Towards a framework for designer/scientist collaboration in sustainable product development

By Ayako Takagi

Bachelor of Education in Science, Saitama University, 2013

Bachelor of Design, Industrial Design, Emily Carr University of Art + Design, 2021

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Abstract:

Many scientists and designers are interested in collaborating on sustainable material/product development. Collaboration can benefit both scientists and designers, yet it must be approached carefully as there are limitations in logistics, challenges in social dynamics, and risks in miscommunications due to boundary objects. To collaborate in a way that truly brings merit to both designers and scientists, they have to respect and understand that they carry different values, goals, and approaches, and then think about how to work together realistically. This thesis discusses the key considerations that need to be taken into account and provides guidelines for developing a framework for collaboration between scientists and designers.

Keywords:

Design Science Research (DSR), cross-disciplinary research, sustainable materials, collaboration, systems thinking, information systems (IS), boundary objects, industrial designers, scientists

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I acknowledge that this study was conducted on unceded, traditional and ancestral territories of the xʷməθkʷəy̓əm (Musqueam), Sḵwx̱wú7mesh Úxwumixw (Squamish) and səl̓ilw̓ətaʔɬ (Tsleil-Waututh) peoples. Some of the sustainable materials featured in my design science research come from local trees – I respect trees as symbols of history and important parts of Indigenous communities. I appreciate the research opportunities we have, and will continue to consider our relationship with land.

Introduction

1.1 Problem space

Climate change is one of, if not the most, complicated and serious global challenge we are currently facing. All measurable data – the increasing number of forest fires, rising sea levels, record temperature highs year after year, stronger monsoons than ever before, and more – tells us that we all need to change how we live our lives, and develop strategies and pathways to change the systems that encode and shape them. The problem is clear, yet solutions are difficult to come up with as they require consideration of many different conditions. This type of problem is defined as a "wicked problem" in the design community (Rittel & Webber, 1973; Muratovski, 2021). In order to understand wicked problems, Rittel and Webber (1973) suggest listing all possible solutions related to the problem to take all components into account. If we apply their theory to one of the many required shifts to address climate change, which is developing sustainable materials/products, practitioners would need to be experts in material science, business, design, politics, etc. to truly consider all of the possibilities that would influence the process. In reality, it is nearly impossible for one person alone to have an in-depth understanding of all fields. Thus, it is desirable to team up with people from different fields to first understand and then solve the problem together. We call this activity "collaboration." We can understand this cross-disciplinary teamwork as a general example of collaboration. In this paper, I will develop a more concrete idea of the forms and practices of design and science collaboration that are required to address sustainable material/product development.

1.2 Research context

In 2021, I started working as an industrial designer at the UBC BioProducts Institute. My role is to collaborate with scientists to prototype and develop sustainable bioproducts. Over the past four years, I have had many opportunities for collaboration with fellow scientists. My design practice is integrated with scientific material development; part of my practice is manifested in their contributions to new material development (Guo et al., 2023; Banvillet et al., 2023; Yu et al., 2023; Samsami et al., 2025). I am also passionate about cross-disciplinary study at the intersection of science, design, and traditional crafts, and have explored this topic with several artists and scientists (Takagi et al., 2025). Besides contributing to scientific research, I also helped facilitate collaborations between designers and scientists at ECUAD and UBC. Although all collaborations were meaningful in different ways, I found a common issue across the various collaborations I was involved in. There are many people who are enamored by the term "collaboration" and yet do not think deeply about how to approach it. They are highly motivated; however, they often fail to make progress or it results in one-sided "collaborations" that are often inconsiderate or unfair to the other collaborators.

This issue usually stems from a lack of mutual understanding of the differences between research approaches across different disciplines, and a plurality of individual approaches amongst collaborations themselves. It will lead to the mismanagement of “boundary objects,” which we will discuss later, and cause problematic behaviours which can create distance within the collaboration. For example, while they say and believe that they are giving their collaborators due respect, their attitudes and actions may not reflect this. Without the context given by developing an understanding, they may feel that the collaboration was a great success without noticing that it was only successful for one party. Even if they do not intend to hurt their collaborator, the lack of understanding can indeed do so and in some cases results in the collaboration ending unexpectedly. Working with blinders is dangerous for all parties in a collaboration as it can result in one party experiencing a form of damage and the other experiencing confusion as they are unable to understand why the collaboration appeared to break down. It can have far-reaching impacts as the collaborators who experience this damage will likely be discouraged from participating in future collaborations, and without developing an understanding, those who caused the problem are likely to repeat the same mistakes in the future. If the prerequisites for collaboration collapse, we will not even be able to meet at the starting line of sustainable materials and product development again. However, these challenges are perceived as general communication challenges in collaborations, and they do not reach the fact that there are fundamental collaboration system/information system (IS) issues we need to tackle.

In considering this specific cross-disciplinary collaboration, the following questions are raised:

1. What are the challenges for designers and scientists to collaborate with regard to “developing sustainable materials/products”?
2. What types of risks exist in these collaborations?
3. What can limit collaboration?
4. What are the key considerations to make collaboration beneficial for both disciplines, and ultimately have an impact on climate change?

Through answering these questions, I will explore the research question “How can industrial designers and scientists collaborate to develop sustainable materials/products together?”

2. Methodology

2.1 Research methods

This research is supported by three core research methods: literature review, autoethnography, and ethnography. For the literature review, "design science research (DSR)" was the focus topic in order to understand the background of designers and scientists' collaborations. Ethnography was selected to understand the characteristics of scientists and designers who engage in the sustainable material/product development. Autoethnography was conducted to define the problem area and refine the design research questions which can be expanded to ethnographic research perspectives. To compare the findings from autoethnography and ethnography with praxeology (the study of human behavior and action, especially purposeful, intentional action), several sociology, psychology, and business theories were reviewed.

2.2 Literature review

The design research question of this thesis, "how can industrial designers and scientists collaborate to develop sustainable materials/products together", can be categorized as a specific question related to *design science research (DSR)*, which has been studied since 1971 under the category of *information systems (IS)* (Nunamaker et al., 1990). The goal of DSR is to generate scientific knowledge while simultaneously creating practical utility (Otto & Oesterle, 2012). Despite a substantial number of DSR studies being completed since its introduction, it is hard to define what DSR is as both the terms and approaches used in the theory are not rigidly defined. For instance, "knowledge" can mean "knowledge that" (i.e. scientific knowledge leading to truth) and "knowledge how" (i.e. applied knowledge and technologies), (Nanamaker et al., 1990; Niedderer, 2007; Otto & Oesterle, 2012). Design is both a process (set of activities) and a product (artefact) (Otto & Oesterle, 2012; Walls et al., 1992). Confusingly, an artefact is also defined as a system or system component by some researchers, and as a theory or theory component by others (Peffers et al., 2018). In addition, DSR has operated according to many different paradigms, and the paradigms have not been formally classified. This lack of formal classification and understanding can lead to theories proposed by individual researchers losing their intrinsic value, as the value is hard to quantify (Peffers et al., 2018). Another issue of DSR is that it is difficult to apply the theory to practical contexts (Lukyanenko & Parsons, 2020). Van Der Merwe et al. (2020) summarized the complex concepts of DSR proposed over the years and presented seven guidelines for DSR novices, but did not specify practical ways to apply them. Lukyanenko & Parsons (2020) tried to convert DSR theories into practical methods, yet found this was difficult to do since there are multidimensional problems in each topic that make it challenging to fit topics to a framework.

In order for two disciplines to effectively collaborate, many DSR authors mentioned the potential of applying action research (AR) in DSR (Carlsson, 2006; Holmström et al., 2009; Mathiassen, 2002; Otto & Oesterle, 2012). Iivari & Venable (2009) validated that AR and DSR are compatible, and could work synergistically if design and science researchers' research interests, research purpose and activities align. AR is a qualitative research method that follows an iterative process in which researchers and practitioners work together on a specific cycle of activities including problem diagnosis, behavioral intervention, and reflective learning (Avison et al., 1999). Lukyanenko & Parsons (2020) also urged (scientific) researchers and practitioners (designers) to work closely to each other in order to make both parties aware of each other's challenges (reflective learning and problem diagnosis) and increase clarity by using common language as a part of their conclusions (behavioural intervention). However, as there are a variety of disciplines within both science and design, a perfect framework for the specific situation of development of sustainable materials/products has not yet been reported on. In order to create a framework for this topic, it is necessary to understand the values of scientists and designers working in this field, and to specifically understand what points they are likely to align with and what points are likely to cause disagreements. This thesis focuses on identifying "key considerations" that may serve as foundations upon which a framework for collaboration may be built."

2.3 Ethnography and autoethnography

Ethnographic research is a classic qualitative and anthropological research method for understanding a target community's values. This research method was selected to understand the character of people in the science and design communities who are working on or interested in sustainable material/product development. However, the fundamental challenge with ethnographic research is that it is impossible to completely eliminate the researcher's own involvement and influence in the research results, which prevents objective discussion, while on the other hand, the research problem cannot be defined if the researcher's personal perspective is completely removed from the context (Davies, 1999). Davies adds that the recognition of their influence from individual ethnographic researchers and the development of their research techniques, factors which acknowledge and utilize their subjectivity, are an indispensable part of their research, and while challenging, should be incorporated into their work. Taber proposes a method of introducing autoethnography to ethnographic research as a starting point in an effort to not just apply the theories, but live them (2012). Considering these points, I decided to use autoethnography to define the problem area and enrich the study by including my experience as a part of each community, and to develop interview questions based on autoethnography as a starting point. Embedding the researcher into the community deeply suggests aspects of participatory action research (PAR), where researchers actively contribute to developing the theory or data; my research goal is not to create a framework (theory) but to understand the related values and behavioral science, which aligns more with ethnography and so I will define my main activity accordingly.

2.4 Interviews

A series of interviews were conducted to understand the values of each discipline after guidance from Research Ethics Boards at both Emily Carr University of Art + Design and the University of British Colombia. A total of 24 designers and scientists (12 from each field) at various stages in their careers (students, staff, project managers, associate professors and professors) participated in these interviews. Participants from different backgrounds were chosen to understand how each stage of their career influences the goals and values they hold, in addition to general trends specific to each discipline. To preserve anonymity, associate professors, professors and project managers are categorized as "manager", master's and PhD students as "graduate student", and undergraduate students as "student." The interviewees consisted of people with experience working at the interface of science and design, people who are interested in design and science collaboration, and people who cover both fields. The interview consisted of twelve questions related to collaboration and past collaboration experiences. Questions were shown as PowerPoint slides, and the interviews were done conversational style either in person or via Zoom. The list of questions is attached in Appendix A. The interview data was coded using thematic analysis methods (Maguire & Delahunt, 2017) and trends for designers and scientists were analyzed to study the interpersonal and social aspects of collaboration.

2.5 Dimensions of design/science collaborations: environmental/condition aspect, interpersonal/social aspect, and the foundation of collaboration (trust)

There are various ways to categorize the components of collaboration. For instance, in the field of "information systems (IS)," the umbrella category for DSR, the dimension of collaboration is divided into the components "people, structures, technologies, and work systems" when they consider developing a framework (Alter, 2003; Bunge, 1985; Simon, 2008). In this study, the dimensions of collaboration will be divided into the *environmental/condition* aspect, the *interpersonal/social* aspect, and the foundation of collaboration, *trust*. The relationship among these three components is shown in Figure 1 and the reason will be described below. The term *environmental/condition* aspect considers the conditions of physical working spaces, tools that designers/scientists need to use, and resources (time, labour, and funding) which would be required for collaboration. The *interpersonal/social* aspect includes discussion of how scientists/designers define goals, mechanisms of trust and respect, how they communicate, and how they drive collaborations. Lastly, *trust* is an essential factor in collaboration.

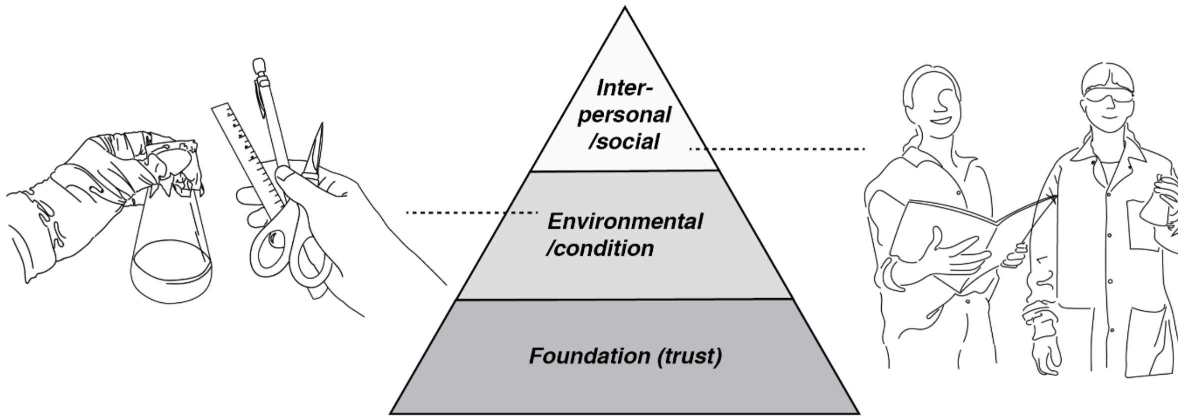

Figure 1. A diagram contrasting the environmental/condition aspect (left), and the interpersonal/social aspect (right)

3. Environmental/condition aspect

3.1 Environment and conditions for a collaboration

The environmental/condition perspective is discussed in various ways in literature, though it is not necessarily named or categorized as "environmental/condition" challenges. In interdisciplinary research, the importance of the environmental/condition aspect is acknowledged, yet how it could affect collaborations does not seem to be studied actively. "The extent to which an environment enables collaboration is relatively unexplored in literature. There is a fair amount that talks about leadership behaviors and organizational culture, and undoubtedly these are very important. There is less, however, on the physical or environmental factors, such as workplace design, or the uptake and adoption of new technologies" (Emmens, 2016, P31). DSR researchers do acknowledge the challenges associated with the environmental/condition aspects: "Without having environmental support, it will act as a barrier"(Hepp K. et al., 2015) "(Obstacles for collaborations would be) access to the "right" resources – refers to a general problem in collaborative DSR projects, namely personal discontinuity of key resources critical for the project's success" (Henningsson et al., 2010). In information system (IS) design research aimed at providing socio-technical solutions to real-world problems, Henningsson claims that resource-dependent theory (RDT) is a promising theory to apply. RDT describes how an organization's external resources affect its behavior (Pfeffer et al., 1978), and this "resource" perspective can be adopted to explore how designers see the external resources (scientists, scientific knowledge, skills) and vice versa, and define the environmental/condition factors.

In order to outline environmental/condition requirements for collaborations between industrial designers and scientists, the resources that industrial designers and scientists have, and how the resources are connected to their work condition are discussed below.

Through autoethnography, four elements that are required for designers/scientists to complete their tasks independently are made clear. (1) Materials, (2) Knowledge and skills, (3) Tools/equipment, and (4) Facilities (Figure 2). If even one of these elements is missing, it would be extremely difficult to complete the task. Examples to concretize these elements will be discussed next.

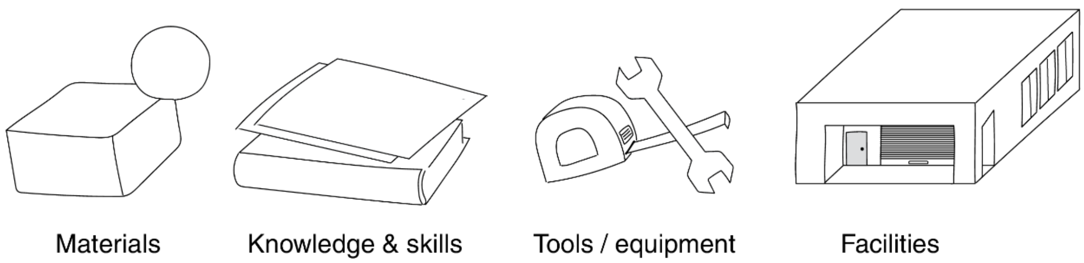

Figure 2: Four elements for designers/scientists to complete their tasks:(1) Materials, (2) Knowledge and skills, (3) Tools/equipment, and (4) Facilities

If an industrial designer works in ceramics, they need clay, which is the material to start. They need to know how to wedge, form shapes, use different kinds of glaze and adjust temperature for firing, all of which are categorized as knowledge and skills. They need a variety of tools/equipment such as wires, spatulas, sponges, carving tools, wheels, and kilns. Finally, they need access to a facility that can run the kiln safely and provide a space for their work (Figure 3).

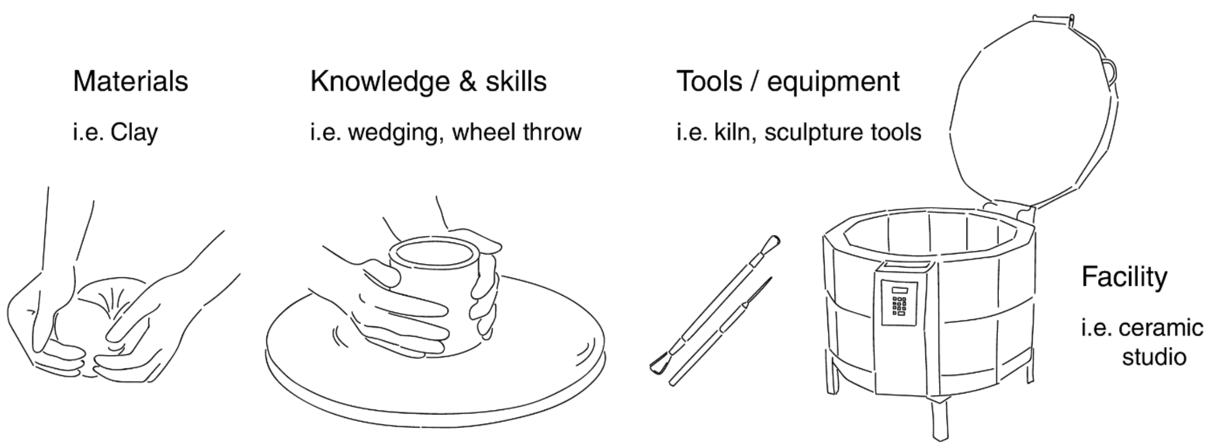

Figure 3: Examples of industrial designers' working environment and conditions (i.e. ceramics)

The same idea applies to the scientists' environment. They need raw materials such as agricultural waste, industrial waste, or forest products (in the case of the lab that is the focus of this project). They also need chemicals to treat the raw materials. As science's goal is to generate new knowledge and is built upon a previous foundation of work, they need to gain specific knowledge and skills that support their research. They need tools and machines to create the materials that they design, and to evaluate their material properties and performance. Finally, they need a lab which is a facility to safely complete their experiments (Figure 4).

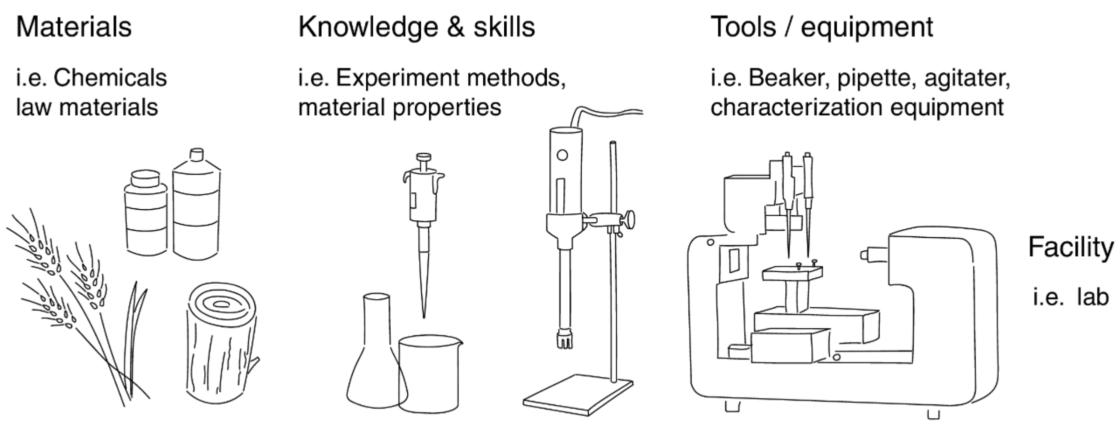

Figure 4: Examples of scientists' working environment and conditions

A common mistake that should be highlighted is that people tend to disregard the impact of the environmental/condition aspect and not notice how it influences research. For example, if a design research team hires a competent scientist but the team does not give necessary access to tools/equipment/facilities to the scientist, the scientist cannot fully work as a scientist. The opposite is true as well. In action research (AR), the extent to which these environmental factors can be shared is the key to the depth of collaboration that can take place. However, I also found that there are structural walls or barriers that prevent sharing these elements, which links to the points Henningsson (2010) raised earlier.

3.2 Barriers preventing environment sharing

What are the challenges of sharing environments with collaborators? Through both ethnographic design research and autoethnographic research, four factors were identified: community access, regulation/safety, funding and resources, and confidentiality (Figure 5).

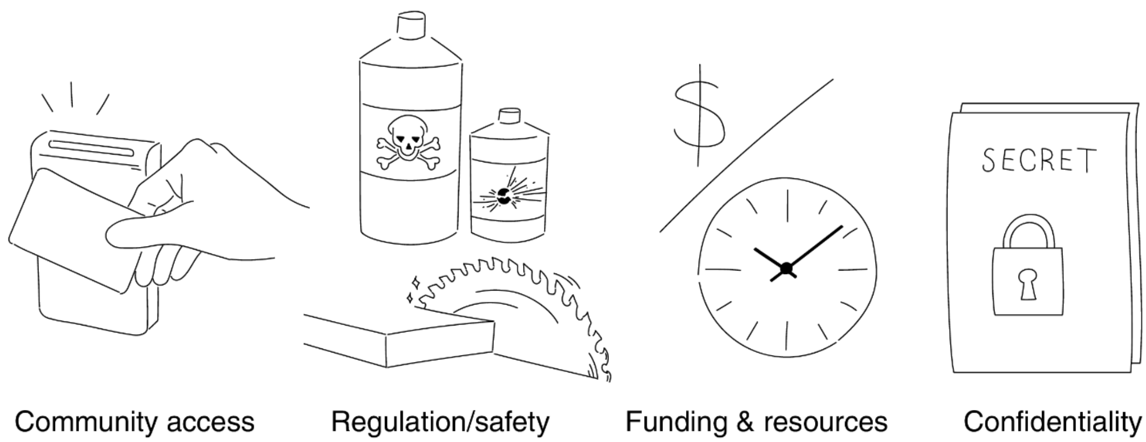

Figure 5: Four types of barriers preventing sharing environments

3.2.1 Community access

Priority access to facilities (studios/shops/labs) and equipment (tools and instruments) is given to the original community members – understandably so, as they are the main users. However, collaborators are often considered “outsiders,” and tend to experience no access or very limited access to facilities and equipment. If outsiders request access to a community that they do not belong to, they may be subject to an extended waiting period before receiving access as approval would require agreements between departments, organizations, or institutions and irregular or atypical documents would need to be processed, slowing down administrative operations. If the communication chain fails among supervisors, technicians, and other staff members such as administrators, managers and accountants who do not have direct relation to the collaboration, the request is often declined or forgotten. Even if the collaborators could get access to the necessary facilities, they could be denied the use of certain equipment or charged extremely high service fees that indirectly prohibit the use of equipment. To become a community member, in many cases, the outsiders are required to be affiliated with the institution (at a university, they need to become a student, professor, research assistant, or technician), which can be difficult to overcome as a collaborator who only temporarily has connection with the institution.

3.2.2 Regulation/safety

There are materials and equipment that require special knowledge and specific training for use and operation in both design and science communities. If collaborators who do not have appropriate training try to use the equipment, there is a high risk of serious injuries to themselves and other people who use the same facility. Without training, they could also damage the equipment. Therefore, collaborators would not be permitted to use or access this equipment without the original community members' help. Since tools/equipment and community members are often protected by insurance however collaborators are not, this can be another reason that collaborators cannot gain access to the facilities. Even if the collaborators have previous training to operate equipment, if the community does not recognize their previous training or experience, collaborators will not get access to the facility. As the knowledge and training to operate equipment appropriately are often provided by a community for the community, this issue has a deep connection with the community access challenge.

3.2.3 Funding and resources

Because of the limited access to resources (facilities, equipment, tools, and time) due to community access and regulation barriers, there are many situations in which certain tasks need to be completed by a specific team member in a collaboration who has proven (and validated/accepted) skills and training. When the collaboration team faces this situation, they need to consider if the amount of work and operation time are fair to the member. Further, if the collaboration work gets in the way of the community, the collaboration team may need to reconsider their operation style to respect the original community members. In addition, costs related to the collaboration should be discussed as some tasks would require purchasing extra materials or paying additional access fees to other facilities. Time needed to accomplish the task and travel to get to the facility should not be discounted as it takes up the space for them to work on their original tasks. Funding sources must be found and an agreement on how to allocate the funding to each task needs to be agreed upon between related departments/community members/institutions/organizations before proceeding. If this process is skipped or not seriously considered, the collaboration can turn into exploitation and can result in the failure of the current collaboration or rejection of future collaboration.

3.2.4 Confidentiality

Confidentiality plays an important role in collaborative research, and it can be applied for both design and science research. However, based on my experiences, scientists seem to distinguish the boundaries between their research and actively draw a clear line so as not to infringe on the research of others. In contrast, the very nature of designers encourages them to be creative by not distinguishing boundaries. Thus, designers are unfamiliar with the concept of confidentiality in the same sense as scientists. Confidentiality in science does not necessarily only apply to specific numbers or parameters. It can apply to an idea, process, or production of a tool for specific experiments, applications, etc. The comfort level of an individual scientist to talk about their ongoing research depends on their relationship with their collaborators, research culture background, personality, topics, type of research (whether the aim is publishing paper in academia or product development for private companies), sponsors, and the timing of the publication (academia) or patent (business). If the scientist works for a company, their study most likely includes patents or proprietary information so they will not be able to share any details with the public. If a scientist works on academic papers, the timing of the collaboration that is meaningful is before publication; however, they would not always feel comfortable to share their research due to insecurity about sharing confidential information and new/novel ideas. It is safe for the scientist to share their study if it is after publication, but they would likely have moved on to new topics and therefore cannot easily justify the time to explore the topic that is already "completed" (published).

3.3 Observations about environmental/condition challenges in relation to literature

Once the environmental/condition challenges were defined, the relevant discussion points in literature became clearer and challenging points were identified.

Henningson et al. (2010)'s point of not having the "right" access such as personal access to key resources critical for the project's success is highly related to the multiple environmental limitations that were discussed. For instance, if a researcher is only allowed to have access to equipment/facilities during a certain study term and they cannot use it after that, it will become an environmental/condition challenge unless the project timeline exactly aligns with the researcher's study term. If the researcher's status changes – i.e. they graduate and their status goes from "student" to "staff," sometimes the access fee will become expensive or access itself will be declined as they are no longer covered by the same insurance plan as in their previous role. In AR, it is important to be able to "try and see" if ideas work as a part of the learning process and sharing the experience with collaborators. However, if the access fee to the equipment/facility/service becomes too expensive, the experiment/prototype development will be automatically limited since it is difficult to justify the importance of those small trials with a limited budget. Speaking from personal experience, I gave up using certain equipment in my research as the user fee increased approximately twentyfold when my role changed even though I was still considered part of the research group. Both designers and scientists have special equipment/facilities they need to use for their research; therefore, this issue is relevant for both disciplines.

Emmens, an interdisciplinary researcher, states that "sometimes there may be legal reasons holding us back—perhaps we've been required to sign nondisclosure agreements or confidentiality clauses" (2016, P52). Her point was from a social capital point of view; however, this point is linked to “confidentiality” in this research. If the project is related to commercialization, confidential information will become even more sensitive in science, and some researchers will ask external collaborators to sign a nondisclosure agreement. In turn, designers would also ask collaborators to limit showing the mechanism or ideas for prototypes if they are related to product development for certain companies. Depending on the organization’s policy, the knowledge/invention may belong to the organization rather than individual researchers; this could lead to policy-related challenges for external collaborators.

These environmental and condition-related issues cannot be solved by the efforts or ingenuity of individual researchers, but rather require coordination with organizational structures for the use of facilities, resources, safety, and policies. Therefore, if designers and scientists cannot imagine what role they want to play and how they want to invite collaborators into their research while recognizing all the environmental and conditional factors, they will be limiting their own research. This means they would need a clear plan for how they want to work together, including ideas to overcome all four elements of environmental/condition challenges. There may be some projects where it is difficult to plan everything in advance. In such cases, the collaboration team needs to be aware of how the environmental/conditional limitations will affect their projects. If the collaboration team is unable to adequately prepare the right environment for their proposed research, they need to shift direction of the research and think about what kind of project they can propose within the constraints. To make meaningful plans in both design and science, designers and scientists need to understand how the other discipline works, values, and approaches a topic. The next chapter will examine interpersonal relationships between designers and scientists, including differences and similarities in their values, what they expect of other disciplines, and differences in approaches, which may help in developing a plan for collaborations.

Takeaways from environmental/condition aspect:

- Both designers and scientists need: (1) Materials, (2) Knowledge and skills, (3) Tools/equipment, and (4) Facility in order to fulfill their duties.
- There are four factors which prevent sharing environments with collaborators being identified: (1) community access, (2) regulation/safety, (3) funding and resources, and (4) confidentiality.
- Environmental/condition challenges will limit the activities in collaborations.
- In order to overcome the environmental/condition limitation, clear plans which reflect the process towards the common goals with collaborators are necessary.

4. Interpersonal/social aspect

4.1 Reciprocity

In order to overcome the environmental/condition limitations, it is important to set a common goal and make plans ahead of time so that both designers and scientists can predict what will happen in the collaboration and prepare for it. Defining a common goal is also crucial as it is the core reason for collaboration, and many researchers have expressed its importance (Emmens, 2016; Otto & Oesterle, 2012; Avital et al., 2006; Moirano et al., 2020). However, setting a common goal which fully reflects the demands from both designers and scientists is fairly complicated because scientists (researchers) and designers (practitioners) have different interests in general (Mathiassen, 2002). Even so, if they compromise and reach a false consensus or try to avoid conflicts because it is difficult to set the goal, they will lose the trust of their collaborators and research will not go well (Emmens, 2016, P17). I stress the importance of "reciprocity" as an essential requirement for considering this issue.

Reciprocity is a fundamental concept in any collaboration. In fact, reciprocity has been actively discussed in business theories under the topic of "organizational justice" when they explore the ways of improving teamwork and encouraging collaborations (McGregor, 2006; Schmitz, 2020). This theory is applicable to this thesis as DSR's goal is also mutual success – generating scientific knowledge while simultaneously creating practical utility (Otto & Oesterle, 2012). Looking for mutual success in collaborations sounds obvious from an ethical point of view; however, when looking back at my past four years of working and helping collaboration between UBC and ECUAD, I found that, in some instances, it can be difficult for people to put these ideas into practice in the real world. This was because both designers and scientists, constrained by conceptual limitations embedded in their own disciplines, could not fully imagine what would benefit the other field. Therefore, when a designer proposes a DSR project, design and science are not researched on an equal footing; instead, the structure tends to be one in which science is included as part of the design research. On the other hand, when a scientist takes the lead, the research goals and process tend to be more focused on scientific criteria. In addition, reciprocity seems to be overlooked in academic contexts because it is hidden behind the larger mission of "developing sustainable materials."

The reason reciprocity needs to be kept in mind is that otherwise, the collaboration can turn into an "exploitation" of knowledge and labour where one side will unilaterally lose out. This exploitation can occur due to a lack of understanding of the differences in values, methods, and approaches of one's collaborators' work, even if there is no malicious intent. In my position working on the border of two disciplines, I often witness this unconscious exploitation from each side.

I would like to emphasize how important reciprocity is and would like all designers and scientists to think about systems to acknowledge their collaborators' contribution and avoid unconscious exploitation. I hope my analysis will help all scientists and designers respect their collaborators properly.

4.2 Comparing and contrasting interpersonal/social aspects

In this section, the influence of interpersonal/social aspects on collaboration will be discussed. The ultimate aim of this section is to develop an understanding of the differences and similarities between designers and scientists so they can perform collaborations respectfully and work together towards mutual goals. I will unpack this topic by dividing sections into the values, goals, and approaches of each discipline, the strengths and expectations of collaborators, what fosters positive collaboration, and challenges.

I interviewed 24 people (12 from each field) at different stages in their careers: students, staff, managers and professors. This was done to understand how each career stage influences the goals and values held, in addition to the general trends specific to each discipline. To preserve anonymity, associate professors, professors and project managers are categorized as "manager", master's and PhD students as "graduate student", and undergraduate students as "student." The interviewees invited to participate consisted of people with past experiences working at the interface of science and design, people who are interested in design and science collaboration, and people who have both backgrounds. The interview data was coded using thematic analysis methods (Maguire & Delahunt, 2017) and trends of designers and scientists were analyzed. The list of question is shown in Appendix A, and the details of the interview process are summarized in Appendix B.

4.2.1 Values

To understand the values of each discipline, I asked each interviewee to describe what is important to them in their design practice (for designers) or experimentation (for scientists) using five keywords. Words that were heard multiple times are bold, scientists' choices are in blue, designers' choices are in pink, and overlapping words are in purple. Additionally, keywords that are considered science-specific values are placed on the left, and keywords that come from a more designer-oriented perspective are shown on the right (Figure 6).

Figure 6: Keywords from scientists and designers that represent the values in their work

"Innovative" and "novelty" were the most popular words that scientists emphasized as important parts of their research and they frequently appeared throughout the interview session. I noticed this trend and asked a science manager why this might be the case. They answered *"creating new knowledge with high novelty (=innovation) is the core of science. We do not want to repeat something that's already discovered" (science manager)*. The next most common answer was "reproducible or repeatable." This is the idea that results should be universal in order to claim it as genuine technology, not luck. "Practical, operatable, accessible" were brought up by multiple scientists and indicate that the technology is meant to be used. "Standard" implies the technology should be built based on knowledge and rules that have been developed previously. "Rigour, accuracy, and precision" are important assets to support the standardization that individual researchers care about.

On the other hand, the word most frequently repeated by the designers was "functionality." This means designers think their design outcome should be functional (not just for appearance) which aligns with the scientist's value that the technology should be practical. "Culture, history, positionality, community, care and intent" suggest that their designs are typically subjective and social. "Making and building" indicate that the action of making or creating is important to their practice. The designer who picked the keyword "making" explained their own design practice as *"making is thinking. I think about things through making" (Design student)*. "Speculative" was chosen by multiple designers, which suggested that designers' approaches are fluid and not always designing towards the defined goals. This contrasts the scientist's keyword "rational" which limits the ability for exploration and discovery through play if there is no theory or framework to back it up. However, the contradictory word "exploratory" was also chosen as an overlapping value, which in science can allow a broader flexibility in their working style. The keyword "testing" is the concept that functionality should be confirmed through testing, which connects with similar activities as scientific methods. An interesting overlap was "patience." Both designers and scientists describe that the research process is not always straightforward, things do not always work, results cannot be checked right away and therefore they need to be patient. The keywords of "connection, cross-pollination, interdisciplinary, and collaboration" demonstrate that both disciplines value different disciplines' contributions and are open to considering new perspectives or directions that come up during the process. Other areas where the values of both parties overlap include valuing playfulness (collaboration should be "exciting, fun, and joyful"), the commonality of "hand craft" as both disciplines work based on hands-on practices, and consideration for the environment.

4.2.2 Goals for collaborations

Many researchers who studied cross-disciplinary collaborations have expressed the importance of formulating common goals in collaboration. Defining a common goal is also important to overcome the limitations in the environmental/condition aspect since it helps us narrow down the type of resources needed (i.e. time, labour, materials, knowledge, equipment and facilities) discussed in an earlier chapter. This section will consider how designers and scientists see their goals. In this case, the goal considered here is not an ultimate goal such as "developing environmentally friendly materials," but an "attainable goal" that is readily actionable by individual members.

As part of the interviews, participants were asked "if you were to start a collaborative project between scientists and designers to create a sustainable material/product, what would be your tangible goals?" and provided examples*. I recorded the goals chosen by the participants and ranked them in order of popularity (Table 1). The most prominent goal among scientists was to publish, followed by creating a functional prototype and filing a patent. Commercialization and creating social impact are their ultimate goals, but they do not see those goals as tangible goals for each project, instead they pick an attainable goal such as filing a patent for the first step. In the designers' case, creating a functional prototype was chosen as a clear top goal. After the top choice, there was almost no difference in the votes between scientists and designers with most participants focusing on public exposure and engagement, *saying "I'd be happy if I could share my design outcome publicly in some way" (Design manager, Design student).* Since generating functional prototypes ranked highly for both disciplines and their interests, it would be a good candidate to set as a common goal for a collaboration.

*Tangible goal options: Publishing paper/book? Holding an exhibition? Joining conferences? Making functional prototypes? Using the prototype to add to your portfolio/resume? Doing workshop? Teaching in a class/sharing the skill with somebody? Making commercial products? Seeing the social impact of the product that you made?

Table 1: Tangible goals for scientists and designers

Scientist's goal	**Designer's goal**
1. Publication 2. Functional prototypes 3. Filing patents 4. Commercialization 5. Social impact	1. Functional prototypes 2. Publication 2. Workshop 2. Commercialization 2. Exhibition, conference,

At the same time, I also found several reasons why goals are difficult to define. 1. Interviewee's goals are not necessarily limited to one goal, and they can connect to other goals depending on the project and opportunities. 2. Some goals are defined by the project, and people are not in the position to choose them by themselves. 3. The design research process is not necessarily the type of research that proceeds toward a set goal. Sample responses from participants discussing how to define goals are as follows:

・*It depends on the type of project and funding source. If it's a governmental project, they expect us to publish a peer reviewed paper at the end. Personally, I would like to develop functional prototypes. I'm also interested in doing/joining workshops for networking purposes. (Science manager)*

・*Is this question intended to find my aspirations or realistic goals? If your question is about my aspirations, then I would like to see the social impact. If you are asking about a realistic goal, it is publishing papers. (Science manager)*

・*Any forms that let me share the outcome with public work for me, so any of doing an exhibition, attending conferences/symposiums, and workshops (demonstrations) fulfill my goals. Having a chapter of a book is rewarding. (Design manager)*

・*That's a good question. I haven't thought about it beyond making functional prototypes. (Design student)*

Although there are trends apparent for each discipline, it should be noted that how people define goals will also depend on their relationship with collaborators, and their level of understanding of other disciplines. This means that knowing each other before setting common goals is very important. Drawing from personal experience, one of my previous collaborators (a chemist) left me a warm comment related to this question:

"If I were to start a collaboration, with scientific point of view, I would choose a topic and working fields first. Write a proposal based on the research, come up with hypothesis, and develop action plans. But after working with you and experiencing collaboration with different disciplines, I would like to start from looking at each other and finding ways to involve everybody's work. It was very interesting to work with you and see your points."

This highlights the importance of getting to know each other in cross-disciplinary collaborations and how collaboration itself can generate new ways of topic discovery. It also shows that their interest in their work styles extended to being more open to and treating other disciplinary approaches with respect. When researchers get to this stage, *reciprocity* is considered more naturally in collaborations. However, looking back at past experiences I found that it is not easy to expect everyone to have this level of trust in collaborators and build a project from scratch. This is because there is a mismatch between what each party expects from their collaborators and how collaborators contribute to the project (strengths). In the next section, expectations and strengths will be analyzed.

4.2.3 Disciplinary strengths and expectations

What do designers and scientists see as their strengths in collaboration? What do they recognize as missing skills that can be supplemented by the other discipline? What do they expect from their collaborators? In this section, I will explore the different ways that designers and scientists understand their own disciplinary strengths and where they look for opportunities for collaboration. Sample strengths and expectations as defined by the interviewees are as follows (Table 2).

Table 2: Scientists' and designers' self-evaluation of strengths and expectations to the collaborators

The strengths that scientists recognize in themselves	**The strengths that designers recognize in themselves**
・*Giving technical support – improving material properties. (Science staff)* ・*Objective information – we study based on facts, so there is less bias to the information that we provide. (Science PhD student)* ・*Analysis – we know the methods of analysis and we have experience using the appropriate lab equipment to get the data. (Science master student, staff)* ・*Systematic approach, project design, giving structure/organization to the project. (science manager, master student, PhD student)*	・*Visualizing/sketching things – I can make concepts tangible. I can draw ideas out on a piece of paper. (Design student)* ・*Translation skills – things that you can "sense" (things that you can see, touch, smell, and experience) can be accessible to all people who have different backgrounds. Designers can make those. (Design staff)* ・*Facilitating conversation, organizing different perspectives, making space for collaborators to work. (Design student, Design manager)*
What scientists want from designers in a collaboration	**What designers want from scientists in a collaboration**
・*I can make uniform small samples, but I cannot make them look "cool." Designers can add meanings to shapes. (Science staff)* ・*Designers can understand the interaction between materials and people. Having effective ways to communicate our research is very important. It will also help bridge the gap with people from other disciplines if we work as a big team. (Science manager, staff)* ・*Having an object is a feeling! Designers can make prototypes that describe what the material means to people. It's powerful when we communicate with policy makers and funding agencies with prototypes. (Science manager)*	・*Technical knowledge is a big missing piece for designers. (Design student)* ・*Chemistry is hard in material development in design. I would like to get help for a rigorous approach. (Design student)* ・*Scientists understand things in detail – documenting all of their findings, listing all of the contributor/factors. Designers can learn from them and reflect it to our design practice. (Design student)*

Each discipline seems to understand their own strengths in detail, but is less versed in the specifics of the other's strengths. Scientists' perception of designers' strengths are visual representation (graphic design) and prototype development skills which can translate their laboratory research to physical and interactive representations (industrial design). However, design processes such as collecting information from different perspectives, ideation, prototyping, iteration, and testing with users did not come up when discussing how designers' skills could compliment science in the interviews. This implies that scientists may not have a clear understanding of what kinds of design processes there are and how much work there would be in visual representation and developing prototypes. On the other hand, designers' view scientists' strengths as mainly technical support. However, the definition of "technical support" was vague, and concrete types/methods of tests or analysis that would help designers were not clearly communicated throughout conversations. This implies that there is not enough understanding of scientific processes such as deep literature reviews, experimental design, processing materials, characterization and data analysis, similar to the scientists' lack of understanding of design processes. In addition to this point, DSR research revealed that practitioners (designers) tend to seek quick results at the expense of scientific rigor (Otto & Oesterle, 2012). The combination of these findings and the point from the literature raises a concern about the risk of a mismatch between expectations and realities.

Another interesting point is that both disciplines think that they are good at organizing and leading projects. However, as comments above indicate, their approaches are very different: science = systematic approach, vs. design = facilitating different perspective and creating organic structure. If one discipline leads the project in the way they are used to without considering the other, it would not be intuitively understood by the other discipline. Both disciplines are generally open to learning new methods/approaches however, and this point come up from time to time in the other sections of this thesis as well. While both scientists and designers are capable of adapting to unfamiliar approaches, it would be beneficial to know from the beginning how each discipline wants to approach collaboration and the project specifics. In the next section, the preferred approaches of each discipline will be discussed.

4.2.4 Approaches to cross-disciplinary collaboration

In order to better understand members of each discipline's preferred approach to collaboration, participants were asked about activities and behaviours that can foster positive collaboration, as well as actions and behaviours that hinder collaboration. The majority of the suggestions received from the interviewees were general behaviours that can encourage positive collaboration (i.e. "soft skills") and are not necessarily limited or linked to the topic of sustainable material development. There are four main points: 1. define goals and structure 2. know each other well 3. active communication 4. be nice. Sample comments are as follows.

1. Define limits and structure

・*A challenge-centered approach should be encouraged for collaborations. Once goals are clearly defined, people can find their role, proactively communicate and offer help to each other to solve common challenges. (Science manager)*

・*Clarify expectations of each member's contribution. If there are limits, be honest about them so I can respect the boundary. (Science student)*

・*Be respectful to the limit each member has, and do not punish them about not being able to share something. (Design manager)*

2. Know each other well

・*Actually get to know each other. In a big collaboration, we would have a collective goal as a team, but everybody has personal goal – it's important to understand those individual goals. (Design student)*

・*Be open-minded and bring down the barriers. We need to do team building activities. (Science manager)*

・*Go to a café together, and offer a cup of coffee. Be nice and get to know them outside of the context of the project. (Science graduate student)*

3. Active communication

・*Open communication. Having a general culture of being ok to come up to co-workers/collaborators and ask about basically anything! (Design, student)*

・*Try to communicate with language that both disciplines know. (Science, graduate student)*

・*Be honest with both good things and bad things. Be open to communication. (Design student)*

4. Be nice

・*Be nice as a person. Nobody wants to collaborate with you if you are not nice. (Design graduate student)*

• *I would hope everybody would be nice and respectful. (Science graduate student)*

• *Be receptive to feedback. Take it as a learning opportunity rather than a personal attack. (Science manager)*

4.3 Challenges

Based on the interview data and discussions of differences in values, approaches, strengths and expectation, the challenges involved in cross-disciplinary collaboration are analyzed below.

4.3.1 Difference in physical scale

Through my experience working in a laboratory, I have observed the difference in physical scale between science and industrial design, which can influence the approach for collaboration. In particular, if both designers' and scientists' goals are to make functional prototypes, this scale difference could make the collaboration difficult. The scale in science is very small; typically, samples that fit in the palm of your hand or are smaller. In contrast, industrial designers develop prototypes in a variety of scales, ranging from a small wallet to a panel taller than their height (Figure 7). If a scientist is working at the "bench scale*" stage, they are limited to smaller prototypes because they are still in the process of optimizing a new technique (often developed from scratch). As they need to test multiple parameters and different methods, the equipment to produce new materials is designed for small scale to minimize the loss of resources. Additionally, material behaviours often change when scaled up, so it is very hard to create the amount or size that designers seek from a lab operation. If designers hope to be involved at this stage of the research (bench scale), they need to think of what can be done within the size limitation and need to consider how much time it will take, how much work it can be for the scientist to develop the amount of the sample the designers request, and how much it would cost before proposing prototypes. If designers would like to develop prototypes at larger scale, the next level of the research stage (pilot scale*) where scientists start to explore manufacturing methods would be more suitable. If designers cannot get enough materials for their design, it means "material" (one of four elements that we discussed at the section 3.1 Environment and conditions for a collaboration) is missing, which limits their design activities. If designers ask scientists to produce a large amount of material without knowing their capacity and difficulties, they will risk extracting "resource" from scientists as discussed in 3.2.3 Funding and resources. Thus, it is important to understand the right scale that works for both disciplines. To understand the difference in scale, I have included photos of design products/science samples provided by the interviewees and my experiences in Figure 7.

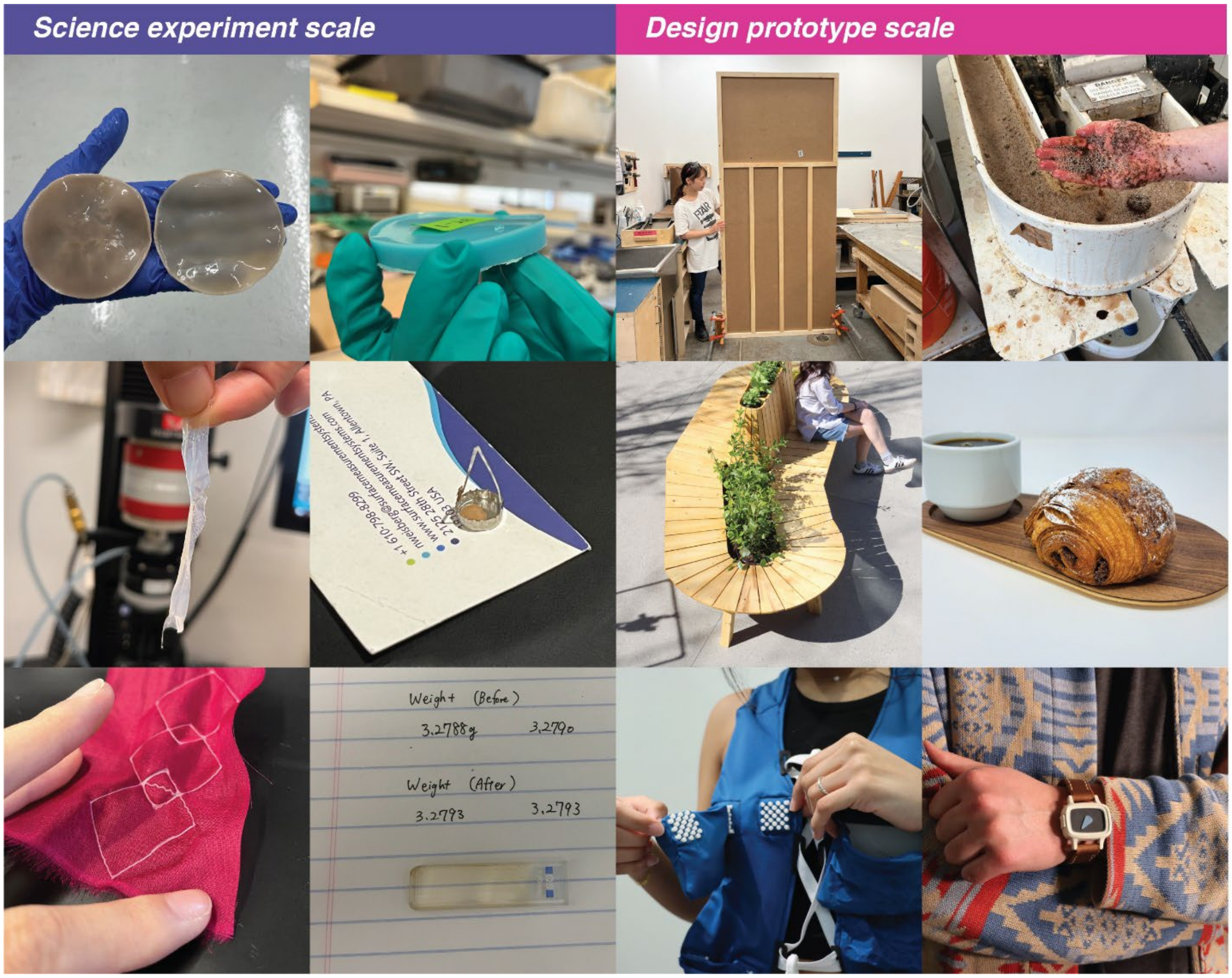

Figure 7: Scale difference in samples design prototypes/outcome provided by the interviewees and my samples, scientists and designers

*Bench scale, pilot scale

There is a business theory called the “Stage Gate Process” (*Stage-Gate Innovation Management Guidelines*, 2007) (or “Phase Gate Process”) which discusses the analysis to derisk the commercialization process after inventing a technique in a lab. This theory can be applied to any inventions with material developments. The “lab scale (or bench scale)” is the first stage of this process; here the technology is defined and developed to evaluate if it has the capability of large production, and is (still) considered small scale. In order to assess the potential for large-scale production, scientists need to prepare techniques for pilot scale, which is considered middle scale. When the technology is ready for pilot scale, scientists can start producing the materials in semi-large scales which can align with industrial designers’ design practice scale. If the technology passes the requirements for pilot scale, the stage will move forwards to full manufacturing scale. The definition of each stage and gate are shown in Table 3.

Table 3: Stage gate criteria: summary of the requirements to move to the next stage of the material development (*Stage-Gate Innovation Management Guidelines*, 2007)

Stage	Gate
1. *Preliminary Investigation and Analysis*: Scoping studies to identify research topics; technical and market assessments; idea generation.	1. *Research Project Selection*
2. *Concept Definition*: Early stage research to explore and define technical concept or to answer a specific technical question; laboratory scale research.	2. *Research Approval*
3. *Concept Development*: Development and testing of prototype technology or process; development of models and informational databases; predictive modeling or simulation of process or equipment performance; evaluation of system scalability and end-user acceptability; demonstration of concept feasibility at prototype or bench scale.	3. *Proof of Technical Feasibility*
4. *Technology Development and Verification*: Pilot scale development of technology or process; verification and documentation of technical performance and validation of economic potential in field test(s).	4. *Proof of Commercial Feasibility*
5. *Information Dissemination and Commercialization*: All activities necessary for information delivery and commercial launch (production scale technology manufacture and installation; development of market infrastructure; demonstrated commercial operation).	

4.3.2 Difference in time scale

・*I'm not sure if it's the case for all designers, but I felt designers' time scale is different from scientists. If designers hold off on the topic for a while after we agreed on a collaboration, the science part of the research will be outdated. (Science staff)*

・*We need to define a targeted goal, define the timeline, and define each member's responsibility. Check the progress and status from time-to-time. (Science staff)*

・*Even if it's an interesting topic, if my schedule doesn't fit, I don't feel I want to collaborate with anybody. It's simply not good timing. (Science graduate student)*

During the interviews, the difference in time scales was frequently brought up by scientists as along with how it influences their approach to collaboration. The reason time scales are important to scientists is likely due to how the nature of science research is a competition, and they need to conduct a large number of experiments to support their theories. For example, if a scientist needs to describe "durability" of the material that they develop in our lab, the main properties the scientist needs to look at are tensile performance, interaction with water, fire resistance, foldability, wear/tear, and biodegradability tests (depending on the type of the materials they develop, there would be different characterization methods that could be applied). Each test takes time to complete as they need to be repeated at least three times to make sure that the material is performing consistently. In addition, most of the tests require analysis after the data is gathered. Running these experiments requires preparing a large number of samples, which also takes time and energy. Due to personnel shortages, it is also common for projects with many parameters that need to be adjusted to hire student assistants. These time limitations can also influence the motivation for a collaboration and the capacity individual scientists have or make available. If collaboration does not proceed according to the agreed timeline due to inaction by one party, this can lead to frustration for the collaborator who worked hard to complete their task on time. The time scale discussion also connects to the environmental/condition aspect that was discussed in 3.2 Barriers preventing environment sharing. If the timing of the collaboration is misaligned – for example, if the plan of the collaboration gets delayed and planned collaborators graduate, engage in different projects, or leave the research group – these collaborators would no longer be able to join the research or gain limited access to facilities.

Avital cited “agility” as one of the principles that fosters positive cross-disciplinary collaboration and emphasized the necessity of continuous adjustment based on each stakeholder’s needs over time (2006). Designers and scientists need to discuss and coordinate in advance how they want to spend their time, and they also need to be flexible enough to adapt as the situation demands.

4.3.3 Conflicting approaches

- *I’m wondering if scientists feel designers are serious with the topic when we are ideating. (Design student)*

- *We talk about a lot of things that are not necessarily objective such as personal stories, cultures, histories and positionality. This could look like designers are not addressing the implication of each research. (Design manager)*

- *Speculative design can be frustrating for scientists because “anything can be possible.” It means that there is no constraint therefore it’s hard to approach to problems. The designers’ behaviours can be taken as “ignoring the scientific problems” or “dismissing.” It could give the impression of “you are not listening to me” to scientists. (Design student)*

Multiple scientists expressed their preferred approach: checking progress and revising the plan accordingly to accomplish the defined goals on time. Since scientists tend to prefer clearly defined timelines, roles and ways of working, it is not hard to imagine that designers’ fluid approaches might not align with their preference. Particularly, speculative design approach would be difficult for them to understand, as the design student mentioned above aims to stimulate participants’ thinking rather than moving towards a defined goal. Speaking from experience, some scientists who joined the process of speculative design in the past asked me *"what are they trying to design? We only have three months for this project, and they seemed to be far behind." (Science graduate student)*

To explore how other scientists feel about uncertain goals, I asked one of the interviewees who showed their preference in well-organized structure but are open minded: "if I'm interested in collaborating with you, but I don't have a clear idea of a project, what do you think?" I asked this question because I felt the majority of designers from the interviews didn't necessarily have a clear science topic in their heads to start a collaboration and preferred finding it organically through the process of collaboration. This is in conflict with how scientists typically approach projects, which is supported by the interviewee's response to my question; *"well, if you don't have an idea, you shouldn't collaborate. It means "now" is not the right time to start collaborating. Let's wait until we know how to approach it." (Science graduate student)*

4.3.4 Varied goals: patents and publications

- *My goal is to share the knowledge with the academic community to help each other learn. If your goal is filing a patent to start a company and make money out of it, it doesn't align with mine. Even if the topics overlap, it's better to work separatory if that's the case. (Science graduate student)*

- *My goal is to hold as many patents as possible before I finish my PhD. Thinking about job opportunities after my graduation, I think companies tend to evaluate patents more than the number of publications these days. (Science graduate student)*

Whether or not to publish research results or apply for a patent depends not only on if a material can be commercialized, but also on the individual's career plans and policies. It also depends on whether the organization is enthusiastic or reluctant in filing patent applications as the application fee is expensive.

Among the designers interviewed, some were motivated to develop products, while others were more interested in sharing knowledge with the community. The scientists' interests were also varied. It is important to keep in mind that if there is a difference in the essential goals between potential collaborators, it may be better not to proceed with the collaboration or have discussions beforehand to see if they can develop a common goal.

4.3.5 Confidentiality

・One of my friends is an engineer and they are working on a project related to a military service. They looked uncomfortable when they were asked to describe their projects to people outside of their team. I imagine it would be uncomfortable for scientists to be asked to share information that includes confidentiality with people who haven't committed to be in the team, like a visitor, even if it's not for military service. (Design student)

Confidentiality was discussed in the previous section (3.2.4 Confidentiality) in the context of how it could limit the range of the collaboration in the form of an environmental/condition aspect. Confidentiality can also influence each researcher's behaviour, feelings, and the kind of information they are comfortable sharing.

The level of confidentiality required would be determined by a combination of the research stage, research type, individuals' goals or personalities, timing of publication/patent, and relationships with sponsors. If we want to appropriately understand the level of confidentiality, the only way to do so is through discussions with the other collaborators and team members who are involved. Some colleagues in my lab have said*, "don't let anyone outside come near my desk in the lab."* In contrast, others have said, *"people in other fields won't understand the depth of my research, and even if they do, they won't be able to finish their research and publish a paper faster than me, so it's okay to share it."* In addition, depending on the project, even researchers within the same lab who are generally open to collaborating may refrain from sharing information to avoid potential conflict. As an example, I will introduce a case study from my autoethnographic approach related to highly confidential situations that designers may encounter below.

One of the projects I am involved with at UBC BioProducts Institute is related to commercialization, and at the time of writing, we are in the process of applying for a patent. It was small in scale when I first joined the team, and my mission was only to make a simple prototype. However, through making prototypes and explaining what the material could be used for, the work eventually gained attention and as a result a serious focus on research with the end goal of product development began.

The basic strategy of patent applications is to define the developed technology as broadly as possible and secure advantageous business opportunities while preventing others from exploiting it. Therefore, confidential information includes not only chemicals, parameters, or manufacturing methods, but also the abstract concept of "making product A using material B." This means that it is difficult to explain what kind of project I am involved in to people outside of the project until the patent application process has passed a certain stage. If confidential information is leaked and copied by someone else in any form, it will be difficult to apply for a patent, and business opportunities will be significantly reduced. This will cause trouble for team members, universities, external collaborators, and sponsors.

Making prototypes that help develop a sustainable society through collaboration is something most of the designers interviewed are passionate about, and it is also what many scientists want from working with designers. In addition, scientists describe the advantage of designers' involvement as how designers can share difficult scientific knowledge with the public and attract investors to promote the research results to the next step. However, if designers share their design work in the wrong context, there is a higher chance of serious confidentiality concerns developing. I have observed that designers seem to be less aware of the type of confidentiality and how sensitive they are in each project than scientists, due to differences in training, unless they have experience in projects that have a more rigorous focus on confidentiality. Designers working at the interface of science and design need to understand the meaning and importance of this confidentiality and the weight of the responsibility it carries. Along with this understanding, open and transparent communication between all collaborators is essential. In the next chapter, I will analyze how we can avoid the risk of revealing confidential information and what makes people who hold confidential information want to share their knowledge.

Takeaways from interpersonal/social aspect

- Creating functional prototypes is a common interest for both designers and scientists.
- There are multiple goals for individual designers and scientists to pursue, and their goals can change depending on the relationship with their collaborators plus their past experiences.
- Knowing each other (values, personal goals, approaches) is important to set a common goal.
- The different scales in time and practices between designers and scientists can create challenges in collaborative processes and outcomes.
- Scientists have strong preferences in defining a structure before the project starts while designers want to build it through collaborations.
- The level of confidentiality can change based on the status of the research, and it influences the motivation for collaboration as well as environmental/condition limitations.

5. The foundation of collaborations, “trust”

5.1 The importance of trust

During the discussion of preferable approaches, both designers and scientists expressed the importance of active communication, sharing knowledge and skills, and being open minded. However, I question whether these are immediately achievable from the start of a collaboration with the risks around confidentiality and appropriation surrounding collaborative projects, as discussed in previous chapters. How important trust is in collaboration and teamwork is actively discussed in business and psychology (Dirks, 1999; Simons & Peterson, 2000; Jarvenpaa & Leidner, 2006).

In sociology and business, two types of trust are defined: “cognitive trust” and “affective trust.” Cognitive trust is a customer’s belief and trust in the ability and reliability of a service provider (Moorman et al., 1992; Rempel et al., 1985) – in other words, trust based on demonstrated or communicated ability. Knowledge accumulation is crucial to support cognitive trust, and it will form a reputation (Johnson & Grayson, 2005). In this research, interviewees defined “knowledge” as how to process the collaborations, individual design/science skills, and abilities to complete their tasks. Therefore, if they effectively communicate those points, they can earn the cognitive trust of their collaborators.

Affective trust is the trust one has in another, based on emotion and resulting from the level of care and concern shown by the other (Rempel et al., 1985; Webber, 2008). It is a form of trust based on emotions and a sense of security that comes from individual experiences (Johnson & Grayson, 2005). Reflecting on the interviewees’ responses, this type of trust would be encouraged by “knowing” and connecting with their collaborators as shown in Table 3. “Be nice, know each other well” – the suggestion from interviewees to promote positive collaboration which was discussed at 4.2.4 can be also described by the concrete actions to earn affective trust. Reviewing the interviewee’s comments, affective trust is the key to bring people to a state of “want to share knowledge,” especially in science.

During the series of interviews, I asked interviewees how important trust is for their collaborations and analyzed the type of trust they value. The comments related to trust are categorized in Table 3. Both types of trust are equally important in collaborations, and the interviews highlight that being able to trust collaborators is generally the foundation for starting a collaboration. Practically the only cases where a personal trusting relationship is not necessary are strictly defined projects where end goals have been broken down into smaller tasks ahead of time and individual members’ roles are clearly defined. In contrast, in the case of AR of DSR discussed above, in which processes or roles are not precisely defined, the collaboration will not work well in the absence of trust since participants would not feel comfortable sharing process and knowledge with their collaborators.

Table 3: The type of trusts and comments related to "trust" from interviewees

Cognitive trust	**Affective trust**
• *In the case of collaboration where tasks are subdivided and clear, personal trust is not necessary from the beginning on an individual basis, but collaboration will not develop in the first place unless there is at least a minimum level of trust from the organization. (Science graduate student)* • *Trust is linked to expectation. I want to trust people that they have skills to accomplish their part in their roles in a collaboration. (Science graduate student)* • *Trust is a confidence of actions. We need to trust that the collaborators are progressing, moving forward with the project agreement. (Design manager)* • *We need to trust the process and collaborators. Even if the collaborators have a hard time, we need to believe that they will get to the goal. (Design student)* • *If you cannot trust the person, you cannot work with them. Respect the idea, boundary, the portion of the work they agreed to do to keep the trust. (Design student)* • *I don't feel comfortable if designers start doing the science portion of the research in collaboration. It's my area of research – if people who are not trained for it can do better science research than me, what is the meaning of my background? (Science, graduate student)* • *If you cannot trust the person, you cannot work with them. Respect the idea, boundary, the portion of the work they agreed to do to keep the trust. (Design student)*	• *Trust is important. If there is no trust, people will not actively spend time on the project and will not try to share information. (Science manager)* • *I have experience being put in a collaboration and joining a collaboration voluntarily. If I know the other party and can trust them, I feel more like "I want to help them." (Science staff)* • *If there is no trust, nothing will move forward. People are reluctant to share their knowledge. If they hid information, I would feel they do not trust me and it doesn't make me want to collaborate. (Science staff)* • *Trust is a foundation for collaboration. I know you won't randomly share my research with others so I can share my research with you. (Science staff)* • *Trust is very important. What is your role? What information do you need? What should I share with you? If I don't know them, I cannot rely on them. (Design student)*

5.2 Trust and boundary objects

When people from different disciplines collaborate, there is often discussion about "boundary objects." Boundary objects were outlined by Star and Griesemer in the context of how amateur collectors and professional biologists contributed to the exhibition at the Berkeley Art Museum with different perspectives and approaches (1989). As a concrete example of a boundary object, they shared an observation of how amateurs and professionals created a collection map. The amateur collectors' way of making the collection map was similar to a general road map – emphasis on landmarks such as the campsite, trails, and collection points, yet professional biologists' way of creating a map focused on abstract ecologically based shaded areas representing the ecological concept of "life zones" (1989, P404). As in the above example, boundary objects are the embodiment of differences in thinking that arise from different contexts. In this example, they seemed to create what appeared to be the same thing – "a map," but with different meanings. Ulrich adapted the boundary objects into a systematic way of thinking and described that boundary objects were "boundary judgments" which were strongly connected to empirical observations (fact-based judgments) and normative evaluations (value-based judgments) in systematic triangulation (2003).This model suggests that our training as designers or scientists can encourage specific ways of observation and create discipline-dependent values, which lead to particular judgements based on the discipline. In addition, Ulrich proposed that boundary assumptions that are specific to the concerns of certain stakeholders may exclude or not fully consider the concerns of other stakeholders (2003). These concerns imply that designers and scientists could take an action which could be beneficial for only one of them or could not consider others because of the boundary objects/judgments.

Considering that trust is the foundation of collaboration, paying attention to individuals' boundary objects and respecting the collaborators' boundaries are strongly recommended. In the next section, we consider actions that inhibit collaboration, which in most of the examples seem to be caused by mismanagement of boundary objects (i.e. 5.3.1 to 5.3.5). In collaboration, we need also be careful with what kind of "boundary objects" our training creates, and how this can be seen by other disciplines.

5.3 Actions that inhibit collaboration

Trust is the foundation of collaboration; however, breakdowns in relationships of trust occur more frequently than we would expect (Elangovan & Shapiro, 1998; Kim et al., 2009; Reina & Reina, 2000; Robinson & Bennett, 1995). Psychology dictates that, although it varies from person to person, recognizing and experiencing trust-destroying behaviours makes us more likely to notice signs of trust-destroying behaviours in the future and more likely to lose trust in response to those behaviours (Fulmer & Gelfand, 2013). There are a number of ways that trust can be broken, but they often involve dishonesty, deception, or treachery, and are perceived as betrayal when there is any action that could potentially bring harm to the trustor (Elangovan &

Shapiro, 1998). Even if their behaviours are unintentional (due to the result of boundary judgement) they can undermine trust, which can unwittingly make future collaboration more difficult. Based on the interview responses, I categorized behaviours that require caution, in the following sections:

5.3.1 Cultural extraction/profiteering

・*I haven't had the experience of facing such a bad experience in the past fortunately, but if somebody doesn't try to understand stories and cultural perspectives, I wouldn't feel I want to work with them. (Design student)*

・*Some collaborators go against of my core value. I designed something not for profit but for a community, however, they tried to make money out of it. (Design graduate student)*

・*There would be material research which has a cultural impact that requires special care. It is better to establish a safety net or protocol to avoid unintended offence before we start the collaboration. (Design manager)*

In the past, I worked with a colleague on applying traditional craft techniques and philosophies to science for developing sustainable materials. We had deep discussions about "how to apply the knowledge from traditional craft to science in an ethical way" since it is easy to get into the situation of taking the knowledge and not returning any value by consequence of working in different fields. As we learned from the analysis of values in the previous section, designers tend to regard their own experiences and cultural connections to the topic as important; however, this is less common for scientists. Designers would feel uncomfortable and possibly disrespected if their work is not properly understood in scientific contexts and is adapted inappropriately. Past examples of this that I am personally aware of included: only ideas being adopted without acknowledging cultural contexts, designers not being properly credited for their ideas, original ideas taken and used as a jumping-off point for separate/unrelated collaborations, and systems that were designed to support communities suggested to be used for business.

5.3.2 IP appropriation

・*Designers have a different understanding of intellectual property and some of them claim other people's work as their own work. I would name it "IP appropriation." (Science manager)*

When asked what they have found unpleasant in previous collaborative experiences, one of the interviewees, a scientist who has worked with designers in the past, responded with the quote above. Developing and proving theories takes a long time in science research. A seemingly simple conclusion can be the result of five years of PhD study. I have seen firsthand how challenging it is for scientists to develop new materials and how hard it is to convey their efforts because their published papers/patents only carry the objective result. As this qualitative research aspect is invisible to external collaborators, they cannot gauge how much time it took to generate the knowledge/material, or the effort was involved in reaching the conclusion. In addition, the technical terms and theories in science can act as a barrier to understanding the meaning of the scientific research, which is difficult for designers to grasp, which may lead to them in turn not understanding the level of effort involved. If designers misinterpret the inherent value of the information shared by science collaborators and incorporate it into their design work without proper credit or discussion, it will be recognized as "appropriation at a minimum." Regardless of whether it was intentional or not, this creates a huge rift in collaboration.

5.3.3 Exploitation

- *I feel uncomfortable if the collaboration becomes getting something from you, rather than true collaboration. (Design student)*

- *When people demand from others, it's unfair and unethical. (Science manager)*

- *I don't feel good when they treat my contribution to the project as service that I need to do for them. (Science graduate student)*

- *I proposed a project to a collaborator. They took my idea and started doing other collaborations with the topic but with more famous professors. They took my place! I didn't feel their behavior was respectful. (Science staff)*

- *I don't like when people are being extractive, and not offering giving back. I don't always expect something back, but we need mutual respect. (Design graduate student)*

The exploitation of knowledge, skills, and ideas is one of the key situations where people feel extremely uncomfortable, regardless of their field. In my experience working in cross-disciplinary collaboration, exploitative situations typically occur when the demands from scientists or designers results in one-way benefits. As an example, we can consider when designers need support related to chemical knowledge as a part of material exploration and ask for help from a chemist. The study was not originally designed to support the chemist's research, so the chemist does not directly benefit in the process of helping the designer. In this case, unless the designer actively seeks out and offers something that will benefit the chemist, this could become exploitative. The same is true in reverse. Collaborations that invite one to the other's research should consider what the benefit is for the collaborator, and whether what they think is "beneficial for the collaborator" is in fact what the collaborator wants and not an assumption by the initiator. Especially in the case of a collaboration where there is no direct benefit for one collaborator, it is important for the initiator to consider how to properly credit the collaborator and show gratitude. This aspect is closely linked with the discussion of 5.3.1 Cultural extraction/profiteering and 5.3.2 IP appropriation.

5.3.4 Devaluing

- *I don't appreciate when people are dismissive of the work you bring. It is devaluing the project, devaluing the collaborators. (Design graduate student)*

- *There are time components as well, but if I see complete refusal of other perspectives and values, it would be a deal breaker to me. (Design student)*

- *Disrespectful attitude such as being dismissive, insulting the work, being disinterested in the process. (Design student)*

- *I feel uncomfortable when people don't think you did enough good work. When they don't value my work. (Science graduate student)*

Most people would not intentionally belittle someone's work. However, problems arise from unconscious belittlement that results from not understanding the other discipline's process and one's own preconceptions.

The risks associated with these factors were discussed earlier in this thesis. In brief, not knowing the process means not knowing the true value of the scientists' or designers' work since they are not aware of the sheer time, efforts, cost, and resources behind the work. The preconceived notions I've observed in design/science communities are typically in line with "something that 'looks simple' must have been easy to make," "anyone can come up with such an idea," "what I asked for is a small sample, so it shouldn't take much time," or "this is how designers/scientists work."

If designers/scientists arbitrarily determine the value of their collaborators' work without understanding it, they are devaluing it to the other person even if they do not intend to. In response to the preconceptions discussed above, the designers and scientists interviewed replied *"simple things are harder to make. There are so many thoughts (put) into it!" (Design graduate student)* and *"It's indeed a small sample, but do you know how much trial and error it took to make this one sample?" (Science staff)*

When I helped with a collaboration-based design class some time ago, a design student looked dissatisfied with the sample a scientist handed them, saying, *"I can't do anything with this small sample."* The sample was the result of the scientist arriving early in the morning and working late to prepare samples for the design students to help them understand the latest research, but this was not considered by the student (i.e. they did not know the process). All designers and scientists have to be extremely careful, as even a casual remark can hurt their collaborators.

5.3.5 Taking credit

- *My deal breaker is when somebody steals the credit and lies to others. The person who heard about it will think that I didn't work. (Science staff)*

- *It is important to give credit to each other when you collaborate. If you cannot give or receive credit, you shouldn't collaborate. (Design graduate student)*

- *I don't want to work with people who want to succeed more than their collaborators. Show all the collaboration fingerprints, and give credit! (Design staff)*

Several participants across both disciplines stressed how important it is to give credit to collaborators properly. If the collaborators' work is not properly acknowledged in the collaborative process, their work in turn not recognized by the public. If the collaborators' contributions to the project are not acknowledged, this in turn affects future collaborations and their careers.

One of the designers who worked in a cross-disciplinary collaboration expressed the difficulties of receiving appropriate acknowledgement due to the different values other disciplines hold: *"sometimes, it's hard to get appropriate credit if the collaborators don't recognize the value of my work" (Design graduate student).* As not being aware of the real value of the work is linked to preconceived notions, the issue of not giving the credit can be the result of devaluing the work.

Cultural exploitation/profiteering is a problem caused by scientists being unable to accurately grasp the intentions and background of a design, while IP appropriation occurs when designers are unable to understand the efforts behind knowledge that scientists generate. Collaborating without understanding in this way is more likely to result in "exploitation," which the interviewees firmly pointed out as something that should not be done. Also, not understanding the actual value from either discipline's work can lead to unconscious "devaluation," which can lead to not giving appropriate "credit" to the other party. The root of this problem lies in "boundary objects" and not knowing one's collaborators. Those issues are connected like a chain. This result emphasizes the importance of understanding the differences in values and ways of working, as mentioned in the previous chapter.

5.3.6 Response to actions that inhibit collaboration

・*There have been some bad collaborations in the past, but I couldn't finish them halfway through. Thinking about it now, maybe it would have been better to break the deal. (Design graduate student)*

・*In reality, there aren't many collaborations that can be stopped halfway through. If I stop halfway through, I will leave a bad impression on the sponsor, so I think I will continue until the end of the project no matter how rude the other person is. I will remember the collaborator as a future reference, though. (Science graduate student)*

・*There aren't many projects that can be stopped halfway through because of responsibilities. For example, if the professor and the student don't get along, the professor cannot easily end the collaboration because they have an obligation to support the student's graduation. (Science manager)*

Although interviewees consider the actions discussed above to be deal breakers, they cannot stop collaboration out of consideration for a variety of reasons including sponsors, the responsibility of their position, and their other team members. However, interviewees unanimously answered, *"I will not collaborate with such people in the future."* This is a mechanism of the silent collapse of collaboration, which is the risk I shared in 1.1 Problem space. Some interviewees were designers and scientists who had experienced these actions, or unpleasant experiences that could have become deal-breakers, which influenced their approach to future collaborations. It goes without saying that not understanding the actions that inhibit collaboration is a significant risk.

In this section, I have discussed how "trust" within the interpersonal/social aspect affects collaboration and what we need to be careful about to maintain trust. Next, I will consider the idea of "degrees of collaboration." This will form a stepping stone to creating a framework by combining the environmental/condition and interpersonal/social aspects, and will reduce the risk of actions that inhibit collaborations.

Takeaways from “trust” in collaboration:

- If designers/scientists would like to try AR in DSR, “trust” is an essential component since it influences the collaborators’ motivation surrounding whether they want to share their skills/knowledge with their collaborators.
- There are two types of trust: “cognitive trust” and “affective trust” in sociology/psychology. Both types of trust are important for collaboration.
- Boundary object mismanagement will cause the corruption of trust in collaboration.
- Boundary object mismanagement is connected to actions that inhibit collaboration such as exploitation, devaluing, and taking credit.
- It is important to understand the true value of one’s collaborators’ contributions to avoid mismanagement of boundary objects.

6. Degrees of collaboration

I work in a lab alongside scientists. From an objective point of view, it would seem that I am in an environment where it is easy to initiate many collaborations. However, I found that it was difficult to propose a project that meets all of the conditions I have mentioned in this thesis. There is always something missing. It could be that there is not enough time, the timing is not right, the other party is not enthusiastic, there are not enough people to complete the task, the topic is not compatible with design, not having the right equipment – the list goes on. If it is difficult for a designer working in a lab to propose a collaboration that meets all of the conditions, it is easy to imagine that it is even more difficult to propose a collaboration from the outside the lab, not knowing the inside story. The environmental factors that support collaboration and those that hinder it, the similarities and differences in individual values, goals, and approaches, and the associated risks have been discussed in the previous sections. The risk of boundary objects also makes the collaboration harder.

In order to make collaborations more accessible, I will refer to Peralta and Moultrie’s “four levels of research engagement” (2010) and use the levels as an indicator of the difficulty in collaboration to discuss what kind of collaborations designers and scientists could engage in. Table 4 summarizes the degree of designers’ involvement in chemistry in a study on how industrial designers can contribute to science, as defined by Peralta and Moultrie.

Level 1 is the simplest type of collaboration in which roles are clearly defined and tasks are divided. As the level increases, the complexity of the collaboration, and the engagement to the research also increases. Level 4 is the most complex type of collaboration where academic boundaries are not determined.

Peralta and Moultrie proposed that the level of collaboration can be a response to the stage of scientific research in which industrial designers are first involved. Referring to Peralta and Moultrie's theory as a starting point, the elements of environmental/condition factors and interpersonal/social aspects will be added, and the mutual involvement of designers and scientists will be incorporated and considered.

Table 4: Peralta and Moultrie's four levels of research engagement model for designers and scientists

Level 1.	Research in which designers act as a "design suppliers" and in which the design tasks are determined by the research group. The design tasks are not directly related to the research questions and designers have no research membership.
Level 2.	Designers are members of the research group, but their tasks are associated specifically to team agreed "design" issues. Tasks are not directly related to the research questions.
Level 3.	Research in which the designers' activity is directly related to the research questions but the research agenda is set and lead by the scientists. Disciplinary roles are kept.
Level 4.	Research in which designers and scientists team up to define the research questions and to find its answers. Disciplinary roles are blurred, and activities are defined by research questions.

In level 1, the working areas are clearly divided, and tasks are determined from the beginning. It is the simplest form of collaboration. Since the working areas are separate, tasks can be completed without requiring the that deep personal trust from the beginning of the collaboration that was discussed in Section 5. The foundation of collaboration, "trust". As there is a minimal need to share information with each other, the risk to confidentiality, which is an environmental limitation and a challenge to trust, is the lowest. Since the goals, roles, and tasks are clear, it is easy to generate a schedule that works for both disciplines, and it is the collaboration method closest to the scientist's preferred approach introduced in Section 4.2.4 Approaches to cross-disciplinary collaboration. However, designers and scientists can feel it is limiting if they want to be involved in the process from the problem definition stage. In order to clearly define each task, deep insight into each other's areas and technologies, broad perspectives, accuracy in allocating work, and an understanding of the amount/value of work are required of the collaboration coordinator.

In level 2, the tasks are clearly defined, but there is more flexibility in how to approach them. The fact that collaborating participants have a choice of how to work means that there is more than a minimum level of cognitive trust between designers and scientists. However, as the flexibility of the approaches does not breach the boundaries between science and design, environmental constraints are still low, and the risk of confidentiality concerns is low. Additionally, clarifying tasks for both parties allows for accurately considering each party's contribution to the project and prevents mismanagement of boundary objects. Although it is difficult to intervene in the project's research questions, there is room to change the approach during the project, which can accommodate the designers' desire for flexible approaches to collaboration.

From level 3 onwards, tasks are not clearly defined. Collaboration begins with the definition of the problem and the creation of a research question. Therefore, this form of collaboration is not possible unless there is strong cognitive and affective trust between designers and scientists before the collaboration begins. Since scientists and designers can think about the research question on an equal footing, it is close to DSR's ideal collaboration format. In order to carry out level 3 collaboration, both scientists and designers must have a deep understanding of each other's domains and technologies, and the environmental/condition aspect discussed earlier in this thesis must be addressed to decide how much technology and skills they want to share. This means that the four environmental factors that prevent the sharing of information and experience in collaboration – community access, regulation/safety, funding and resources and confidentiality – must be resolved before the collaboration begins. These environmental factors are difficult for individuals to solve independently, so the intervention and support of the organizations to which the designers and scientists belong is essential for collaboration at level 3 or above.

At level 4, the boundaries are blurred, and scientists and designers work beyond their disciplines. It is a form of collaboration with no set tasks, problem definitions, or approaches at the beginning of the collaboration. Instead, these are found organically during the collaboration. This requires a trusting relationship equal to or greater than that of level 3, as well as an understanding of the work content of other fields, and the four environmental factors that prevent the sharing of information and experience must be completely resolved. In other words, designers who can achieve level 4 need to have comparable skills and knowledge as scientists, and be able to safely carry out general experiments independently. Scientists also need to adapt to the design process and know the basic usage of design software, tools, and equipment for creation. In addition, they must have access to the equipment necessary for their experiments/design, and their respective communities need to recognize that these designers and scientists have the knowledge and skills beyond their original training. Furthermore, a clear answer is needed to the fundamental question: "why should designers do science? Wouldn't it be more efficient for scientists to do science?" (or vice versa). If this question cannot be answered, it is hard to define each researcher's contribution, and there is a risk that they will subconsciously take work/credits from the other person's field and damage trust. To summarize the conditions for level 4, this type of collaboration cannot occur unless the advanced challenges of completely resolving environmental factors, defining work with deep trust, and ensuring all collaborators have the technology and knowledge to make the collaboration possible are met. Because this level of advanced collaboration is difficult for collaboration novices, it is easier to imagine a flow in which a previous collaboration level 3 or below develops into level 4, or a level 4 collaboration begins naturally when people hit it off and find a new topic while collaborating at or below level 3, rather than collaboration that begins at level 4.

The higher the level of collaboration, the more difficult the collaboration becomes and the more ambiguous the definition of each individual's role becomes. Therefore, if an unprepared researcher attempts a difficult collaboration not only are they likely to fail, but it will also affect the research of their collaborators. My suggestion here is to engage in many small projects at levels 1 and 2 as a starting point. Through lower-level collaborations, collaborators may not be able to engage in ambitious projects right from the start, but they will be able to learn each other's values and ways of working organically over time as they work together on the project. This approach also helps all participants in the collaboration avoid the risk of boundary object mismanagement, as contributions are defined and agreed upon from the beginning of the project. If they are lucky, they might find another possibility which can lead to the "next project" after that. With each new collaboration, they will be able to demonstrate what they can offer to a greater extent than they could in the previous project while respecting their collaborator's way of thinking. In this way, they will build up trust and be able to think from the same perspective, paving the way for bigger, more difficult project (i.e. higher level) projects.

One of the effective ways to collaborate when trust has not yet been established is to enter into an agreement. Reconsidering affective trust, the desire to help others and share information tends to be based on personal experiences, so forcing someone to share information may actually worsen the relationship of trust. An agreement can define the area of study and role of individual researchers and will help promote a relationship of trust in the future since it also is a representation of considering the boundaries that researchers hope will be respected.

The degree of the collaboration and how the environmental/condition and interpersonal/social aspects must be considered, were discussed. As a summary of the thesis, a series of questions that connect with key considerations is listed to identify the opportunities/limitations of a collaboration for designers and scientists who consider initiating collaborations. Although more questions can be added to customize and fit to their specific projects, it can be used as a starting point to brainstorm with their collaborators so that they can assess potential ways to collaborate.

Self-assessment (before suggesting a collaboration):

Reason for collaboration

- What is your goal? Both ultimate and tangible goals. (E/I)*
- Why do you need to collaborate? (I)
- Name your collaborators. (E/I)
- What's your collaborator's goal? (I)
- Do your collaborator's goals align with your goal? (I)
- What benefits can your collaborators get from this collaboration? Is it aligned with their goals? (I)

Related to process/approach

Material, resource

- How will you get materials to begin the project? (E)
- Which tools/equipment/facilities do you need for the collaboration? (E)
- How will you get access to the tools/equipment/facility during the project? (E)
- What support do you need from your collaborators? (List concrete tasks) (E/I)
- How much does it cost to run the process (any specific materials to purchase, access fee to studios/facilities)? (E)
- How much does it cost for your collaborators to run the process? (E)
- How will you cover the cost? (E)

Time components

- What is the timeline for collaboration? How long will it take to complete this project? (E/I)
- Does your schedule align with your collaborators' schedule? (E)
- How many hours per week can you help your collaborators' goals? (E/I)
- Describe how easy/hard it is to complete the task that you asked for your collaborators with these six points: operation, process time, capacity, schedule, and constraints. (E/I)

Assess risks

- What can be concerns/problems for you in this collaboration? (I)
- What are your collaborator's concerns? (I)
- What is your strategy to avoid the concerns come true? (I)
- When are you going to discuss your concerns and your collaborators' concerns? (I)

- Which information do you think needs to be involved in an agreement if necessarily? (I)
- How do you deal with it if concerns happen in the collaboration? (I)
- How do you acknowledge your collaborator's contribution to the public? (I)

Add any additional questions yourself to concretize the project.

*(E) Environmental/condition aspect, (I) Interpersonal/social aspect

7. Conclusion

I initially started researching this topic with the intention of creating a framework that scientists and designers could use to help each other towards the goal of sustainable material/product development. However, as part of my research I learned that there are many challenges and risks at the interface between science and design, and why those challenges and risks are hard to overcome in praxeology. In conclusion, this paper presents key considerations towards starting collaborations between scientists and designers. While these considerations provide a guideline, it is not rigid – further growth, development and adaptation can be considered as needed by individual collaborators to suit their specific needs.

If establishing a framework is a way to nurture a tree that will bear "sweet fruit" (the benefits of collaboration), then my research's position is to clarify the current situation when the soil the tree is planted in is not well prepared and propose ideas for preparing suitable soil (key considerations for collaboration). Possible directions for future research development include (1) optimizing this soil (systems design) – using speculative design or participatory design research methods to encourage knowing each other can prevent mismanagement of boundary objects and grow trust to foster collaboration, (2) exploring ways to grow trees (establishing a framework) – conducting participatory design research to apply the question list and key considerations to develop a practical framework, or (3) growing trees - publishing their observation records (case studies). Any of these directions of research can help designers and scientists to collaborate. However, potential collaborators should always be mindful of the current situation and remember that nothing can grow on unprepared soil without great difficulty.

8. Reflection after the symposium

I found it encouraging to see the audience's faces and hear the questions during my session, as it showed their curiosity about this interface of design and science collaboration. The majority of questions that I received were about the concrete situations of boundary object mismanagement, the role of the facilitator and understanding their limits, definitions of mutual success, and how I applied the theory discussed in the thesis in my design science research. This makes me optimistic for the future because there are people who are interested in collaborating in a way that is mutually beneficial and looking for a framework. I hope my findings help people looking for the framework to build their methods.

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10. Appendix A

<u>The list of interview questions</u>

Each question was shown on PowerPoint slides during the interview, so the interviewees could visually review the questions during the conversation.

1. What are 5 keywords that describe your design practice/science experiments?

2. Have you had interdisciplinary/cross-disciplinary collaborations?

If so, what kind of research was it? (funded research / Mitacs / thesis research / classroom project / others)

3. If you had the chance to start a project to develop sustainable materials by collaborating with scientists/designers, what would be your goal?

(follow up question) How would you define the goal?

i.e. Publishing paper/book? Holding an exhibition? Joining conferences? Making functional prototypes? Using the prototype to add to your portfolio/resume? Doing workshop? Teaching in a class/sharing the skill with somebody? Making commercial products? Seeing the social impact of the product that you made?

4. How would you check if you achieved the goal? Do you have any key markers for success or tangible states that you are looking for?

5. Where do you see the opportunity of collaboration with different disciplines?
How can designers/scientists help each other?

(follow up question) What are missing skills from your discipline that can be supplemented by other disciplines? i.e. what skills do scientists bring that designers don't have, or vice versa?

6. What are the strengths you bring to a collaborative project?

7. What type of person (specific background, skillset, personality) do you think works well in collaborative settings?

8. In a collaborative project, what kind of collaborators' behavior, actions, or unintended events could make you feel uncomfortable?

9. What do you think of the "taboo or deal breaker" for a collaboration? Are there any actions/behaviors of collaborators that would make you feel very uncomfortable and could "end" the collaboration?

10. What kind of people's behavior/actions/ unintended events do you think make the collaborators from other disciplines feel uncomfortable? *If it's easier, specify the position i.e. scientists might not want to show the process of their experiments to designers.

11. What types of actions promote positive or successful interdisciplinary/cross-disciplinary collaborations?

12. Any other suggestions for successful collaborations or concerns that you think people should be aware of?

11. Appendix B

Interview process

Preparation for the series of interviews began with asking myself (autoethnography) what I would like to find out through the interviews. As discussed in the problem space, I have experienced and witnessed “dissonance” in collaborations due to people not knowing the values and approaches from other disciplines. I wanted to find a solution for this so that more designers and scientists can connect strongly and collaborate without misunderstandings. My question started with “why did I feel uncomfortable?” Then it moved to “where is the boundary that designers/scientists need to respect?” This question provoked me to expand the question to “which actions can they make people from other disciplines uncomfortable?” Thinking about this question more, I found the link between this question and the different values each discipline carries. “What are values for designers/scientists?” To explain this aspect, I asked interviewees to share five keywords reflecting their core values and practices of being a designer/scientist. I wondered what their values lead them to expect from their collaborators, and if their expectations align with their collaborators’ skill sets. “Where are their goals?” “How do they want to collaborate?” “What is their ideal collaboration?” – questions came up more as I kept asking myself, as if I were one of the interviewees. The interview questions were formed to encourage conversation (see Appendix A). The first question, asking for the five keywords, was to identify their core values and enable them to think about what’s essential. The second question asking about their experiences was not meant to collect data but to help interviewees remember their previous collaborations. The third to sixth questions were to identify opportunities for collaboration and goals. The seventh to tenth questions were related to the moment they felt “uncomfortable” in collaboration, and the last two questions were to get their suggestions in collaboration.

Unpleasant experiences and successful experiences are two sides of the same coin. Still, since it is easier to remember the moment of an unpleasant experience and these situations are the ones that we want to avoid actively, I focused on asking about these experiences. My final question was prepared to pick up on anything else I had not identified originally that needed to be discussed. Interviews were scheduled based on the category of interviewees and conducted in the following order: science graduate students, science staff, science managers, design students, design graduate students, and design managers. The reason that I separated the groups into different timings was that it was easier for me to find the “theme” within groups with shared backgrounds and training as part of the first step of thematic analysis. During the interview, another keyword that I didn’t prepare a question for came up: "trust.” When interviewees used this term, I asked them, “why is trust important for collaborations?” and took note of their responses. Roughly half of the interviewees (11 people) highlighted the importance of trust in collaboration and sharing their thoughts, even though there weren't any direct questions related to trust. To maintain anonymity, I will not disclose each interviewee’s answer but will share the result of the thematic analysis before polishing it for the main text.

Reasons for having multiple goals

- *It depends on the type of project and funding source. If it's a governmental project, they expect us to publish a peer reviewed paper at the end. Personally, I would like to develop functional prototypes. I'm also interested in doing/joining workshops for networking purposes. (Science manager)*

- *Is this question intended to find my aspirations or realistic goals? If your question is about my aspirations, then I would like to see the social impact. If you are asking about a realistic goal, it is publishing papers. (Science manager)*

- *Any form that lets me share the outcome with public works for me, so any of doing an exhibition, attending conferences/symposiums, and workshops (demonstrations) fulfill my goals. Having a chapter of a book is rewarding. (Design manager)*

- *That's a good question. I haven't thought about it beyond making functional prototypes. (Design student)*

- *There is no good marks of success. Revisiting the project is important to see where the next goal is. (Design student)*

The strengths that scientists recognize in themselves

- *Giving technical support – improving material properties. (Science staff)*

- *Analysis – we know the methods of analysis and we have experience using the appropriate lab equipment to get the data. (Science graduate student, Science staff)*

- *Objective information – we study based on facts, so there is less bias to the information that we provide. (Science graduate student)*

- *Reading the intention behind the data being considered and evaluating if their conclusion makes sense. I think I'm good at spotting fraud. (Science graduate student)*

- *Systematic approach, project design, giving structure/organization to the project. (Science manager, Science graduate student)*

- *Taking leadership, organizing the team, articulating motivation and finding resources for funding. (Science manager)*

What scientists want from designers in a collaboration

• *I can make uniform small samples, but I cannot make them look "cool." Designers can add meanings to shapes. (Science staff)*

• *Enhance the communication – designers can help represent the esthetic side of science. (Science graduate student)*

• *I would like to get designers' help for diagrams and graphic abstracts for my paper. (Science staff)*

• *Designers can understand the interaction between materials and people. Having effective ways to communicate our research is very important. It will also help bridge the gap with people from other disciplines if we work as a big team. (Science manager, Science staff)*

• *Having an object is a feeling! Designers can make prototypes that describe what the material means to people. It's powerful when we communicate with policy makers and funding agencies with prototypes. (Science manager)*

The strengths that designers recognize in themselves

• *Visualizing/sketching things – I can make concepts tangible. I can draw ideas out on a piece of paper. (Design student)*

• *CAD/modeling skills. (Design student)*

• *Working with uncertainty - complicated topics have a lot of uncertainties. I can handle processing a lot of "?" into tangible points. (Design student)*

• *Translation skills – things that you can "sense" (things that you can see, touch, smell, and experience) can be accessible to all people who have different backgrounds. Designers can make those. (Design staff)*

• *Facilitating conversation, organizing different perspectives, making space for collaborators to work. (Design student, Design manager)*

What designers want from scientists in a collaboration

・*Technical knowledge is a big missing piece for designers. (Design student)*

・*Chemistry is hard in material development in design. I would like to get help with a rigorous approach. (Design student)*

・*Scientists understand things in detail- documenting all of their findings, listing all of the contributor/factors. Designers can learn from them and reflect it on our design practice. (Design student)*

How to foster collaborations

1. Be nice

・*Be nice as a person. Nobody wants to collaborate with you if you are not nice. (Design graduate student)*

・*I would hope everybody would be nice and respectful. (Science graduate student)*

・*Be receptive to feedback. Take it as a learning opportunity rather than a personal attack. (Science manager)*

2. Know each other well

・*Actually get to know each other. In a big collaboration, we would have a collective goal as a team, but everybody has a personal goal - it's important to understand those individual goals. (Design student)*

・*Exist in a common space- work together. (Science graduate student)*

・*Be open-minded and bring down the barriers. We need to do team building activities. (Science manager)*

・*We've benefitted from having a long runway of introduction – frequent meetings to understand where we are coming from. New discoveries can be found from conversations. (Design manager)*

・*Go to a café together, and offer a cup of coffee. Be nice and get to know them outside of the context of the project. (Science graduate student)*

・*Ongoing curiosity – willingness to learn each other. Be an active participant to show you are listening to others. (Science manager)*

3. Communication

・*Open communication. Having a general culture of being ok to come up to co-workers/collaborators and ask about basically anything! (Design student)*

・*Try to communicate with language that both disciplines know. (Science graduate student)*

・*Be honest with both good things and bad things. Be open to communication. (Design student)*

4. Define goals and structure

・*A challenge-centered approach should be encouraged for collaborations. Once goals are clearly defined, people can find their role, proactively communicate and offer help to each other to solve common challenges. (Science manager)*

・*External constraints are helpful to narrow down the design approach we should take. I would like scientists to share what kind of problems they have and would like to think of the solution together. Let's work together. (Design student)*

・*Let's start from defining the knowledge gap between disciplines, and think of how to fill it together. (Science staff)*

・*Clarify expectations of each member's contribution. If there are limits, be honest about them so I can respect the boundaries. (Science student)*

・*Set frequent meetings to check where we are at in regards to the initial agreement, and update the agreement according to the situation. (Science staff)*

・*Be respectful to the limit each member has, and do not punish them about not being able to share something. (Design manager)*

Challenges – difference in time scale

• *I'm not sure if it's the case for all designers, but I felt designers' time scale is different from scientists. If designers hold off on the topic for a while after we agreed on a collaboration, the science part of the research will be outdated. (Science staff)*

• *We need to define a targeted goal, define the timeline, and define each member's responsibility. Check the progress and status from time-to-time. (Science staff)*

• *Even if it's an interesting topic, if my schedule doesn't fit, I don't feel I want to collaborate with anybody. It's simply not good timing. (Science graduate student)*

Conflicting approaches

• *I'm wondering if scientists feel designers are serious with the topic when we are ideating. (Design student)*

• *We talk about a lot of things that are not necessarily objective such as personal stories, cultures, histories and positionality. This could look like designers are not addressing the implication of each research. (Design manager)*

• *Speculative design can be frustrating for scientists because "anything can be possible." It means that there is no constraint therefore it's hard to approach to problems. The designers' behaviors can be taken as "ignoring the scientific problems" or "dismissing." It could give the impression of "you are not listening to me" to scientists. (Design student)*

Challenges – preconceptions

• *When I had a collaboration with a scientist, I was surprised and felt slightly uncomfortable with them saying "You are a designer, so you make things!" I answered "Yes, but I don't just make things" in my mind. I probably have a bias of how scientists work though. (Design student)*

• *Since I work with you, I know how much work you do for your graphic design, but if I didn't know about your work, I would think drawing illustrations/diagrams would be easy since the outcome is simple. (Science graduate student)*

Risks – Appropriation

• *I haven't had the experience of facing such a bad experience in the past fortunately, but if somebody doesn't try to understand stories and cultural perspectives, I wouldn't feel I want to work with them. (Design student)*

• *Some collaborators go against of my core value. I designed something not for profit but for a community, however, they tried to make money out of it. (Design graduate student)*

• *There would be material research which has a cultural impact that requires special care. It is better to establish a safety net or protocol to avoid unintended offence before we start the collaboration. (Design manager)*

• *Designers have a different understanding of intellectual property and some of them claim other people's work as their own work. I would name it "IP appropriation." (Science manager)*

• *"One of my friends is an engineer and they are working on a project related to a military service. They looked uncomfortable when they were asked to describe their projects to people outside of their team. I imagine it would be uncomfortable for scientists to be asked to share information that includes confidentiality with people who haven't committed to be in the team, like a visitor, even if it's not for a military service." (Design student)*

Risks/challenges – product development or public disclosure

• *I think the end of the collaboration is not necessarily miscommunication, but having different goals. For example, my goal is to share knowledge with the academic community to help each other learn. If your goal is filing a patent to start a company and make money out of it, it doesn't align with mine. Even if the topics overlap, it's better to work separatory if that's the case. (Science graduate student)*

• *My goal is to hold as many patents as possible before I finish my PhD. Thinking about job opportunities after my graduation, I think companies tend to evaluate patents more than the number of publications these days. (Science graduate student)*

Trust

- *In the case of collaboration where tasks are subdivided and clear, personal trust is not necessary from the beginning on an individual basis, but collaboration will not develop in the first place unless there is at least a minimum level of trust from the organization. (Science graduate student)*

- *Trust is important. If there is no trust, people will not actively spend time on the project and will not try to share information. (Science manager)*

- *I have experience being put in a collaboration and joining a collaboration voluntarily. If I know the other party and can trust them, I feel more like "I want to help them." (Science staff)*

- *If there is no trust, nothing will move forward. People are reluctant to share their knowledge. If they hid information, I would feel they do not trust me and it doesn't make me want to collaborate. (Science staff)*

- *Trust is a foundation for collaboration. I know you won't randomly share my research with others so I can share my research with you. (Science staff)*

- *Trust is linked to expectation. I want to trust people that they have skills to accomplish their part in their roles in a collaboration. (Science graduate student)*

- *If you cannot trust the person, you cannot work with them. Respect the idea, boundary, the portion of the work they agreed to do to keep the trust. (Design student)*

- *Trust is very important. What is your role? What information do you need? What should I share with you? If I don't know them, I cannot rely on them. (Design student)*

- *Trust is a confidence of actions. We need to trust that the collaborators are progressing, moving forward with the project agreement. (Design manager)*

Devalue

- *I don't appreciate when people are dismissive of the work you bring. It is devaluing the project, devaluing the collaborators. (Design graduate student)*
- *There are time components as well, but if I see complete refusal of other perspectives and values, it would be a deal breaker to me. (Design student)*
- *Disrespectful attitude such as being dismissive, insulting the work, being disinterested in the process. (Design student)*
- *I feel uncomfortable when people don't think you did enough good work. When they don't value my work. (Science graduate student)*

Credit

- *My deal breaker is when somebody steals the credit and lies to others. The person who heard about it will think that I didn't work. (Science staff)*
- *It is important to give credit to each other when you collaborate. If you cannot give or receive credit, you shouldn't collaborate. (Design graduate student)*
- *I don't want to work with people who want to succeed more than their collaborators. Show all the collaboration fingerprints, and give credit! (Design staff)*

Exploitation

- *I feel uncomfortable if the collaboration becomes getting something from you, rather than true collaboration. (Design student)*
- *When people demand from others, it's unfair and unethical. (Science manager)*
- *I don't feel good when they treat my contribution to the project as service that I need to do for them. (Science graduate student)*
- *I proposed a project to a collaborator. They took my idea and started doing other collaborations with the topic but with more famous professors. They took my place! I didn't feel their behavior was respectful. (Science staff)*

- *I don't like when people are being extractive, and not offering giving back. I don't always expect something back, but we need mutual respect. (Design graduate student)*

Breaking promises

- *I know it's pretty obvious, but people who forget or ignore promises cannot be trusted. (Science graduate student)*
- *Accountability is important. If you say you will do it, then do it! (Science manager)*
- *When a role is given to the member during the initial stages, I don't feel comfortable if they step back and don't work on it. (Science student)*