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Renewing technology-driven materials research through an experimental co-design approach

Kirsi Niinimäki[a*]

[a]Aalto University, School of Art, Design and Architecture, Design Research, Finland
*Corresponding author email: kirsi.niinimaki@aalto.fi

Abstract: The design thinking approach and co-design methods have gained popularity in recent years. Also, design thinking is increasingly often applied to solve complex problems in different domains. This case study focuses on the issue of how to renew technology-driven materials research through an experimental co-design approach. The project under study is a material development project that ran for three and a half years. This project focused on emerging material technologies and therefore used a design-driven approach to further boost the material innovation aspect and to challenge the technological side of the project. Deductive analysis has been used to build an understanding of the constructivist learning that occurred in this case. The findings show that the experimental process influenced the materials research and that learnings occurred through knowledge, skills, attitudes and values. A new layer has been added through 'soft' knowledge into technology-driven materials research. Pivotal learnings occurred between disciplines and even serendipitous elements have been identified.

Keywords: Co-design, Design-driven, Interdisciplinary, Innovation, Constructivist learning

1. Introduction

This paper presents a case study of a project where design-driven experimental methods guided a multidisciplinary material innovation process. In the studied case, designers and design researchers worked together with material scientists, market experts and the manufacturing industry. The aim of the project was to develop new innovations from waste using novel technologies. The technologies used in this project are in the stage of early development and therefore can be defined as emerging material technologies. Traditionally, materials research has been done mainly in a lab setting and lab environment and through a technology-driven approach. In the current case, the goal is to find new ways to construct innovations by means of an experimental and creative approach and through an iterative co-design process. The learnings in this case have been quite influential for all participants but the focus in this paper is on design influences in the context of technology-driven materials research.

According to Carloppio (2010), design skills – here meaning creative explorations and experimentations – are especially important when trying to achieve novel strategy innovation by opening multiple and creative options for the future. Storvang, Jensen and Christense (2014) explain that design can be an important driver for innovation, as design can integrate bold visions, market information and technological aspects in striving for new, innovative products. That said, how can a design-driven approach be used when aiming for new material innovation in the stage where the technologies are still in the early phase of development? Can a collaborative approach and co-design methods enhance this innovative process?

Sanders (2015, p. 296) points out that collaboration is a key to the innovation process; through collaborative creativity we can make sense of complex issues. Accordingly, creativity is not owned by the designers in multidisciplinary collaboration. 'Collective creativity refers to acts of creativity that are experienced jointly by two or more (and sometimes even crowds of) people' (ibid., p. 296). Creative and shared activities can even build bridges between disciplinary practices and disciplinary knowledge, and therefore an experimental co-design process provides opportunities to construct multidisciplinary or multi-professional understanding, thereby leading to innovation.

At best, design thinking can be understood as a process where a designer's material practices can contribute to the innovation process by relating these design competences to meaning making (Antle and Fraser, 2017). The cognitive processes of meaning making can be seen to involve combining tacit and intuitive knowledge with more academic knowledge. In this way, knowledge creation and understanding can be linked to experiences and even to tacit ways of knowing. Designers are able to enhance a collaborative innovation process by capturing different knowledge flows and different perspectives, and based on this process they can create and visualize a concept or construct a prototype. This concept or prototype can be shown to others, which further enhances collaborative knowledge creation and the whole innovation process can be iterative (more so than linear).

Puonti (2004) points out that '[i]nformation is a central factor in collaboration: information held and acquired by various participants must be shared.' Information sharing is crucial for multidisciplinary collaboration, but this is not enough for deep collaboration. If we want to achieve deep learning, new knowledge has to be constructed based on shared activities, in which the co-design process can be helpful. As Puonti (ibid.) highlights, 'mutual interactions' are needed for deep learnings and to construct new knowledge. In the studied case, the whole process was designed to push collaboration and force shared learning by using workshops organized four times a year. In these workshops, representatives from each organization (normally around 35 people) worked together for two days using creative and experimental methods to solve problems together.

In this kind of process, the co-design approach and iterative process can help to build the right mindset and to construct a co-design innovation space between disciplines (Niinimäki 2018). Now, after three and a half years of collaboration, it is time to evaluate how the design-driven process has succeeded and especially how it has influenced the ways in which the material scientists think or do science. To lay the theoretical grounding for this study, the next section introduces constructivist learning, which has formed the theoretical framework for deductive data analysis.

2. Constructivist learning

In multi- or interdisciplinary projects deep and even pivotal learnings or interdisciplinary understanding can occur. In a project based on a design-driven approach and which uses experimental and generative tools from design thinking, learnings occur through a constructive approach. Constructivist learning in a multi- or interdisciplinary project means learning that can happen only in relationship with others. 'There is no me without you,' says Dewey (1931, 91) and this approach links to constructivist learning, meaning that there cannot be learning without social interaction, without learning from others and learning with others. 'Therefore, learning in the constructivist perspective is a process of constantly adapting to situation, which consist of ever-changing relations between subject, object and context' (Scheer et al., 2012, 8).

For constructivist and pivotal learning, it is not enough to just share information. Sharing information is an important aspect of interdisciplinary collaboration, yet for deep learnings 'information exchange is not sufficient to manage the transforming object: new knowledge has to be acquired on the basis of the information and mutual interaction. This implies learning. Learning is not restricted to mastering the substance of the case. The participants also have to learn to collaborate.' (Puonti, 2004)

Information sharing can help while learning the content, but for deep learning, it is crucially necessary to 'internalise knowledge, metacognitive competences, attitudes, values and action skills' while learning to collaborate (Sheer et al., 2016, 8, based on Weinert, 2003) in an interdisciplinary setting. These skills can be developed and on the other hand these skills are needed in, for instance, an interdisciplinary project like the case under study.

Holistic learning can occur in an interdisciplinary setting through reflection and experiences (Sheer et al., 2016). Therefore, constructivist learning builds knowledge through action, interaction, experience and reflection. Constructivist learning happens in a certain context, in most cases in a real-life context and in a collaborative manner (de Corte, 2010). In this kind of learning situation, crises and chaos are common, which may pave the way to real and deep learning (Sheer et al., 2012). Here, a design-thinking approach can also be adopted while using a team-based approach and team-based learning methods. A design-thinking approach helps to deal with complex real-life problems. Design thinking here refers to the use of creative thinking to solve complex problems and to find diverse options for solutions (Kröper, 2010). The design thinking process is not only a cognitive problem-solving activity, but it can also be seen as an experimental toolkit for the innovation process. The design thinking process can lead to transformation, evolution and innovation and has for this reason gained popularity in recent years. (Tschimmel, 2012.) It can be said that the design thinking process is at its core a constructivist learning process. Constructivist learning does not merely involve the transfer of knowledge alone – it also deeply influences and develops the potential of individuals (Sheer 2012).

Earlier studies have identified the key competences of constructivist learning as knowledge, skills, attitude and values (Weinert 2003), which also form the basic qualities for learning in the constructivist process. This division and understanding lay the grounding for this study. In the current study constructivist learning has been used as a theoretical framing while doing the deductive analyses (more information is provided in a Results section).

3. Research Design

This study aims to empirically investigate interdisciplinary collaboration in a research and development project called Trash2Cash (read more https://www.trash2cashproject.eu/). In the current study the focus has been especially on understanding how an experimental co-design approach affected the materials research side, i.e. the knowledge, skills and practices of the participants in their own domain.

The project involved 18 stakeholders from ten different EU countries and ran for three-and-a-half years. The overall objective of the project was to develop new high-quality materials from waste materials via a design-driven approach and using co-design methods in the context of a Circular Economy. The project consisted of nine work packages. Four times a year all stakeholders (around 35 people) got together to work in a collaborative setting to solve problems or develop ideas together. These sessions formed the most important asset for constructivist knowledge co-creation in this project. These workshops were quite experimental and therefore different methods were used. Information gathering and sharing, social interactions, reflective tools and generative tools were used to push the project further. To read more detailed description of the design-driven process and steps in it, see Tubito et al. 2019.

The current research focuses on the question of how would it be possible to design a space for serendipity in a controlled research discipline, namely technology-driven materials research? Further, how can an interdisciplinary co-design innovation space challenge materials research? How can technology-driven materials research be challenged through an experimental and iterative design-driven approach while aiming for material innovations? While focusing on the aforementioned topics, this research will highlight, based on findings from empirical data, the outcomes of interdisciplinary collaboration for materials research and what kinds of advances this kind of experimental approach can bring into materials research. In short, how can a design-driven approach challenge technology-driven research?

A case study methodology was adopted in this study. Case study research is particularly suitable for studying emerging phenomena whose dimensions are not yet well known (Yin, 2003). The methods of ethnography, participant observation, and interviews have been used to collect data over a period of three and half years. Especially for this study, the feedback and reflection from material researchers at the end of the project were important, as they were collected to build an understanding of how this project has influenced their work and further their understanding of the design-driven approach and creative methods. A particular focus is placed on the constructivist learning dimension as an outcome of this collaboration.

Constructivist learning builds the theoretical framework for analysis of the data. The data has been analysed through deductive analyses, and the four levels of constructivist learning – namely knowledge, skills, attitude and values based on Weinert (1999) – have formed the categories for analysis. The aim of this analysis is to answer the research questions and to construct understanding of what kind of influence the design-driven approach has had on the materials research. Over the course of this long and explorative project, many obstacles and boundaries were identified (see Niinimäki et al. 2017, Niinimäki 2018); this longitudinal study also featured lucky accidents and deep and even pivotal learnings from interdisciplinary collaboration. Following text describes the findings of this study. Straight quotations from interviews of material researchers give a colour for the findings.

4. Results

4.1 New knowledge

Adding a soft knowledge layer to materials research

Through an experimental approach and especially through ‘playing’ with material samples (touching, feeling, describing the haptic experience in co-design sessions) and through co-imagining material attributes, a new layer of material understanding has been added to technology-driven materials research. Traditionally, material researchers focus on quantitative methods and numerical data while further developing material attributes. Designers on the other hand are used to trusting their tacit and haptic knowledge of materials and especially of how to apply different materials and their attributes in different use contexts or for different product types. Especially the fabric hand and the haptic experience provide plenty of information to experienced designer. This approach has provided a new angle for material scientists to understand the material they are developing through the sensorial experiences materials can give. Workshops organized in a collaborative setting have helped in transferring this knowledge from designers to material scientists.

> I do believe that knowledge has been transferred (in this project). I mean a lot of tacit knowledge that could not have been transferred in any other way.

User-centred knowledge

> We are material scientists. What we do, we just repeat the spinning of the lab material, but designers, maybe, have a lot knowledge on the commercial fabrics, commercial yarns. This is really important to learn from them.

From a designer’s point of view, incorporating user-centred knowledge into a material development process is exactly the aim of the design-driven material innovation process. Designers want to push the boundaries and achieve high-quality materials and properties that can add value to this new material, also from the user-centred viewpoint. This highlights an important new aspect for material scientists to take into account: meaning making in the context of the users’ world. This is the core of design thinking, the meaning making (making sense) in a certain context. Therefore, it can be said that designers bring in market- and user-centred viewpoints. This approach also challenges material scientists’ way of working. While it is not enough to aim for what is technologically possible (for example in terms of fibre quality and fibre attributes), taking end-users’ wishes into account can raise the ambition level in materials research. To achieve a competitive edge in innovation, market- and user-centred realities need to be considered in materials research.

> That we say our fibre numbers are that and that strong, and that’s it. But what does that really mean….., if you’re aiming for a product or another innovation.

4.2. New skills

New time perspective through a futures view

Design thinking can use inductive, deductive and even abductive thinking, meaning creative problem-solving, suggesting that something is more than its initial impression. This is the grounding for creativity in design and therefore design thinking can ‘look into the future’ and show ‘what could be’ (Cross, 2007, Niinimäki et al., 2015). In the current case, one process that made a big impression on material researchers was the megatrend session that was held quite early on in the project. This session, which involved longer time perspective, ‘looking into the future’ through big development paths, was quite eye opening for them. While they were evaluating the whole process and especially the design-driven approach to it, material scientists stated that:

> [It enabled us] to look a bit further than what we usually used to do. We should develop [material properties] for the future.

In this way, a design-driven process can introduce a futures aspect into the project. Even if the project runs for quite a long time (in our case 3.5 years), an even longer view of the future might help to understand how to define the goals and where exactly to aim for with these new materials. Where are the future markets and what will future consumers want? What are the social or environmental developments which have influence in industrial development? This creates a different and quite pivotal timeframe for the material researchers' work, which normally takes a shorter view and concentrates more on what is possible to do with this technology. Megatrend, scenarios, longitudinal view and futures views are aspects that can transform material development and, further, these can turn the view away from technological possibilities or limitations to a market-driven viewpoint. This process can also facilitate the process to better define the framework for material development (where to go, what elements to develop further) and more importantly also exclude some development paths (what not to research further). In this way, the futures view can provide the possibility to include a strategic aspect into innovation development.

Storytelling

Based on empirical data, I argue that one important aspect of this kind of long-term interdisciplinary project is the power of imaginative skills. In the current case, storytelling served as an element that engaged stakeholders to collaborate and keep the goal alive. Storytelling uses verbal forms and future scenarios to visualize the idea that is collaboratively constructed. Storytelling may be difficult for some partners who are not used to using their verbal skills to link to their own tacit knowledge (Sanders, 2015). Here designers can help. By sharing dreams of future materials and scenarios of future application areas, designers can also transmit their ideas to others (e.g. more technical or business-oriented) disciplines. Storytelling can also keep 'the dream', the goal of the project, alive throughout the long project. This is one way to keep people engaged in the process throughout each step. Moreover, storytelling is a way to bridge the gap between the fuzzy-front-end stage and the more straightforward product development phase.

In the feedback interview, a material scientist mentioned that his most important takeaway from the project is the understanding that you have to create and tell the story behind the new innovation. You have to first introduce the material with the story. This is a powerful way of creating a first-hand expression and a memory for other people. He mentioned that this way of introducing materials is something he will also use later on in other projects and in other events and with new partners.

Creative methods

Design-driven methods support creative thinking and co-thinking throughout the process and they involve creativity from all partners, whether they are designers or not. Accordingly, designers' reflective skills (Schön, 1983) are used even with people with no design skills.

> At some point, these lines got dissolved and got blurred. That you can't really distinguish anymore between the typical research and the creative design. Or we could approach each other, let's say so.

Designers often start the creative task with vision work, a starting point for the storytelling, which can grab the attention of stakeholders and participants, and thereafter the vision sets the stage for the process to be followed (Tabeau, 2016). In T2C the vision was not so clear and the development process was more iterative and evolving than in a typical design-driven process. The T2C narrative grew slowly and vision work just set the starting point for the creative 'co-dreaming' process. Co-dreaming here means setting the goal in a creative and iterative way and using generative methods to develop the whole process further. That said, the process made extensive use of co-creativity. These sessions involved collective use of creative methods that had an influence on the material researchers' way of thinking.

> I admire a lot the deep expertise of designers. I have learnt a lot. Especially the way designers think and create new ideas. Through observing designers' way of thinking I have learnt a totally new mindset, a new strategy and this has had a deep influence on my own thinking.

Design can be used not only for creating new ideas but also for communication. Using visuals to explain or describe scientific information is a powerful way to capture attention. Imaginary storytelling is part of this method. Material researchers can adopt this creative approach or use designers to tell the story they want to tell about their materials research.

4.3. Attitudes

Opening up for collaboration

One important learning from the project concerned the change in attitude: materials research has become more open towards multi- or even interdisciplinary collaboration, towards creativity and even towards experimental ways of working. This can be identified as a pivotal learning outcome.

> I don't know, it's very difficult to define, but maybe to get a little bit out of our bubble, of the science bubble.

The above quote from a material scientist describes the viewpoint of material scientists on the design-driven and experimental process in the studied case. This experimental process pushed people outside their comfort zone (Niinimäki et al. 2017) and opened a new way of thinking and doing materials research in a collaborative setting.

> Unbelievable that this process has succeeded to make everyone with different background to collaborate and do things together.

Different kinds of knowledge were used in different stages of the project and they were integrated to construct prototypes and design cases at the end of the project. In this way, the prototypes can be seen to express not only interdisciplinary knowledge but also interdisciplinary learnings. It would not have been possible to make these prototypes without the participation of all stakeholders. Everyone (scientific partners, industry partners, designers) made their contribution. This collaborative process had an influence on materials research, which can be seen in the previous quote. This learning had an influence and the material researchers are now more open to collaboration than they were before this project.

4.4. Values

Appreciating other types of knowing

The studied case showed that several ways of knowing and several ways of constructing knowledge are important while aiming for a new type of materials innovation. Even conflicts and frustrations might be important points and they can create pivotal learning points for understanding other disciplines. Therefore, I argue that the construction of a knowledge network (tacit, haptic, industry, business, intellectual, cognitive, academic) is the key for this type of innovation work. Furthermore, the knowledge network has provided new learnings for materials research.

> I guess we really learnt a lot from other areas. Because before that, I was so much focused just on what I was doing, and I didn't really… I just felt that my stuff was important, but not other people's stuff, like really. And it really showed that there are so many people involved, and everyone's got their role.

The important learnings – the new value base – constructed through this experiment comprise appreciation of other disciplines and also other professionals, and also more practice-based knowing brought in by industry partners. Everyone was needed for this collaboration. Quantitative knowledge was needed for fibre development, but so too was qualitative knowledge for a haptic understanding of materials and especially material experiences. User-centred knowledge (empathic knowledge) was combined with industrial knowledge (technical and business information). Everyone found their place and their role in the project and everyone influenced the others.

4.5. Transformation

Based on this study and the findings from the empirical data, it can be pointed out that the most important and pivotal learning for material scientists was that they now have a more open attitude towards creativity and other types of 'soft' knowledge. Technology-driven materials research has really been touched and influenced by the collaborative creativity. The sensorial world of materials and the haptic properties of materials and their meaning to end users have been added to technology-driven materials research.

Seeing into the future through scenarios, which adds a longer time view for research, was another pivotal learning. This has opened a totally new development aspect for materials research through the viewpoint of how to position material development and its challenges in a futures timeframe. How should the technology be developed according to future needs? Understanding industrial developments through the aspect of megatrends and even through societal developments provides a totally new perspective on materials research. Forecasting material, industrial and consumption developments challenges two or ten years ahead provides a totally different and more strategic perspective for the development and innovation work.

Also, moving the materials research out of a lab environment had an effect. The participants found it easier to jump into co-creativity and into 'soft' information gathering and co-constructing outside the lab environment. Creativity is supported by a creative and inspiring environment. Through co-construction qualitative methods and empathic design have been added to quantitative methods in material science.

As highlighted earlier in this text, constructivist learning means not merely transferring knowledge, but also deeply influencing and developing the potential of individuals (Sheer 2012), and this really occurred in this project. Material scientists not only want to continue collaborating with designers, but also have incorporated some of the learnings into their own practices, like storytelling. Furthermore, the process challenged not only the individuals but perhaps even the disciplinary knowledge.

Our study shows that it is possible to construct an experimental co-design innovation space in a project (especially in the so-called fuzzy-front-end stage). This innovation space not only defines the outcome of the project, in our case the prototypes and their innovation potentials, but also enables constructivist learning. This co-design innovation space enables co-learning, co-playing and co-dreaming, which happen through experimental methods and through a design thinking approach and in deep interaction with other disciplines and for the be-all and end-all with others.

5. Discussion

A design-driven approach through an experimental co-design approach can strongly influence other disciplines. Our study shows that design can add a new sensorial layer into technology-driven materials research. Furthermore, a design-driven approach can speed up the development work and can establish a longer view for the development work. Our findings show that an experimental and collaborative approach, meaning a design-driven material innovation process, added a totally new layer into technology-driven materials research. While traditional materials research focuses on technological solutions, such as how to use waste material as a source of a new fibre and to create technical inventions for this process, the design approach adds sensorial, user-centered and functional attributes to the development of new materials. Further mapping possible application areas and adding meaning making into these application sectors have been crucial for finding innovation possibilities and new fibre attributes with commercial advantages for recycled materials. These findings show that experimental co-designing adds totally new layers into materials research (strategic, haptic, emotional and sensorial knowledge, imaginative storytelling, user-centred aims, system understanding and commercial understanding) and therefore I argue that a design-driven process can renew or even transform technology-driven materials research.

The role of serendipity in the research and development process has been crucial. Everyone in the project has learnt from the three-and-a-half-year process. The open, uncertain, iterative and reflective co-design process in the studied case successfully resulted in a deep co-learning process where material researchers learned from design thinking and design processes, while designers and other stakeholders learnt from technology-driven materials research (especially the technological challenges involved in fibre development). Even more important in this case has been the collaborative learning that occurred through the constructivist learning process. New knowledge has been created on how an integrative discipline can be constructed as an exploratory platform where co-creation can take place. Therefore, even if the main goal of the project was to develop a new material innovation, the main outcome of the project can be deemed to be constructivist learning, which happened in a collaborative setting and through experimental co-creativity. Constructivist learning has increased knowledge and skills and moreover made the material researchers more open towards collaboration and laid a new value base for appreciating other knowledge areas. Constructivist learning even enabled pivotal learnings, fundamental learnings from other disciplines. Serendipity in this studied case emerged from a combination of the right people and the right mindset, a somewhat crazy and very experimental research approach to material development.

Creating innovations is not an easy road. That road is full of obstacles but also possibilities. As a material researcher pointed out in a following quote:

> If it is an easy road and easy to implement through technology, there is no big win to achieve. Here exists that kind of driver that can change the development and something valuable can come out.

With this quote, the material scientist highlighted the value of employing a design approach in an interdisciplinary project. Everyone can learn from each other. Even if the process might cause frustration, it can also provide lucky accidents, moments where not only can deep learning occur, but also innovation opportunities can be identified and co-created.

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About the Authors:

Kirsi Niinimäki is an Associate Professor in Design, especially in Fashion research at Aalto University. Her own research focuses on holistic understanding of sustainable fashion and textile fields and furthermore design management especially in multidisciplinary projects. Niinimäki runs the Fashion/Textile Futures research group in Aalto University, http://ftfutures.aalto.fi.

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