitating the full exploitation of a diverse array of expertise and skills and sharing knowledge as well as facilitated the users' involvement in the development.

The following section describes how the users developed their role and became more active in the development process.

5.2.1 FROM EVALUATOR TO CO-DESIGNER

A first observation concerns changes in the users' role; from passive observers to proposing solutions and even new application areas for the new technical solution.

At the outset of the project, the users often took the role of rather passive observer of the performance of the prototypes. They appeared unfamiliar with providing more detailed feedback to the designers than if the test of the prototype had been successful or a failure, without offering any information regarding, for instance the motives behind decisions taken during the test situation. In the following example (1) the users have tested the initial prototypes of the textile electrodes and meet the designers in the following project meeting.

> *User 1: OK, so we had this little session, and the summary is that we succeeded. In all cases, but more so in two cases. So the next question is; what is the next logical step? (Meeting 3)*

One reason behind the users not providing more information (at this stage in the process) may be that this input is what typically is requested from them in product tests and that they therefore lack experience of verbalizing their knowledge. Another reason may be that the use situation is so familiar and well-known to them that they are not aware of the knowledge that they bring into the situation and the interpretation of the outcome. The knowledge may be of an implicit nature but the implicit knowledge needs to be externalized so that the user's knowledge of the product in use can become explicit and visible in the development process.

In another meeting (example 2), at a later stage in the process, one of the users is taking actioby describing an alternative product that he has seen and he wants to share his awareness of this new design solutions with the team. The user explains enthusiastically to the team what he has seen by making sketches, i.e. in this case he produces his own product representations in order to communicate his idea.

> *User 2: I saw something ...was thinking about maybe to show you (the user draws a picture of a design from another product).*
> *Designer 1: ... It is similar to what I am thinking of ...*
> *User 2: They just filled it from the side*
> *Designer 1:- From the side?*

User 2: Yes, the band is not wider than the electrodes so they just ... like this...
Designer 1: That is similar to what I want in our prototype ... so my idea is to end up in something between those two sizes in the ribbon (the designer shows two different textile ribbons) and also make it ... (the designer crosses the two ribbons)something like that is the aim in my head ...
User 1: So you think of a more ribbon structure ...
(Meeting 4)

The designer notes that there are some similarities to the kind of technical solution she has thought of and the designer can fill in by referring to samples of material and earlier prototypes. The example (3) illustrates how the user now acknowledges the technical solution (the ribbon structure) and as the user begins to grasp the design in more detail, he begins to visualise opportunities to solve problems that the new solution could remedy but which have not been raised as issues earlier in the dialogue. The consequence is shown in the example (3).

User 1: So you think of a more ribbon structure...
Designer 1: Yes, and they (the ribbons) will be connected so I think of a kind of net-structure (the designer arranges several ribbons on the table and arrange earlier electrode prototypes on top of the ribbon net- structure)... because I think maybe it is good to that you have the electrodes reachable...
User 1: In some of these examinations they need to get access to the head and they fastening needles[4] ... this is interesting ...
(Meeting 4)

When analysing the process along its timeline, it is evident that the users became more and more involved and that a shift occurred step-by-step. As the users gained more knowledge of how the prototypes functioned, together with an increased awareness that the designers needed more information on how the tests of the prototypes had been performed as well as the users' interpretation of the results, it could be noted how the users started to describe and share with the designers what they did and what they experienced in the tests. In this example (4) the users have tested a new version of the prototype, which this time was assembled as a whole system.

User 2: The prototype ...I didn't it feel it – no discomfort!
User 1: It (the signals) looked good after a few minutes of stabilization, which is a normal process...and it worked perfectly which is great, especially since no scrubbing (to prepare the skin) of the skin was done this time.
(Meeting 7).

The example illustrates how the users now contributed more spontaneously with their experiences from the tests and their know-how to the designer. The users explained what they experienced with the new prototype and they guided the designer in what was observed in the test situation as well as how the test was carried out.

[4] Injection needles are used for blood sampling, it is for different reasons easier to attach these needles to the scalp of the infant.

The shift continued and towards the end of the process the users began to leave their role as evaluators and take on a more active one, as co-designers, The following example illustrate how the properties for the next development loop of the next prototype are discussed and how the user, not the designer, acts to find solutions. The example (5) shows when the user for the first time proposes a change in the properties of the prototype:

> *User 1 : Hmm ... probably it is a good thing to have ... in the end ... more elasticity to improve the contact between the electrode and the skin.'*
> *(Meeting 7).*

These examples show that time is essential to make the shift for a user from a traditional evaluator to a co-designer in a development process. When the user starts to act as a co-designer the user's knowledge can be communicated in more 'product' or development terms and hereby the knowledge can more easily contribute to fulfilling the needs and requirements of the user in the forthcoming product.

5.2.2 TEACHER AND LEARNER

The analysis of the data also reveals several instances where the relation between the designers and the users can be described as a teacher-learner relationship. In this process as well as the development process overall, questions and questioning were identified in the empirical data as a key element which opened up the dialogue between the team members and facilitated a higher degree of shared understanding and knowledge in the project. The different team members had initially little common knowledge about how the product could be developed which may have meant that it was not obvious what issues were relevant to ask questions about. Initially the questioning was therefore of a more general nature, and there were not many follow-up questions from the users or from others in the team when, for instance the designer provided an explanation or an answer to a question. However, as the knowledge grew and the understanding of the importance of the respective participants' contributions developed over time, more specific questions were asked.

In some cases the user acted learner, in other situations the designers. This was for instance the case when the designers needed to access the users' experience and gain a deeper understanding of the problems that the users had identified in the present solution in order to be able to (in collaboration with the user) define the requirements and the potential solutions. Therefore the designer needed to understand how the solutions, which the users at this stage had tested, would potentially contribute to an improved product. In the following example (6), the designer is uncertain about the methods that are used today, how to perform the long term EEG measurements and tries to understand if the user sees any potential in the design solutions that the project has discussed. The discussion has been preceded by the designers having demonstrated basic prototypes of potential solutions and hereby trying to envisage design solutions in the future product.

> *Designer 3: But I am not really sure, to what extend is this possible to do today...to record for a long time?*
> *User 1: It is done, here as a routine it's done for epilepsy surgery and in variations, so sometime they come on Monday and come back on Wednesday and sometimes they stay over weekend and most of them stay while recording... So that can be a number of days.*
> *Designer 3: But in that context you don't add gel or anything?*
> *User 1: Yes, sure, and manually and often they have to check it and redo it because something has happened, so that is work intensive process.*
> *Designer 3: Like 24/7 or is it like every morning they checking the EEG again?*

User 1: Yes, in practice that is how it is organized, all this /not audible/ by electrodes areput there by people from here and we don't have that around the clock service. And at the ward where they are staying they have people … but they are not trained and so skilled to do this but that can of course be changed. I mean just adding a little water; salt water that will be easy if that is needed.
Designer 1: Yes, I see.
Designer 3: … In comparison to the way it is done now?
User 1: Yes, so this (aiming at the discussed design solution for this project) is a big lead forward anyway.
(Meeting 3)

The designers needed to get the users to assess the potential of the solutions that the designers intended to place in the forthcoming product, but in order to do so the users needed to understand what they were to assess. In examples 7 and 8 it is shown how the product representations support the user obtaining technical knowledge by inviting the user to ask concrete questions on a detailed level. The physical product representations demonstrate and visualize suggested forthcoming solutions. The examples (7 and 8) illustrate how, when the user holds the physical representations in his hand and can feel and squeeze the materials, questions to the designer are triggered. The representation seems to stimulate curiosity and the user wants to understand more of how the technical solution could work. In the example (7) one designer and one user discuss a potential solution for the connectors.

User 1: Is that plastic?
Designer 1: It is.
User 1: Very surprising, and that is isolation against humidity I guess?
Designer 1: Yes.
User 1: … Not against electricity?
Designer 2: Yes, it is.
User 1: Sounds like a good thing.
(Meeting 5)

With the prototypes, centrally placed on the table, the user could feel, touch and point at them when he asked the questions to the designer. Visa versa the designer could enlist help from the product representations when she wanted to explain something.

The following excerpt is another example (8) of when the product representation supports theuser to develop a better understanding of the technology by visualizing the technical solutions' future opportunities. The designer can with support from the representation demonstrate the technical characteristics and the prototype´s operation to the user:

Designer 1:…This is the … is a coaxial cable…
User 2: So that is a coaxial cable?
User 1: Meaning …?
Designer 2: Five layers.
User 2: Five layers??
User 1: What signifies this coaxial? What does it really mean?
Designer 2: That it…here it has a core and then isolation and conductivity to shield… and then it is a shield…
User 1: It's one centre and then it is isolated?
Designer 2: Yea.
User 1: So it's both a leader and a shielded or whatever… It is very amazing… it's extremely thin and delicate… that can be very practical in this for us.
(Meeting 5)

It was not only the users that had to develop new knowledge, the designers needed to obtain more detailed knowledge in areas which were outside their expertise to be able to understand and fulfil the users' need and requirements. In the next example (9) the different parts of the solution have been assembled and the solution will be tested as a whole for the first time in the project.

The electrodes must be placed according to special international positioning system (so called 10-20 system) in order to work properly during the measurement and in this situation the designer needs support in understanding how to position the electrodes in the prototype. It is obvious that the solution does not fit properly. The designer has earlier received verbal instructions from the users but has not really managed to transfer the instruction into practice and therefore asks the users for assistance in identifying the errors:

> *User 1: Jae … It should be a little bit wider so they (the electrodes) are further down but I guess. … But if you really want to know ...then you should bring one of the experienced BMA – technicians (specialist) which do this all the time...*
> *(Meeting 6)*

First in this situation, when the (mis)interpretation of the designer becomes evident, the relevant piece of information is elicited. At this stage in the process it is made known for the designer that there is another specialist who performs this task in practice and the user therefore wants this specialist to be involved in the positioning of the electrodes to ensure that is properly done. A special trained specialist, a Bio Medical Analyst (BMA), is therefore called in to the meeting[5] The situation is one of several examples that affirm previous research on sticky information where e.g. Hippel (1994) points out that information in new development is often hidden and difficult to identify and verbalise since it does not occur until it is faced in the design process.

In the following example (10) it is shown how the designer asks questions to the specially trained user, the BMA, and uses the prototype to demonstrate and to concretize the issue. In this case one of the users, or rather the head of one of the users, becomes a mediating tool. The individual on whose head the prototype is placed uses it to point at and demonstrates the answers when the designers need to understand in detail how the electrodes should be positioned in relation to each other when the measurement is executed.

> *BMA (user 3): Yes, and so it is a bit .... it is supposed to sit so ...*
> *Designer 1: It should sit at the ear?*
> *BMA (user 3): Yes, it is a little too far forward*
> *Designer 1: … But this with the ear?. .. You start here?*
> *BMA (user 3): Yes, and then to the bump where 10 cm*
> *Designer 1: But the bump .... there are so many? ...Is this it?*
> *BMA (user3): Yes.*
> *(Meeting 6)*

To be noted is that in this example the prototype is not only an object watched and touched by the participants but also an object that is manipulated together. The implications are that if product representations are actively used in this way they can contribute to transferring tacit knowledge from one individual to another, such as from users to designers and from designers to users.

[5] In this study, also this expert is considered a user

Another example shows the importance of time and how, at certain occasions, leaps in understanding can occur. The example (11) is preceded by a long discussion on how the proposed technical solution may work, how the solution could be manufactured in different materials, etc. The designer now demonstrates how different materials can be assembled in the future design of the product. The product representations that the designer has used in order to explain in a way which the user will be able to follow, are various, previously used, representations such as single electrode prototypes, textile ribbons, and various cables.

User 1: Oh, there is plenty to retrieve... it can be improved so much...
Designer 1: Mmm....
User 1: So it is not entirely science fiction to imagine that you can weave everything in one piece ... with conductor and surfaces and everything...
Designer 1: Mmm ...
User 2: O yes.... several layers... the circuit boards is made like this... with various conductive layers
Designer 1: Mmm ...
User 1: Suddenly it strikes me... something completely different. Strange how you connect things ... eeh ... the most common imaging technique nowadays is the MRI scanner. Can you choose metal on this surface in such a manner that it might be possible to scan people in a standard MRI camera without doing anything?
Designer 1: Mmm ...
User 1: I don´t know.... but it might be something to have in mind... when it is so early in the development.
Designer 1: Aah, it sounds really exciting.
User 1: So we don't miss such a thing ...
(Meeting 8)

At this stage the user starts to comprehend the full potential of what the technology offers, an understanding that seems to lead to seeing new opportunities for the technique. The product representations could be claimed to have helped the user to combine old knowledge with new knowledge gained regarding the advantages of the proposed new technology.

5.2.3 COMMON OBJECTIVES

When the users and designers first met the designers had brief knowledge of a medical device problem that the users faced in their daily work. The first meeting that was initiated had the purpose to discuss different opportunities for collaboration with the aim to find potential opportunities to solve the user's problems or part of them. Different approaches were ventilated and the users described various problems and disadvantages with today's methods. The designers on the other hand described verbally and demonstrated physical materials from previous projects which they had brought to the meeting. Different possibilities to solve the problem were hereby introduced by the designers to the users.

A platform for sharing information was decided upon and it appeared as though everyone in the team had the same target scenario of how the problem might be solved and what the design of the solutions might look like. The initial meeting resulted in the common view that it was interesting to continue to work as a project. A flowchart, where different scenarios to solve the problem were identified and presented, was organised by the designers. In the flowchart different solutions that were expected to provide the team with information of the function were described such as material samples, solitary simple prototypes and three-dimensional, woven prototypes.

From the first meeting in the project the designer described the design of the future product as a net- or ribbon-structure in which the electrodes were integrated. Example (12a) illustrates how the designers try to explain the potential solution and how it might be manufactured:

> *Designer 1: I want to make the whole net-structure in one process...*
> *Designer 3: And it also opens for weaving electrodes into another structure, supporting textile (and) isolating textile in one process .*
> *(Meeting 3).*

The users described the design of the future product in other terms, such as a cap or helmet. The following example (12b) is from the same meeting where different needs and the advantage of the potential solution are discussed.

> *User 1: Yes, of course, the fact that you don't need to place the electrodes and scrub them, you just put on a helmet or whatever and you just ...(monitor the signals).*
> *(Meeting 3).*

In retrospect, it is evident that no one really grasped that the solutions that users and designers had in mind did not accord to each other more than on a fairly general level. The users and the designer had different mental images of the solution which are communicated by terms such as 'a ribbon', 'net-structure', 'cap', 'helmet' or even as 'bicycle helmet' without any attention being given to the fact that the members of the team use different terms to describe the design.

At this stage in the process, the product representations used were solitaire electrodes, solitaire cables and improvised sketches on the white board to demonstrate and visualise included details. When the users started to test different prototypes, the prototypes consisted of solitary electrodes. Since the representations consisted of solitary parts and not of parts mounted as a whole structure none of the product representations really challenged the different mental images and therefore both users and designers could hold on to their respective image. The users' mental image of the final design solution was not challenged for a long time: it appeared to be based on the solutions that are available today. One event changed however the situation. In example (13) one of the users has seen a prototype of a new product where the design was new to him.

The prototype was demonstrating a future product in which all including components were assembled and the function and use were demonstrated for him. The user demonstrates and visualizes by hand-drawn sketches how the design was carried out.

> *User 2: Yes, the band is not wider than the electrodes so they just ... like this... (hand drawn sketches are drawn by the user)*
> *Designer 1: That is similar to what I want in our prototype ... so my idea is to end up in something between those two sizes in the ribbon (the designer shows two different textile ribbons) and also make it ... (the designer crosses the two ribbons) something like that is the aim in my head ...(meeting 4)*

For the first time, both users' and designers' mental target images are challenged. The designers see in the user´s illustration that there are similarities in how they plan the final solution and can explicitly point this out to the user. The representation that the user produces makes the designer see that there are different mental images within the team, and the user grasps that the designers' design is different from that of the users mental image (example 14).

User 1: So you think of a more ribbon structure ...this is interesting... (Meeting4)

Again the examples show that time is a key factor and essential in order to make the team grasp, in this case, similarities and differences in their respective mental images. In this case the users had to abandon their mental images of the final solution but to abandon this image, the individual must understand the other idea and see the benefits before they can take another one in consideration. The creation of the product representation led to an insight that the team members had had different mental target images of the end design but also that both the designers and the users had used different words to describe the design. In the situations illustrated, the representations opened up the dialogue in the project and a common objective on a more detailed level emerged between users and designers. The product representations stimulated and visualized the similarities and the differences between the team members' view of the end product and facilitated the integration of perspectives to form a common objective.

5.2.4 THE DIFFERENT ROLES OF THE PRODUCT REPRESENTATIONS

The analysis of the data reveals the importance of the product representations mediating the discussions and the sharing of knowledge but also that the product representations played different roles in the process. Table 3 presents a categorisation of five different roles that the product representations were noted to have and through which they supported and enabled the collaboration in the multidisciplinary team, consisting of users and designers.

The roles can be categorized into two main groups; as explanatory and concrete roles such as Verbalize and Demonstrate and as more proactive roles such as Visualize, Stimulate and Integrate.

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Table 3. Illustrates the different roles which the product representation acts in.

The roles of product representations				
Demonstrating	**Verbalising**	**Visualising**	**Stimulating**	**Integrating**
Unlike visualisation, demonstration is more concrete in nature, and clearly provides evidence as to the existence of something.	The product representation assists in putting a problem into words, when terms are missing or terms are not understood by other members in the team.	The product representation assists in the creation of visualisations or mental images.	The product representation encourages a process whereby an individual becomes inspired to and generates new ideas.	The product representation facilitates the integration of perspectives from diverse disciplines, and unites different perspectives
The product representation provides practical explanations.		The product representation aids in recalling or adapting mental images to make them fully comprehensible.		
The product representation demonstrates the operation or use of something.				

Furthermore and in contrast to categorizations of representations made by other researchers (Ben Mahmoud-Jouini et al., 2013) the results of the analysis do not support positioning the various roles along a process timeline. In the empirical material presented here (examples 1-14) the various, facilitating, roles have instead co-existed throughout the project. The different roles were identified in situations at different stages in the project and, in addition, the product representations acted in different ways at the same occasion which is illustrated in table 4.

Table 4. The occurrence of the different roles of product representations in the examples included

The occurrence of the different roles in described examples					
Example number	Demonstrating	Verbalising	Visualising	Stimulating	Integrating
1	X				
2	X		X		X
3			X	X	
4	X				
5	X		X		
6	X		X	X	
7	X	X		X	
8	X	X	X		
9	X			X	
10	X	X		X	X
11			X	X	X
12	X		X		
13	X		X		X
14			X		X

The roles of 'Verbalize' and 'Demonstrate' were nevertheless identified to be more frequent in the first part of the project. When the product representation has the role of 'Verbalizing' it serves as a facilitator to fill in where words as missing or terms are not understood across the disciplines. Both the designers and the users used the representation to point at and asking questions such as "What is...?". In example (4), for instance, the user points at the product representation in front of him and asks: *"Is that plastic?"* Other ways of using the representation was to point at, and hereby localise, different elements, as in example (7) when the designer wants to localize the exact position for one of the electrodes: *"But this with the ear?. .. You start here?"*

The demonstrator role occurred frequently when the designers introduced new design options or needed to demonstrate or clarify the influence that the proposed design might have on the forthcoming product. The product representation served as a demonstrator between the user and the designer and helped to concretize questions and answers.

The questions and questioning are considered to have been a key element in achieving a higher level of shared knowledge. In addition, the physical existence and tangibility were important features of the product representation, i.e. when the users were able to physically handle and explore the product representations, they were triggered to ask the designer questions about materials, functionalities, and design. In the same way the designer had the opportunity to ask questions concerning potential usability and clarify whether or not the users' requirements had been met (or not).

Furthermore the product representations provided the user with evidence regarding the feasibility of the technical solutions. This was obvious, for instance in example (2) when one of the users exclaims: *"The prototype ...I didn't it feel it – no discomfort!"* The representations exhibited the operation of the prototype (product) in use but they were also evidence of the designers' acknowledgement of the users' input to the design, something which most probably facilitated the users' shift from passive observer to active evaluator.

The roles of 'Visualize', 'Stimulate' and 'Integrate' are of a more proactive character and occurred more frequently when the team had gained more shared knowledge and could use the shared knowledge to discuss the impact of different parameters in various scenarios, even if the proactive roles existed throughout the project.

Visualize denotes a situation when representations support individuals to recall or evoke mental images. When the representations support the creation of common visions or support mental images to be created and shared, they support shared knowledge. In example (4) one of the users has gained awareness about another project's design which he wants the team to take part of.

The user creates his own representation in the form of a hand-drawn sketch that visualizes (his mental image of) the solution that the user wants to share with the team,..".. *I saw something... "*. The hand-drawn representation visualizes not only the user's contribution in terms of a design solution but it triggers the designer to fill in how the designer's image of her solution looks like: *"... It is similar to what I am thinking of ..."*. By using the product representations to visualise different mental images a more unified view of the design was developed between users and designers which supported the process of sharing knowledge.

Product representations can also assume the role of stimulator and is identified when the product representations encourage a process whereby an individual becomes inspired or enthusiastic. This facilitates the generation of new ideas or design solutions and the progression of the project.

In example (3) for instance, the product representation has enabled the user to gain deeper knowledge of the technical solution and the representations stimulate the user to see more opportunities in how the future product can facilitate his daily work: "...*this is interesting* ...". In example (11) the user has gained a more thorough understanding of the functions and design through the representations tangible and physical form: *"...there is plenty to retrieve...it can be improved so much..."*. Here, the representations enabled the user to see future possibilities.

In example (9) another kind of stimulation occurred. When one of the prototypes is to be tested and when it becomes obvious that the position of the electrodes is not properly done by the designers the user is triggered to invite another (user) expert: *"...if you really want to know...."*. The representation stimulated the user to invite another expert when he understood that the designer needed more detailed information in order to place the electrodes correctly in the design even at this early stage in the project.

The fifth role is the most complex one and can be defined as a representation bringing parts together, unifying or incorporating (parts) into a whole. The representations facilitated the integration of perspectives between the different disciplines and supported to unite different perspectives in the team as in example (11). The designer has here demonstrated and visualized, with various physical representations, how the technology can enable the design of the textile system and one of the users begins to understand and grasp on a more detailed level how the designers intend to design the product *"... So it is not entirely science fiction to imagine that you can weave everything in one piece ... with conductor and surfaces and everything...."*
This leads to that the other user (which has a signal engineering background) starts to transfer and integrate the information into his own expertise *"... O yes.... several layers... the circuit boards is made like this... with various conductive layers"*.

Using product representations which supported the dialogue the different perspectives, the users' and the designers' views could be integrated. Knowledge could be translated into an individual's own area of expertise, and thus it could contribute to evolve shared knowledge, support the integration of knowledge and understanding of different actors' contributions to the development process of the future product.

6. DISCUSSION

The primary purpose of the research presented in this thesis was to investigate and describe how mediating tools are able to facilitate interdisciplinary collaboration between designers and users. The development of a textile system for medical technological usage forms the basis for the study of the collaboration between users and developers during the early stages of an innovative project.

In the thesis has been discussed that users possess important knowledge that is not merely valuable, but of decisive importance for the commercial success of a new and innovative product. It has been argued that users are in possession of knowledge regarding the problem which the new product is to solve, and that they should be involved in the development process, during the initial stages and on a continual basis, in order for their perspectives to become an integrated part of the project (Herstatt and von Hippel, 1992; Karlsson, 1996; Rogers, 2003; von Hippel, 2005b; Veryzer and Borja de Mozota, 2005). By inviting users into the development process as a resource in the team, opportunities are created to capture knowledge regarding requirements, which would otherwise be difficult to access for the designers. In addition the users themselves are given an opportunity to develop their role, from that of traditional evaluators to co-designers.

There are, however, many obstacles to overcome in order to succeed in this endeavour. The need for some kind of mediating tools to bridge the gap between the disciplines and their often disparate vocabulary and expertise has therefore been highlighted (Star and Griesemer, 1989; Herstatt and von Hippel, 1992; Karlsson, 1996; Carlile, 2002; Veryzer and Borja de Mozota, 2005).

Nevertheless, although researchers (Cook and Brown, 1999; Carlile, 2002; Engelbrektsson, 2004; Garmer et al., 2004) agree on the need for mediating tools to support innovation processes where users and developers form a multidisciplinary team (Karlsson, 1996; Kaulio, 1997; Brandt, 2004; Rhinow et al., 2012) understand how, in particular physical product representations, can facilitate the innovation process and collaborations in multidisciplinary teams.

The intention of the work presented here has been to highlight the need for concrete tools that might mediate the dialogue between users and designers in an innovative development co-design process.

In the thesis, various roles of product representations have been identified, described and put into a social context. The rationale behind is that *illustrating how product representations can act as mediating tools may lead to increased awareness and knowledge about how to support the dialogue and process in a multidisciplinary team, and in particular how to elicit the users' often tacit or "sticky" knowledge (von Hippel, 1994).* It is only when users are able to fully articulate their thoughts and explicit their knowledge that developers are able to process and comprehend them; conversely, developers must describe their ideas and theories in such a way that users are able to wholly comprehend, in order for the user to take the step towards becoming a co-designer on the team (von Hippel, 2005b; Karlsson et al., 2011)

6.1 PRODUCT REPRESENTATIONS AS MEDIATING TOOLS

Mediating tools can be described in many ways but common is their ability to mediate and facilitate dialogue between individuals. The purpose of the mediating is to bridge the gap that often exists when different disciplines interact. The gap may consist of different language and terminology cross borders, and/or a lack of knowledge about the various professions' knowledge and skills (Star and Griesemer, 1989; Karlsson, 1996; Carlile, 2002; Lee, 2005; von Hippel, 2005b). Concrete tools that are introduced as product representations are for instance prototypes and material samples etc. However they do not represent a static solution, instead they serve as a vehicle in the development process and introduce users to possibilities from a technical aspect. This is possible when the designers can develop new representations in an iterative process where new information and new knowledge emerge cross borders.

In this study, different product representations have been developed and used, intentionally or not, as mediating tools to facilitate the dialogue in the development process.

The findings imply that the product representations played different roles in the process but all facilitated the dialogue between the team members. The representations enabled to externalise implicit knowledge that both the users and the designers brought to the project. The physical representations helped externalise the designer's know-how and the users could touch, use and test them together with the designer. The using and testing helped in turn externalise the users' knowledge. The physical interaction with the product representations was noted to invite questions which required answers. The designer was forced to describe technical issues in a manner that the users could grasp – and vice versa. The resulting dialogue between the participants in the team can be described as a 'teaching and learning process' and should be considered as an essential part of the development process. This process integrated diverse knowledge, combined knowledge and generated new knowledge. This may be compared to the SECI model (Nonaka and Takeuchi, 1996) which describes how knowledge can turn from implicit to explicit and from explicit to implicit knowledge in a social integrated context.

The physical representations, the prototypes, furthermore allowed the users to test different versions in the intended use environment. This process helped the users to develop the specification of requirements for the new product (cf. the notion of emerging requirements proposed by Karlsson, 1996). As the users got evidence that the technology worked the trust between users and designers grew in addition to the users' knowledge of the technical possibilities of the 3D textile. Being able to verbalise requirements, developing a belief in the feasibility of the solution, and an insight into the possibilities offered are considered to have provided them with tools needed to become, over time, more active in the project and increasingly a co-designer. The designers, on the other hand, were provided with tools to concretise, demonstrate, and visually present, to the users, various scenarios in which the new product could be utilised. The prototypes visualised and demonstrated functionalities and properties, hereby stimulating the generation of new ideas, insights, and solutions existing within the process but which have yet to be discovered.

Hence, by working actively and purposefully to develop concrete product representations which facilitate a dialogue between users and designers, it is possible to create a platform where shared knowledge and common objective are obtained in the development process of innovative products.

6.2 LEARNING THROUGH PROTOTYPING

It is often argued that virtual reality media and virtual prototypes can replace physical prototypes used, for instance in order to enhance communication in multidisciplinary teams (Gupta et al., 1997, Kuutti et al., 1997). Virtual reality as well as CAD tools is no doubt important tools in the design process, but the question is if there is a slight overconfidence in that these tools will constitute the optimal communication tools in new product development.

According to Bailey et al. (2012) the benefits are sometimes overestimated since it is seldom possible to simulate correctly without access to real parts to compare solutions and confirm designs.

As the textile area and textiles increase in complexity, it is reasonable to assert that the textiles of tomorrow will integrate multiple functions in advanced textile systems. Therefore, research is aiming to develop opportunities to use CAD tools for textile development in the same way as other advanced industries (Chen, 2008). The designer may predict important properties and visualisations can to a certain level be done in various CAD systems

Nevertheless, despite the rapidly increasing digitisation of textile product development processes, it is essentially impossible to make accurate predictions regarding end results in textile development. There are multiple reasons for this. One is that each stage of the process, from fibre to finish, affects the behaviour and the end result of the material(s), in terms of softness, bending, tensile strength, etc.

However, these systems might limit the creativity of the designer and his/her ability to externalise expertise knowledge since (a) they are often very advanced systems, b) they often have limited access, c) possibilities are limited to what is looked in into the system.

Other reasons relate to the possibilities to involve users. Users may (still) be unfamiliar with this form of digital displays and may, deprived of the ability to physically handle the product representation, find it difficult to identify new properties or generate new solutions (von Hippel and Tyre, 1995; von Hippel, 2001; Söderman, 2005; Bailey et al., 2012). Contrary to what is often advocated, i.e. that the development can only be streamlined using various CAD tools (e.g. Gupta et al., 1997, Bailey et al., 2012) this thesis argues that *cut-and-paste methods or 'Textile Rapid Prototyping' (TRP) are of great value in the design of physical product representations during the initial stages of the development of innovative products, when one has no prior experience to rely on*.

Learning can be regarded as a journey (Engeström, 2003) which is in constant motion and development. In new product development processes, there are many situations of learning. Problem solving involves processes in use, and learning by doing may involve new and innovative thoughts of the processes as a result of solving a problem which is impossible to foresee (Gomaa and Scott, 1981, von Hippel, 1994). The reason for this is solutions which lie concealed are , impossible to predict and which are identified and "found" only as a result of practical experiments or when a new solution is tried (Gomaa and Scott, 1981; von Hippel and Tyre, 1995; Karlsson, 1996). The hidden information can be described as "sticky information" (von Hippel, 1994) which refers to information that is specific and difficult to articulate and to transfer. The stickiness of the information is linked to the complexity of the product and beside how information is transferred between team members.

During this project, the product representations were developed in an iterative prototype-driven process according to a 'Textile Rapid Prototyping method (TRP)'. The designers brought new product representations to each meeting with the users; the representations were based on the requirements and desirable properties identified during the sessions and discussions in and between meetings. This iterative development process provided opportunities to examine and test materials and design solutions for both the developer and the user. This was in contrast to a specification-driven development, in which written documents form the basis for the development of the product. One of the problems, which may occur during such specification-driven development processes, is that users find it difficult to describe their requirements for the product in 'specification terms' (e.g. Karlsson 1996). Another problem is that a specification of requirements formulated by the desigern may be difficult to understand, as it may include terminology which is unfamiliar to the user (von Hippel and Tyre, 1995; von Hippel, 2001; Engelbrektsson, 2004).

However, prototyping using TRP, which provides opportunities to experience new materials and techniques by produce product representations quickly and easily, requires access to craft skills. The craft skills provide opportunities to push the boundaries of the techniques and make it possible to investigate entirely new methods for the design of representations that may have previously been impossible to accomplish using existing industrial methods. Jones (1992) describes this as the purpose of design methods; to orderly or muddledly get into one´s mind and become familiar with the unknown possibilities and limitations of the new before taking irrevocable decisions

In the iterations described in the case, the product representations provided both users and desingers with experience and knowledge regarding solutions, functionalities and properties. By a stepwise development of new, relatively simple product representations, the representations inspired and developed trust in the technical solution. This was possible since the representations were physical and tangible and the users were able to test them in every step in the process, both in order to engage in explorations of the functionality of the technology and to improve their understanding of which parameters affected the results. This allowed the user to return to the designers with insights gained in the experiments; the users were provided with evidence and gained more in-depth knowledge of the technology used. The designers on the other hand, were able to experiment with and hereby discover materials, functions and processes as well as possibilities and barriers in the forthcoming product. In addition, manufacturing methods were identified and understandings of what can be achieved with contemporary technology, and what aspects require further development was achieved in the learning process. By using the cut-and-paste method, problems or prerequisites, which initially are not possible to identify, become visible early in the development process and hidden information is discovered both for the user and the designers.

In this project it was shown that 'Learning by doing' with prototyping can be used as a method to seek new solutions to a problem and may therefore be considered to be an efficient tool for eliciting requirements for product properties and functionalities, which initially may be unknown in early phases of innovations.

6.3 CHANGING PERSPECTIVES

In multidisciplinary constellations, where users are represented, several different perspectives have to be considered. The basic idea in Activity theory "asserts that the mind emerges, exists and can be understood only in the context of the subject-object relationship" (Kaptelinin and Nardi, 2006). Human activity is mediated by socially produced artifacts which has been developed by use of various kinds of tools and which the subjects bring into the context (Bertelsen and Bødker, 2003) (Figure 24). Interaction between people, their minds, culture, personal history, and motivations, along with social factors, the entire system within which activities are carried out, the role of the tools, and the complexity of the situation are factors that influences the outcome of a collaboration in an Activity theory perspective (Engeström, 1987; Bødker, 1989).

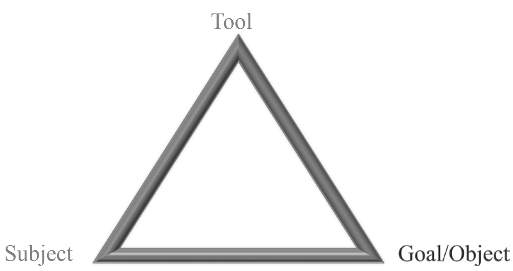

Figure 24. Triangulation of 'Subject', 'Tool' and 'Object' in Activity theory based on Engeström (1987) and Bødker (1989).

A development team may be studied as an activity system which consists of subjects, objects, and different tools, which the actors possess when entering the project. The project described in the thesis involved a group of researchers from different disciplines. Most often a team of researcher gather to identify and solve a problem, and no efforts are allocated to what the different individuals bring to the project in terms of objects or tools or what kind of discipline they represent. However, in this study the individuals were identified and described as users and developers. Once the actors (the subjects) have been identified as designers and users, as opposed to a group of researchers, and as a unified team set out to investigate technological innovations, the issues associated with such multi-disciplinarity may become easier to understand.

It can be argued that the user and the designer act in different activity systems. In the activity system of the users, the users use a product to reach a goal; in the particular case the users' goal is to treat patients. The users' tool is the device that examines brainwaves but they also bring specialist knowledge in neurophysiology and signal engineering, and their know-how includes expertise regarding the environment in which the future product is expected to function and in which problems may arise. In the activity system of the designers, on the other hand, the goal is the product solution. They bring specialist knowledge in textile manufacturing methods and textile materials, and detailed knowledge of the various processes.

In order for the designers to be able to design a product which meets the users' need and requirements, they depend upon understanding the users' tool-goal perspective, but also the knowledge that the users bring to the project. In a similar way it is important that the users understand the product from the designers' development perspective and what the designers bring into the project. Such a shift is necessary if the users are to become active participants and develop into 'co-designers'. When a change of perspective has taken place new knowledge can be developed and shared within the team and the future product can become the goal for the activity. In this process of changing perspectives (Figure 25) product representations play an essential role.

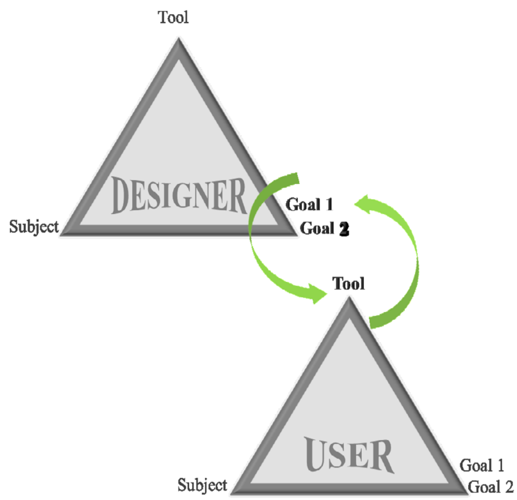

Figure 25. The shift in perspectives.

The different product representations are argued to support a necessary 'breakdown' of the designers' initial goal-product and the users' initial tool-goal perspectives through their different roles. The representations challenged for instance the users' and the designers' mental images of the solution of the future product as well as how the product might be used.

6.4 FROM PASSIVE EVALUATOR TO CO-INNOVATOR

An important part of shifting perspectives is developing a common goal (or goals) for the process. In literature, there is often mentioned that multidisciplinary development teams which incorporate users have to develop a common vision of the objective, and that this is a prerequisites for users to eventually become co-designers during the development process (Urban and Von Hippel, 1988; Bødker and Grønbæk, 1991; Leonard-Barton et al., 1994; Bharadwaj and Menon, 2000; Paulus, 2000; von Hippel, 2005; Johansson, 2006). Although no illustration or description has been found (to the author's knowledge) which describes the order of the steps to be taken, it is often implied that the establishment of a common objective precedes the process in which users become co-designers.

In the project presented in this thesis it became evident that users gradually began to assume the role of co-designers as they gained more trust in and knowledge of the possibilities offered by the technology provided by the designers and gradually began to take a more active role in the design process.

Clearly, users and designers shared a common idea of why they first met and what the overall objective of the project was. In spite of this, a clear, commonly held vision of the future product and its design in more detail did not exist at this stage. The users became increasingly involved in discussions concerning the design solution; but not until the shift took place, from that of users as passive evaluators to active co-designers, did the team develop a clear and more detailed common objective (Figure 26).

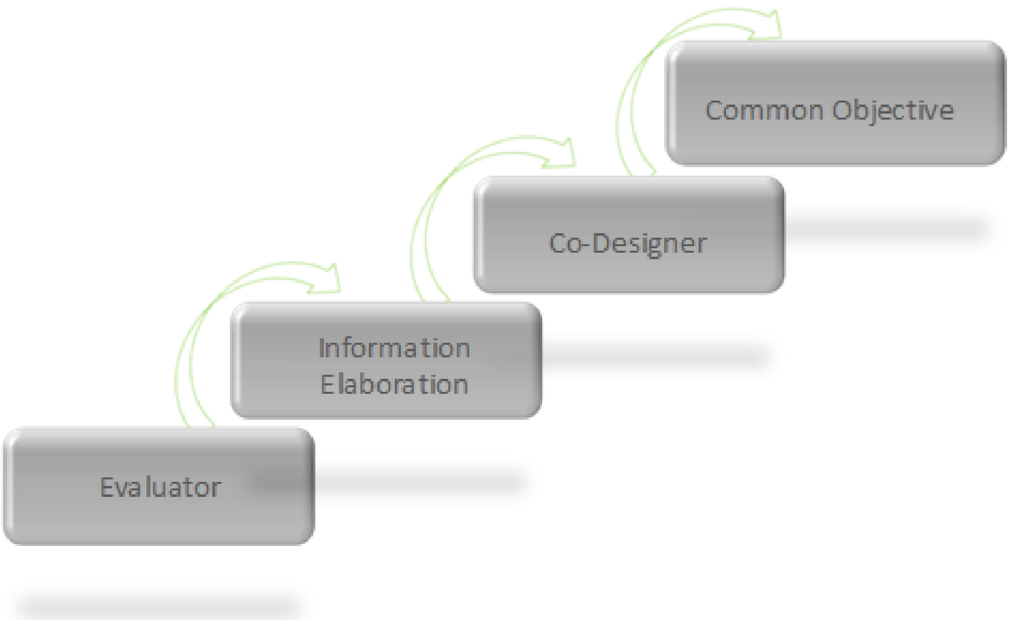

Figure 26. The steps of the development process of the user, from evaluator to co-designer.

Analysing the empirical material further, certain realisations were made. In a multidisciplinary collaborative effort where users are represented, it is not the intention that the members of a team shall become experts in one another's fields. A condition for the development of innovative products is, however, that users, who possess knowledge regarding how the product should ideally function, must gain as much knowledge as possible regarding design solutions and technical functionalities so as to encourage them to take part in the process of 'thinking up the next step' in the development of the product. What became clear, in the review of the material, was that any movement towards shared knowledge was preceded by an intense period of 'information elaboration' (Figure 27); where information was exchanged and discussed (cf. Hoever, 2012) between the users and the designers before the users adopted a more active role in the development process.

The new information which is transferred from one team member to another has to be understood and transformed into one's own area of knowledge before the it can emerge to shared knowledge (Figure 27). The users processed information though testing the prototypes in their own environment as well as observing demonstrations or visualisations of the design face to face with the designers. This asserts to Nonaka and Takeuchi (1995) that new knowledge is achieved when individuals are able to externalise knowledge in a social context for instance by meeting face to face with individuals or by practice. The tests of the prototypes in the users own environment worked as a toolkit to discover, externalise and integrate new knowledge with the users' "old" knowledge in the process (cf. von Hippel, 2001).

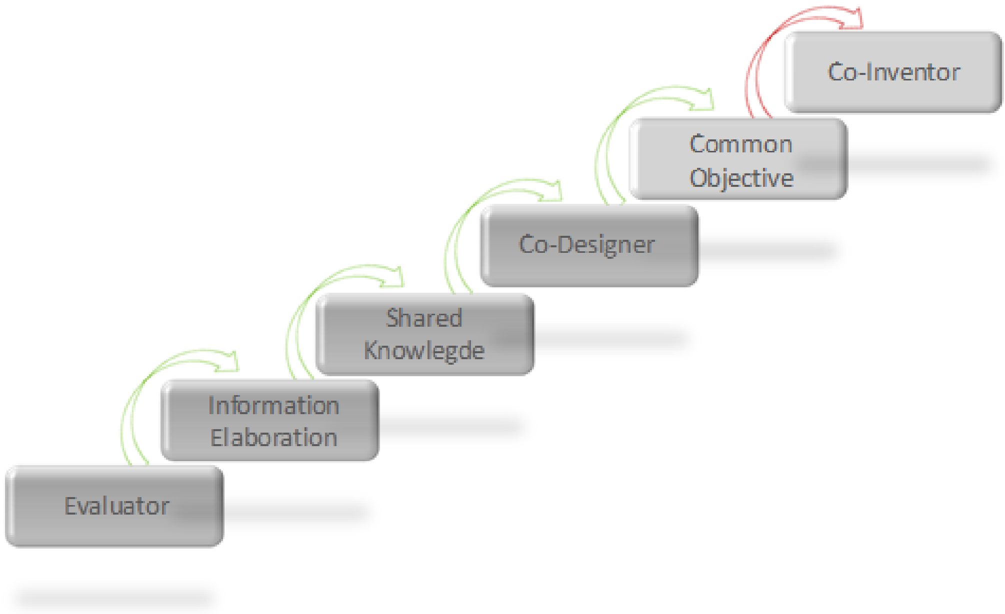

Figure 27. The steps in the process from evaluator to co-inventor

In retrospect it was as the users gained more detailed knowledge of the technology, that a common objective was established, which in turn stimulated the users to contribute with new innovative product ideas. With the support of the discussion in this thesis, the model in figure 27 has been expanded to include new and additional steps. For users, more stages of individual self-development are required in order for them to fully take part in the process and contribute with ideas which may lead to innovative products. When this occurs, it may be said that they move beyond being co-designers, and take the step to becoming co-inventors for new innovative products.

7. CONCLUSION AND IMPLICATIONS

Today new technology gives us unprecedented opportunities to design textiles in a way that were not possible before. New textiles with complex structures will be developed in new ways. However, the new opportunities also entail new challenges. New complex groupings, consisting of various disciplines, will be required in order to develop those new textile innovative products. There is a need to create creative arenas where different individuals with different expertise can meet and learn from one and another and integrate their knowledge in the quest for developing new innovative products.

The importance of getting users involved early in the development of new innovative products is argued since the users are the ones who have the best knowledge and experience of the product in use, and they can discover needs in the forthcoming product that have to be resolved as the process evolves. Such multi- or even interdisciplinary groupings increase the complexity further.

There are several barriers to involving user in the development process, such as that users may be unaccustomed to be a needed resource associated with development for new technological products, they may have difficulties to assimilate concepts that the designer uses or they are unfamiliar with the design solutions that designers advocates. For these and other reasons misinterpretations or misunderstandings will occur when different areas of knowledge meet and work together. Research has pointed out that mediating tool can facilitate the dialogue between the different expertise and which help the process to move forward are needed.

The aims in the study have been to increase the understanding what roles product representations might have as mediating tools in the process and how product presentations can facilitate the user becoming a resource in product development, early in the innovation process. Questions posed were:

a) how can product representations facilitate multidisciplinary co-design processes;

b) what roles do the product representations play in facilitating cross-disciplinary collaboration;
and

c) what changes occur in the process as new product presentations evolve and are presented to users?

However, despite that textile artifacts played a central role throughout the study, the ambition has been that also other areas of expertise can find ways to facilitate the collaboration process where different disciplines come together in order to develop tomorrow's innovations.

Based on the empirical study, a main conclusion is that the product representations in different ways supported the team's exchange of knowledge and experience so that the team could generate shared knowledge. Five different roles that product representations can play were identified, occasionally separately but sometimes one and the same representation adopts multiple roles:

- demonstration;
- verbalisation;
- visualisation;
- stimulation;
- integration.

The roles occurred at different times during the development process and there was no clear time line associated with the different roles. However, the explanatory and more concrete roles (i.e. demonstration, verbalisation) were more frequent in the beginning of the project when the team needed to gain more knowledge about requirements and technical constraints as well as opportunities. The more proactive roles (i.e. - visualization, stimulation, integration) were more prominent when the project had proceeded for some time.

More specifically, the physical representations, the prototypes:

- helped to support questions being posed and answers being provided between users and developers;
- helped verbalise information where words were missing;
- demonstrated problems and solutions as the actors could use them to point at and show concretely or even put together new versions of the representations in real-time;
- made it possible for the users to try them out in the intended use environment which created evidence of and confidence in the technology
- enabled the team to visualize and demonstrate problems and potential solutions;
- supported users in expressing their needs, requirements, and experiences;
- helped 'unstick' sticky knowledge;
- helped to externalise tacit knowledge;
- helped to integrate different knowledge;
- stimulated new thoughts and new ideas;
- facilitated the integration of different skills.

The product representations supported a process by which the users moved from being passive evaluators to became co-designers in the process, even co-inventors.

8. CONCLUDING REMARKS

Finally, the hope is that this work may influence the discussion in a broader perspective and contribute with keys to new textile development and innovation processes that are a head.

The textiles industry traces its roots back to handicraft processes and, despite the fact that textile manufacturing was an area in which great breakthroughs were made during the early days of industrialisation, the textile industrial development after industrialization foray has mainly been aimed at machines to produce textiles at an accelerating rate in order to be economically efficient in a hard competition. Today innovative technologies provide us with new materials and possibilities to integrate functionalities in textiles in ways which have not been possible before, and which may, to some degree, replace contemporary production methods.

By smart textiles leading the change, creating textiles which interact with their environment in different ways, the textile sector is almost facing a paradigm shift which requires new processes, new ways of working and new roles to be developed. This creates challenges for the future of textiles industry which today may be unaccustomed to "taking the lead" for the development process of new innovative products as well as unfamiliar with developing products in interdisciplinary contexts. The textile industry needs to shift perspective from being a supplier, where other stakeholders initiate the innovation, to be an actor that initiates interdisciplinary teams to develop tomorrow's multifunctional textile products.

By introducing a holistic perspective at universities where tomorrow's textile designer and textile engineers are educated, the possibilities to gain this new insight increases. A tool to achieve this awareness, on how to develop innovative textile products with the users' perspective in focus, may be that students get training in how to reflect on how to use textile materials and textile prototypes in a manner that facilitates communication cross border. Another way to stimulate the awareness of the value of physical product representations as knowledge-generating tool is to organize a venue where various disciplines may join together and feel, try and examine the physical product representations jointly. Product representations can demonstrate and visualize the function and features in the forthcoming product and introduce someone with another type of knowledge to what is possible to achieve. The design case presented in this thesis shows that this can lead to stimulating new innovative ideas in the encounter across disciplines. By increasing the awareness of how product representations may facilitate the dialogue in the these new constellations, the textile industry may with support from trained former students take the step from a traditional textiles development process to become a co-designer or even co-inventor in the development of new innovative products.

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