When Art meets Science: Conditions for Experiential Knowledge Exchange in Interdisciplinary Research on New Materials

Camilla Groth, University of Gothenburg, Sweden & University of South-Eastern Norway, Norway.

Margherita Pevere, Aalto University, School of Arts, Design and Architecture, Department of Art, Finland.

Pirjo Kääriäinen, Aalto University, School of Arts, Design and Architecture and School of Chemical Engineering, Finland.

Kirsi Niinimäki, Aalto University, School of Arts, Design and Architecture, Department of design, Finland.

Abstract

Interdisciplinary research across art and science offers the potential to open up new areas of knowledge previously hidden in-between disciplines. At the same time, differences in disciplines' theoretical frameworks, verification methods and expectations can cause discrepancies, which can be fruitful but may also require further navigation efforts. In this paper, we discuss the potentials and challenges of combining scientific and artistic research in interdisciplinary projects studying new materials. We interviewed 11 researchers working in different projects that combined scientific and artistic research in Finland and Germany, in order to investigate how they deal with different epistemological approaches and the limitations and possibilities that they brought up the interviews. In this paper, we focus on experiential knowledge sharing between the researchers in their research of organic materials. Our findings show that the prerequisites for experiential knowledge transfer need to be built consciously, over a long period of time by engaging in hands-on practices and cognitive activities that surpass the personal comfort zone of all members, and the common goals and research questions need to be motivating for all involved. Although academic research funding agents encourage interdisciplinary research, funding alone is not sufficient to motivate people to work and truly learn together. Even when motivation and common goals are found, the short longevity of funding might drive researchers to multitask, which in turn may damage the ideal conditions for transformational learning and knowing together. Thus, in addition to recruiting enabling professionals who have t-shaped experience of two or more disciplines, we suggest that conscious education in a new discipline could create a new generation of thinkers and makers who feel comfortable in the possibly unsettling zone between the disciplinary borders of arts and sciences.

Keywords

Art; Science; Research; Interdisciplinary collaboration; Knowledge transfer

As the architect John Zeisel says: people collaborate when they want to do more than they can do alone (1981/2006, 47). However, over the last decade, the research landscape has changed rapidly as a result of globalisation and emerging complex phenomena such as digitalisation, environmental crises and social awakenings. General research policies guide researchers towards

actively solving material, societal and global challenges through problem-oriented, solution-focused and collaborative research strategies (Lamy, 2017; OECD). In such research efforts, collaboration over disciplinary borders is inevitable, as the issues are multifaceted, complex and involve several networks and relationships between multiple actors as well as deep domain-specific knowledge.

Moreover, creative fields are being encouraged to transgress from the disciplinary border; for example, the Arts and Humanities Research Council (AHRC) advocates collaborative projects between science, arts and humanities, claiming significant potential in such collaboration while also pointing out the limitations of using scientific approaches in isolation to tackle societal challenges, for example. Similarly, many European funding agents have formulated special research programmes around the subject, such as Horizon 2020, the OECD, the Academy of Finland, Volkswagen Stiftung, Robert Bosch Stiftung, and the Kone Foundation.

It is thus recognised that interdisciplinary research is acutely needed to solve complex societal and environmental problems that cannot be solved within a single discipline. Discussions on the possible challenges and benefits of fundamentally different epistemologies meeting are now topical. Well-established best practices that would work regardless of context are yet to be modelled. However, these practices need to be based on recognised enablers and previously experienced pitfalls and communicated in such a way that it forms general understandings.

Words such as *interdisciplinary*, *multidisciplinary*, *cross-disciplinary* or even *non-disciplinary* have been discussed from different viewpoints in the creative field and the humanities (Zeisel, 1981/2006; Peralta and Moultrie, 2010). Challenges, benefits, pitfalls and new understandings have been compared and the use of the results questioned (Crix, 2010; Niinimäki, Tanttu & Kohtala, 2017; Pirinen, 2016; Solberg, 2018; Scott, 2006; Schildrick et al, 2017). This research borrows Alexander Refsum Jensenius's illustration of what these different words mean, as this illustration clearly shows the level of 'sharing' of experience:

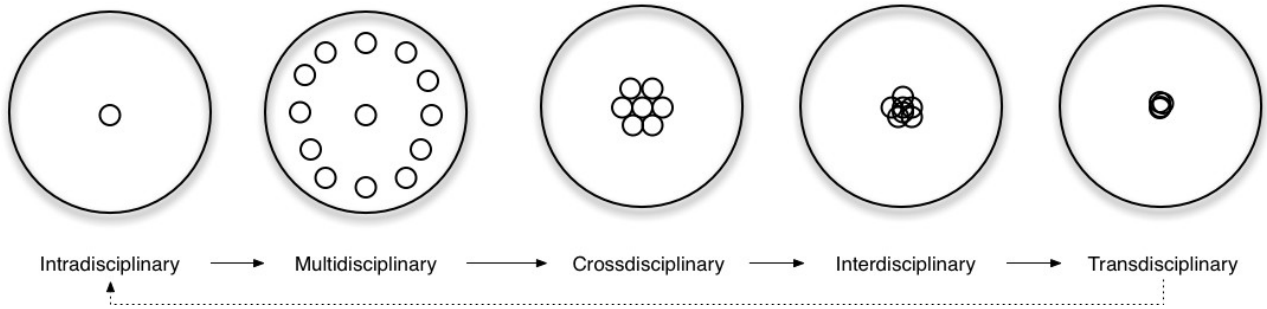

Fig 1. Drawn by Alexander Refsum Jensenius, 2016 (http://www.arj.no/tag/interdisciplinary/), based on an original drawing by Zeigler 1990.

The different modes of interaction shown above are explained by Refsum Jensenius (2016) as follows:

- Intradisciplinary: working within one's own single discipline.
- Multidisciplinary: people from different disciplines working together, but each person drawing on their particular disciplinary knowledge.
- Cross-disciplinary: viewing one discipline from the perspective of another discipline.
- Interdisciplinary: integrating knowledge and methods from multiple different disciplines, synthesising the different approaches.
- Transdisciplinary: creating a unity of intellectual frameworks beyond disciplinary perspectives.

The illustration shows how complex collaborative research is. Several recent conferences have

highlighted interdisciplinary research in which creative practices collaborate with different fields of science. The diversity of case studies suggests how a general template is hardly possible as the collaborative fields differ in each case study, and so it is difficult to form general understandings and templates for an ideal collaborative format on the basis of individual research projects.

The present paper stems from a collaborative research project studying biomaterials and material development and involves researchers from the fields of design, crafts, bioart, synthetic biology and biochemistry. The aim of the project is to cross-pollinate research methods and foster experiential knowledge transfer across disciplines through co-creation workshops and discussion. The different fields represented by the project's researchers contribute through diverse interests and approaches to materials and materiality, including experiential knowledge (Niedderer, 2007), new materialism (Bennet, 2010) materiality and innovation (Karana, Pedgley, & Rognoli, 2015), and feminist critique of embodiment and bioart (Radomska, 2016).

For the purpose of this paper, we are interested in general features that could facilitate the transformative exchange of experiential knowledge in such interdisciplinary projects. The authors' background in the field of crafts, design and art inevitably influences the motivations, perspective, design, literature and data analysis of the research. While acknowledging its limitations, we embrace this situatedness (Haraway, 1988) as the basis for reading interdisciplinary research in new materials that do not aim to be either universal or exhaustive, but rather – hopefully – offer valuable specific insights into the field.

In this paper, we take a closer look at how to share experiential knowledge in interdisciplinary research through a set of interviews of researchers working in Finland and Germany, as outlined in the research design section below. In order to encompass the wide field of creative domains that our interviewees refer to, we use *creative practices* to refer to arts such as craft, design and related artistic research (Varto, 2018; Biggs, 2010). When referring to *science* we refer to natural sciences such as biology, chemistry, physics and biotechnology. While acknowledging that these are gross simplifications of the various practice fields included here, we highlight that they are necessary to enable an overarching reading of the different interdisciplinary projects in which our respondents engage.

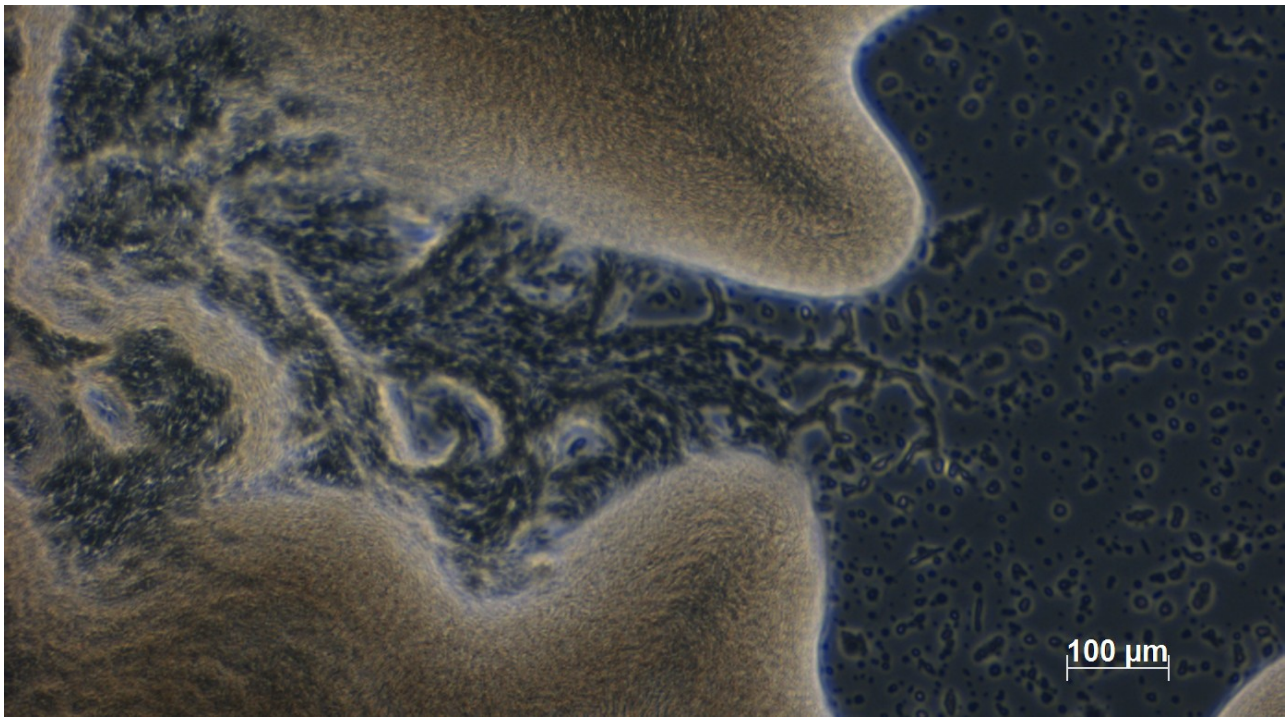

Fig 2. Detail of microbial biofilm, microscope picture by Margherita Pevere 2018

Experiential Knowledge

Experiential knowledge, also called *a posteriori knowledge,* is a type of understanding that can only be gained through experience and never through theorising only, or before the experience (*a priori)*. One can achieve such an understanding through close interaction with the phenomena under study, be this through sensory interaction or mediated by tools. Both the scientific and creative fields use this type of experimentation through a practice-led process which tests assumption and during which new questions might emerge (Candy & Edmonds, 2018).

Evaluations and judgements are based on expertise that grows over time and they are connected to previous experiences. Knowledge becomes embodied in the researcher as tacit or implicit knowledge. Within the same discipline, or between colleagues who share the same research experience, experiential knowledge is more easily shared. However, sharing experiential knowledge beyond disciplinary borders can become challenging, as the research methods and epistemic frameworks might differ radically (Ingold, 2018). However, as Ingold (2013) suggests, by investigating phenomena *through practice* rather than merely observing them, one can capture the true nature of the practice and knowledge is transformational rather than merely documentational (p.3). This transformation means that what we learn changes us and becomes part of who we are. However, such change may not happen in an instant, and often it requires a long time to develop.

Pilot Interview: On Fundamental Epistemological Differences between Scientific and Artistic Research

We formulated our interview questions as follows. First, we worked on our own research notes from the aforementioned research project. On the basis of these notes, we ran a pilot interview with a scientist who has had a long term collaboration with artistic researchers. The pilot interview highlighted the potential for knowledge production, mutual fascination between disciplines, but also friction areas and weak points, such as the different epistemological frameworks underpinning scientific and artistic research. We eventually compared what emerged from the pilot interview with the reference literature outlined above. Providing an exhaustive discussion of the epistemic differences between science and creative practices, as well as between scientific and artistic research, is beyond the scope of this paper as it tackles fundamental issues of knowledge production. However, for the purpose of our research, we must outline a few clusters that emerged from the preliminary research and pilot interview.

Objectivity is crucial in science as it aids reproducibility and production of novel knowledge on the basis of previous research. In artistic research, objectivity is less strict, and even considered unnecessary by some (Varto, 2018) as most processes are conducted in a subjective manner in a qualitative frame with a close, situated approach. Consequently, *verification* of results is not relevant in an artwork and related artistic research processes, whereas in science it is paramount. In the pilot interview, this aspect led to criticism of the validity of the knowledge produced through artistic research and to the differences in artistic practice vs. artistic research practices.

Different understandings of *cause and effect* create challenges, especially in explorative research processes. Artists have a subjective understanding of interaction with materials and may animate their materials in this process. *Language* can vary greatly between the two fields. In science there can be no confusion between what is stated and the nature of facts. In art, metaphors and poetic language are used to make a stronger, immediate connection between experience and conceptualisation.

Finally, *beliefs and politics* tend to be excluded from scientific research. In contrast, beliefs, subjective positioning, political aspects and societal issues form the core of most artistic research. In their report on the qualities of artistic research, Hughes, Dyrssen & Hellström Reimer, (2011, 1) state that ‘The aim (of artistic research) is often to reveal hidden concepts, critically examine social phenomena or highlight alternative values, perspectives and scenarios’ (parenthesis by the researchers), a thought that can be extended to certain design areas such as critical or speculative design.

For the purpose of this article we analyse how our interviewees dealt with the aforementioned topics and how they were or were not able to share their knowledge with others. We dive deeper into how the interviewees perceived their collaborators as benefitting from the understandings they gained together and how they facilitated the knowledge transfer between the participants.

Fig 2. Margherita Pevere performing with microbial biofilm in *Eingeweide* by Marco Donnarumma in collaboration with Margherita Pevere (2018), detail of a picture by Manuel Vason.

Research Design: Special Interest Group Interviews

In order to explore the challenges and potentials of interdisciplinary collaborations, we approached 11 scientists and creative practitioners who had engaged in projects that involved researchers from both creative and scientific fields. Although our respondents worked for large organisations or institutes with various interests, they were all interested in cross-fertilising research and can thus be called a special interest group.

Participants:

We chose the participants on the basis of their recent activities and successful funding applications in the context of interdisciplinary research. Our group of participants was gender-balanced and included scientists (5), creative practitioners (6) and researchers at different career stages: some of the more experienced scientists ran large research teams and had published more than a hundred international research papers. Apart from one, all either had or were pursuing a Doctoral degree in their field. To expand our research beyond a specific national context, and based on our own research experience, we interviewed researchers working in Finland (7) and Germany (4).

In order to obtain uncensored answers in the interviews we keep our interviewees anonymous. For most of the interviewees, interdisciplinary research covered only part of their research activity as interdisciplinary projects only last for a limited period of time. Some of them had education or training in both art and science. Most of them had researched new materials in either long- or short-term research projects. Their role in the collaboration varied from facilitating the research through funding, acquiring staff and materials, and providing and actively participating in discussions on the research issues to concrete hands-on actions and interactions with the materials and other participants. Table 1 below presents our dataset according to the most relevant parameters.

Table 1. Education, country, level of experience, main research field, interdisciplinary project area and role of participants.

Education	Country	PhD	Main research field	Interdisciplinary project area	Role in the project
Creative practitioner with science interest	FI	2008	Design	Biomaterials	Facilitator and participant, hands-on
Science	FI	1997	Chemical engineering	Material research	Facilitator and participant
Science	FI	1980	Neuroscience	Neuroscience and art	Facilitator and discussion partner
Science/ painting	FI	1987	Synthetic biology	Biomaterials, bio art	Facilitator and discussion partner
Creative practice	DE	2018	bioart, media art	Bioart; biomaterials	Hands-on
Science/music	FI	1983	Physics polymers	Bio materials, design	Facilitator
Scientist	DE	2014	Computer scientist	Bioart	Hands on, Facilitator
Humanities, art	FI	exp 2020	Bioart	Material research, bioart	Hands-on and discussion partner
Scientist	DE	1986	Microbiology	Biomaterials, design, humanities	Hands-on, facilitator, discussion partner
Creative practice	FI	No PhD	environmental, media and bioart	Environmental, media and bioart	Hands-on
Scientist	DE	1983	physics	Biomaterials	Facilitator

The Questions:

Our questions explored the underlying epistemological differences and how researchers navigate these in the context of interdisciplinary research. We asked them about the extent of their collaboration, their role in it, what led to the collaboration and what added value the collaboration brought. We explored the participants' views on the differences and similarities between the creative field and sciences, such as different research paradigms, methods, validity or beliefs. We also asked about the language they used, as we were interested in how collaborators created a mutual way of communicating. We also asked what challenges the researchers encountered and what advice they could give. Discrepancies and friction points and how to navigate these and the possible benefits that they saw in engaging in the collaboration were also elicited. Finally, we asked about their individual experiences of success or failure and what had led to these.

The interviews took place orally (except for one), in a conversational situation guided by a set of questions. This method has the advantage of balancing systematic data collection while allowing spontaneous observations to provide further insights. However, conversational situations might lead to rewording, which may reduce the comparability of responses. For the purpose of collecting qualitative data, we decided to prioritise the diversity of information over their comparability and compensated for this with a qualitative analysis of the interviews.

Analysis

Each interview was transcribed and two of the authors conducted an initial meta content analysis to see what types of general features emerged in the discussions. Based on these general

features, we carried out a second co-analysis process in which we detected issues that emerged outside the predetermined questions of the interviews. The issues that generally emerged mostly related to the respondents' views on the differences and similarities between their own disciplines and those of the others, the problems or breakthroughs that had emerged, and how to navigate this field. This paper presents the initial analysis of the general features that emerged from the interviews and we account for these though examples from the transcript excerpts.

Results

A central issue that emerged in the interviews was that many of the scientists we interviewed were still unclear about what *artistic research* entails. In Germany, practice-based research in the arts at the doctoral level is still a young discipline, with a discrete number of conferences but very few PhD opportunities. In Finland, on the other hand, the discipline was established in the early 1990s. The existence of interdisciplinary research projects in Germany, some of them newly funded, suggests that the field is expanding. Despite this difference, scientists from both Germany and Finland showed some confusion regarding artistic *research* and art *practice*.

The general attitude among the scientists we interviewed was that the creative fields bring new ways of disseminating scientific research results through either their expressive display or design application. Few scientists embraced the artistic researchers' ability to influence the scientific direction of the project and few took into account the possibility of utilising artistic results in their own research outputs other than through images or prototypes. However, some of the artists reported that their ideas contributed through raising new research questions in their group.

Most of the creative practitioners aimed for truly *transdisciplinary* collaboration, whereas the scientists held a more *multidisciplinary* stance, according to which the two disciplines add to each other's work while maintaining their own expert areas. However, most of the scientists appreciated the potential of interdisciplinary collaboration whereas most of the artistic researchers were frustrated that their full collaboration potential was not understood by their partners beyond a functional purpose. Almost all the participants agreed that if one has to compromise the quality of one's own contribution too much in order to maintain collaborative aspects, collaboration becomes meaningless.

There was consensus on the fact that building trust and solid communication in collaborative research requires regular presence and common activity. The opportunities of knowing together require people to work together in the same space or facilities and engage in the research hands-on and/or through discussions on a regular basis. Some suggested a minimum meeting interval of about one week, but preferably daily interaction. The longevity of the project was mentioned as a key factor for enhancing the understanding between the participants, thus short projects would be unable to affect the participants' way of thinking or how they are able to understand their partners' very different approaches. Engaging in the other partners' literature and way of thinking, although this may mean stepping outside one's own comfort zone, is essential for educating oneself and each other and for building bridges and a common language that can serve as a mutual platform on which to stand in the project.

Naturally, the factors that hindered collaboration were the opposite of the enabling conditions. Trust, respect and appreciation of each other's work and attitudes were considered crucial, and if there was failure in any of these aspects, the collaborations could fall short. Both the creative practitioners and scientists agreed that 'personal chemistry' meant a great deal when inviting collaborators into a shared project, even though this feature was hard to describe. Disagreements between collaborators were avoided using the same recipe. While the participants agreed on these points in general, their expectations of the outcomes differed, as did the notion of successful collaboration or a successful outcome as opposed to unsuccessful ones.

It also emerged that, even between different scientific disciplines, individual interests, personalities, and most importantly epistemic differences may affect collaboration. Some of the interviewees noted how the division into disciplines according to training or research fields may be

incorrect even within their own department. Interestingly, a certain ‘boundary-crossing’ emerged in the way both the scientists and creative practitioners related to and spoke about the materials they worked with. Although science generally requires a fundamental objective approach, some of the scientists had no problem relating emotionally or subjectively to their material explorations. In contrast, some of the creative practitioners considered it important to relate to their material processes through a scientifically organised and systematic approach in order to validate their findings in the science contexts and to be able to contribute to publications beyond the creative field.

Providing a generally valid definition of what is a ‘successful’ collaboration in interdisciplinary contexts is hardly possible given the variety of types, duration and objectives of interdisciplinary collaborations. Importantly, measuring success in disciplines that are entirely different involves different acknowledgement systems, value systems, expectations and even career paths. While the above results were the general issues that arose in the interviews, the following discussions focus on the challenges and opportunities of experiential knowledge transfer that the interviewees revealed.

Discussion: Experiential Knowledge Transfer in Interdisciplinary Research Collaborations

An analysis of the interviews outlined some key enabling factors for experiential knowledge transfer in interviewees’ experience. We tracked what the participants considered to be major benefits of the collaboration, the challenges, and the factors that enabled them and grouped them as follows:

1. Close physical and mental collaboration, which is only possible when people work hands-on in the same premises.
2. Motivation to solve the same research problem while using one’s own expertise in the mutual new context.
3. Trust, personal chemistry and the ability to transgress into the uncomfortable: the importance of mutually educating each other and building a new language.

1. Close physical and mental collaboration, which is only possible when people work hands-on in the same premises.

As outlined earlier, for most of the interviewees, the interdisciplinary research covered only part of their research activity. This might have affected an aspect that most of the researchers considered crucial, namely the time spent and the regular work done together. All the interviews highlighted how intensive and regular communication was key for collaborating successfully, as it allowed the partners to meet on a next to daily basis and nurture their mutual understanding of the processes, so that everyone could understand what needed to be done next, why and how. However, also listening to each other’s ideas and being ready to step outside one’s own comfort zone in the process of trying to reach a common understanding was highlighted. Although regular collaboration in physical proximity may facilitate different kinds of collaboration, this may be particularly relevant with regard to research on new materials due to the materiality of the research subject.

One interviewee told us how the discussion and the process of analysing their results together influenced their understanding of new possibilities, but also that failures may bring people closer together:

> We failed completely in our first attempt, but that opened our eyes and we learned to discuss and understand different ways of doing things, and actually the failing was the key in this process of forming the group.

It was also generally understood that the process of finding ways in which to work together takes time:

> I don't think we can expect very quick results. It actually takes some time to find the right ways of doing it. I think there are very few examples of how to do this combination of research. There are not any methods for it. So, we have to do a lot of searching of ways to go forward.

2. Motivation to solve the same research problem while using one's own expertise in the mutual new context.

Collaboration only succeeds if partners have a mutual interest in the subject and believe that they can shed light on aspects that cannot be covered by the disciplinary approach only. The respondents agreed that funding alone could not make research partners work successfully or make them motivated to work together. One of the scientists, who was not so pleased with the collaboration, mentioned that motivation to solve a mutual research question was a key enabler:

> But if we all had a common question, (...) then I would have gone straight to him and said let's start talking every week about this and see how we can do an experiment, how we can find some earlier writing and maybe go to some place and do experiments there. Then we would have a mutual interest, and that certainly is the key!

One of the creative practitioners explained:

> In our team we managed to create new methods and to create new materials and use areas, but we couldn't have done this without each other's help. We really needed the scientists and designers working together for this and the combination of these two ways of working led to success.

3. Trust, personal chemistry and the ability to transgress into the uncomfortable: the importance of mutually educating each other and building a new language

Most of our interviewees raised the need to build a common language and clarify the setting in which such language could be used. However, this can only happen with mutual effort to communicate, trust, and understand each other. Although funding bodies request/propose that research positions in a funded project should be open in order to ensure that the best applicant is selected, many of our informants were of the opinion that the team should be handpicked. The reason for this was the awareness that personal chemistry has a great influence on the success and motivation of the collaboration. In the words of one of our respondents:

> Complications arise in all fields, not only in collaboration with artists. It's about what kind of people are able to work together, about personal chemistries. Communications skills, but not only skills, because if we want to collaborate, we should have a common interest and know that we can learn from each other so that we are both happy to work together.

Another interviewee said:

> I think the chemistry between people is really important for the success of any collaboration, so the formation of groups might be the key to success. Because many scientists are not able to work with creative practitioners, I think we should think more about what kind of people are able to work together. And not just think that ok now we have 'an artist' coming to the science lab, because that happens a lot.

Mutual respect and acknowledgement were also paramount. The creative practitioners in our cohort perceived their work as undervalued when it was used for communication purposes only. On the other hand, the scientists did not feel comfortable if they were seen as a mere source of skills or resources. In our interviews, the scientists mentioned the potential for communication of the creative practitioners' input and the creative practitioners mentioned that collaboration offered the opportunity to access resources and technologies. However, these aspects were only marginally mentioned, and both the scientists and the creative practitioners highlighted mutual learning as the most valuable contribution of the collaboration.

A creative practitioner from the design field had the following experience:

> (…) most scientists want to stay in their own bubble, and it's not that easy to find the kind of scientist who really wants to open their mind, to see new ways of doing things. But, in a couple of groups I worked with we really took huge steps when we trusted and respected each other. But in most cases I think that the scientists thought we were only stylists or product designers, and that's typical. They didn't think we could add value in other ways such as by really bringing about something new or offering new knowledge.

To create mutual understanding and respect that crosses disciplinary borders, more than one participant suggested that their team needed time and dedication to reach such understandings. One experienced scientist told us:

> We've been discussing artistic research in regular meetings for over two years now, including workshops and mutual artistic exercises, we have even been on a retreat together, but it's taken a long time to find ways, and the right words to communicate. We are very interested in each other's work and ideas, and we are working on a mutual paper, but we haven't been able to produce anything concrete yet.

While working hard to understand each other, difficulties also arose. One scientist explained their experiences as follows:

> There is a gap between us, and the gap between scientists and artists is larger than I thought it was. I believe that we can bridge this gap, but the key is that the people involved are willing to do that. Even just negotiating the words so that people just a little outside (their own discipline) could understand.

The way out of such a situation is awareness that it is difficult but that giving up will not take one any further. The friction points should be seen more as possible passages and enablers of change, as they are the point at which a bridge may be built, or where new concepts that both parties may understand should be developed. One of our informants claimed that:

The main point is that in order to understand more in any field there has to also be some contradictions. Somehow people can't be in concert all the time; they need to also find some friction points, some contradiction. In order to proceed from these friction points, you have to be able to communicate with the others.(...) In order to understand how people are in the world and how they understand the world we try to combine these different views, but first we have to bridge the concepts so that we can talk to each other.

However, the usually limited duration of funding challenges regular commitment to interdisciplinary research projects. Many researchers work on several projects simultaneously to ensure a regular income. This in turn makes it difficult to prioritise the process of achieving qualitative results over the dissemination of tasks in the expert fields represented in the collaboration. Thus, the good intentions of interdisciplinary sharing were forcing the collaboration into a multidisciplinary approach in which the different disciplines in fact worked side by side, only combining the different results of their separate processes in the final product of their project, the research article or prototype. Alexander Refsum Jensenius (2016) and Zeisel (1981/2006) also reflect on this notion of thinking that collaboration is inter- or transdisciplinary when in fact it turns out to be multidisciplinary.

Challenges in collaborating might be turned into enablers

The discussion above shows a cluster of factors that can lead to rewarding or even successful collaboration. Most of the interviewees clearly suggested that the lack of factors such as time spent working together or willingness to understand each other's language might negatively affect the research. These conditions might lead to miscommunication, feeble personal connection and trust, and no shared language on which to build or publish. Not acknowledging the work of others can create frustration or distrust among collaborators. Some interviewees referred to further disrupting factors including stolen work, hidden agendas or difficult power relations as a source of distrust and consequent failure.

While these unfavourable conditions certainly set collaboration on the wrong track, we might also

think of failure, disruption and miscommunication as opportunities for deeper reflection. Kahane (2017) suggests a strategy for dealing with such instances by 'stretching' the collaboration and shifting away from the wish to control every part of the process or to change the others in the team. Instead we should enter the uncomfortable zone to be able to embrace conflicts and move beyond them (2017, 42). This might enable open-minded experimentation with new possibilities even though it may at first seem to go against what feels natural.

We found that truly interdisciplinary breakthroughs could emerge precisely in the space that nobody could have considered without having to stretch beyond the comfort zone of their familiar discipline. Niinimäki et al. (2017) find that multidisciplinary collaboration in research on new materials requires participants' readiness to step outside the practices of their discipline and learn collaboration (2017). However, as the challenge to understand everything in several disciplines is overwhelming for anyone, Niinimäki et al. suggest that learning is not enough; a new type of knowledge intermediator is needed to bridge knowledge gaps between disciplines, so that shared understanding can happen (2017, 9). In their case this was a textile engineer, but the notion of t-shaped knowledge skills is also common in the area of design, in which professionals have a generally broad understanding combined with a great deal of domain-specific knowledge.

Within a different field of research, Schildrick et al. (2017) give a comprehensive account of an experimental interdisciplinary research project on heart transplantation across medicine, the humanities and art, which shows how an unprecedented research assemblage may lead to a fuller comprehension of the significance and experience [of heart transplantation] as the first part gave a feeling that the multi-disciplinary team collaborated on the heart transplantation procedure/surgery as such (Schildrick et al., 2017, 46). Drawing on previous research (Niinimäki, 2017; Schildrick 2017) and the valuable experience of our respondents, we embrace a daring approach to interdisciplinary research, and hope that it may pave the way for novel paradigms in research.

Conclusion

Based on our interview analysis, we would like to make a general note to researchers embarking on research projects involving both sciences and creative practices, in order to help them facilitate knowledge transfer between participants. Trust and openness are key to communication in most contexts, but the specificity of interdisciplinary fields requires further care. Our respondents' experience clearly shows how mutual understanding and the prerequisites for experiential knowledge transfer need to be built consciously, over a long period of time by engaging in hands-on practices and cognitive activities that exceed all the collaborators' individual comfort zones while the common goals and the research questions are motivating for all of them. Trust and respect need to be nurtured even when the ideas of the other discipline feel unnatural or incomprehensible: breakthroughs may emerge in areas of discrepancy.

While academic research funding agents prompt and encourage interdisciplinary research, the present research suggests that money alone cannot motivate people to work together. Even when the motivation and common goal is found, the short longevity of funding might drive researchers to multitask, and this is counteractive for maintaining the ideal conditions for truly transformational learning and knowing together. Thus, in addition to inviting enabling professionals who have t-shaped experience of two or more disciplines, we suggest the conscious development of novel paradigms that could educate a new generation of thinkers and makers who feel comfortable in the unsettling zone between disciplinary boundaries.

Limitations of the research:

Interviewing a homogenous group of researchers, for instance, only creative practitioners or only scientists, from one country or a single research area could have provided comparable data on factors such as experience, internationality or research objectives. Instead we chose to look at the qualitative aspects before the comparative aspects. Additionally, a mixed author group may have resulted in a more comprehensive research design and data analysis, including more of the scientists view into the subject matter. Although this might give rise to the same challenges our

respondents described, an interdisciplinary approach to the subject may create provocative research questions.

Future research:

The formation of novel paradigms that truly combine the sciences, creative practices and humanities still alludes us, and research on interdisciplinary processes that can generate models for best practices is still needed. Another aspect that might be worth addressing is how funding might shape collaboration according to whether it is obtained by scientists or creative practitioners, and how this aspect might affect power structures within the group as well as the continuity of the research.

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Camilla Groth

Camilla Groth has a traditional craft background in the field of ceramics and for her PhD she studied aspects of embodied knowing in design and crafts and developed practice-led research methods. Her research interests revolve around experiential and embodied knowledge and materiality. Groth is currently conducting her post-doctoral research at the University of Gothenburg and also holding a 20% Associate Professorship in arts and crafts at the University of South-Eastern Norway.

Margherita Pevere

Margherita Pevere is an artist and researcher with a visceral interest in biological matter. Bacteria, animals and plants are her allies in the exploration of the underlying theme of ecological complexity, which she pursues with sophisticated bodily aesthetics. Created in both the studio and biological laboratories, Pevere's installations and performances are chimeras which intertwine poetics and controversy, critique and desire. Pevere is a PhD candidate in Artistic Research at Aalto University, Helsinki, in collaboration with Biofilia Laboratory – Base for biological arts. supported by The Finnish National Agency for Education (2017–2018) and the Kone Foundation (2019–2020).

Pirjo Kääriäinen

Pirjo Kääriäinen is a designer and facilitator in the intersection of design and material sciences. She currently works as a Professor of Practice in Design driven fibre innovation at Aalto University, Finland. Kääriäinen has been developing interdisciplinary CHEMARTS collaboration between chemical engineering and design since 2011, focusing on the research of bio-based materials.

Kirsi Niinimäki

Kirsi Niinimäki is an Associate Professor in Design in Aalto University, Finland. Her research focuses on holistic understanding of sustainable fashion and textile fields and connections between design, manufacturing, business models and consumption. Niinimäki has also studied transdisciplinary collaboration and design-driven methods in collaboration. At Aalto University Niinimäki runs the Fashion/Textile Futures research group http://ftfutures.aalto.fi.