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From Guests and Guides to Collaborators: Negotiating Roles in Design and Biology Collaborations.

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In recent years, the design community has started envisioning biology as a design medium and designers are entering laboratories to pursue designer-biologist collaborations. To ensure that these collaborations lead to rich outcomes, we need to better understand the roles performed by biologists and designers in these collaborations. In seven case studies of collaborations between designers and biologists, we found that strong role dynamics appeared during the collaboration and can be divided into four phases: discovering, defining, developing and delivering. We show how biologists successively act as guides, influencers, supervisors and librarians while designers act as visitors, apprentices, amateurs and lone makers. We found that, despite their interdisciplinarity, projects followed traditional design project structures. While biologists tended to take the lead on project content, designers framed the projects using their methods and processes.

Keywords: collaborative design; design practice; interdisciplinarity; bio-design.

Introduction

Over the last 50 years, scientists have developed more powerful tools to understand, describe and control living cells. Many biologists, specifically those in the synthetic biology community, have

come to view living organisms as a medium for production, manipulation, and programming (Collins 2012; Freemont et al. 2012; Fu 2006; Elowitz and Lim 2010). Scientists within this community use language that compares living cells to machines, factories, and computers, introducing engineering and design methods into the scientific practice (Agapakis 2013; Catts and Zurr 2014; Oxman 2016; Ginsberg et al. 2014). Therefore, synthetic biology focuses on ‘life by design’ (Bensaude Vincent 2015) and proposes, as design does, to make things rather than focusing on understanding existing ones. This perspective has come to influence the design community (Antonelli 2008; Dunne and Raby 2013; Miller 2014) and a growing number of industrial, product and fashion designers started entering biology laboratories to incorporate cells and living systems into their design practice (Myer 2012; Chieza et al. 2018; Camere and Karana 2017). Reflecting on ‘Synthetic Aesthetics’, a set of pioneering projects that associated designers and biologists, bio-designer Ginsberg explains that ‘as synthetic biology attempts to design a new biology, there is an opportunity to reinvent design: if design is to engage in these technologies, it should proactively claim a role in shaping them’ (Ginsberg et al. 2014).

As designers entered laboratories, researchers started describing and categorizing the different goals and outputs of natural science and design collaborations (Figure 1). Driver et al. (2011) studied several science and industrial design collaborations and identified three major contributions: to ‘challenge the research direction and support scientists in demonstrating, communicating and exploring potential future application.’ Moultrie (2015) showed how designers can help bridge the ‘valley of death’ between fundamental research and the commercialization of new products by creating ‘design demonstrators’. Rust (2007) argued that ‘designers can act as provocateurs in the early stages of interdisciplinary work’ as a means to drive scientists to ask ethical questions about their research. Balmer et al. (2016) stated that ‘moving the

societal research upstream, to earlier stages of the research process, imply that societal and environmental implications is part of the scientific development, rather than following it'. For all these reasons, it is important to integrate designers at the early stages of the scientific project in order to address societal concerns.

[Figure 1 near here]

However, in existing accounts of collaborative projects between scientists and designers, both designers and biologists have explained how such collaborations can be challenging. For example, Lee and Agapakis, respectively fashion designer and biologist, discussed the ambiguity of working at the intersection of the two disciplines, showing how designers' concerns don't always align with scientists' ones (Lee 2018). Driver et al. (2011, p.5) conducted a series of interviews 'to gauge scientists' initial perceptions of design as well as to understand their views on how designers might support their research activities'. They reported that 'scientists were generally sceptical about the potential for industrial designers to contribute to early stages of scientific research'.

If we want to ensure that collaborative projects overcome these issues and reliably deliver the different outcomes identified by researchers, we first need a better understanding of how design and biology collaborations currently unfold. However, Peralta and Moultrie (2010) in their literature review on science and design collaboration have noted that 'little work has been carried out in relation to how designers and scientists collaborate in scientific research. [...] For example, in the field of bioscience [...] access to useful information about these initiatives is limited'. Given the unique nature of synthetic biology in the realm of natural sciences, our goal with this paper is to explore and analyse the specificities of design and biology collaboration by looking at how both disciplines engage with each other.

Related Work

Design researchers have tried to understand both the differences and similarities between science and design since the origins of the discipline. In their literature review about science and design collaborations, Peralta and Moultrie (2010) summarized the different perspectives on these questions. They show how most authors recognize that design and science are concerned with different objects. Simon (1969) for example expressed that: ‘the natural sciences are concerned with how things are [...]. design on the other hand is concerned with how things ought to be’. Krippendorff (2007) argues that science explores the unobservable while design explores the observable. Bonsiepe (2007) similarly suggests that scientists produce ‘new knowledge’ while designers create ‘new experiences’ but he also recognizes that designers and scientists both proceed experimentally. Regarding collaboration, we found that while both designers and scientists have strong traditions of collaboration that have been well documented and studied, they differ in that scientists generally collaborate across scientific disciplines while designers collaborate with the many non-designer stakeholders.

In the subsequent paragraphs, we briefly review the literature on how both disciplines respectively collaborate and the roles they traditionally play in the collaboration. Sonnenwald (2007) reviewed the existing literature on collaboration among sciences and found that in natural sciences most publications now result from collaborations and teams are gradually growing bigger. One identified model for successful collaboration is to have well defined and complementary roles (Hara et al. 2003), for example between theoretical and experimental research in physics. However, science collaborations are facing new challenges because they are ‘increasingly ill defined, technically complex, and interdisciplinary’ (Leahey 2016). On the design side, designers’ interdisciplinary collaborations have mostly been studied in the context of designers and non-

designers collaborations, especially in the case of participatory design. Researchers have shown how designers can play the role of facilitators. In her study about communication roles that support collaboration during the design process, Sonnenwald (1996) characterize the role played by designers to facilitate a shared understanding across different disciplines as ‘interdisciplinary stars’ and show how they simplify their language and avoid jargon to do so.

Peralta and Moultrie (2010) argue that interdisciplinary studies provide interesting frameworks for studying design and science collaborations, in particular, they present John-Steiner’s (1998) categorization of interdisciplinary work to show how the forming and performing of roles can profoundly impact the collaborations and the level of integration of disciplines. They show that in the most asymmetrical situation, one discipline can end up being ‘tokenized’ (Reich et al. 2006), resulting in one-sided collaborations. This situation was for example observed by Dawson (2009) in the context of design and engineering collaborations, when one discipline’s role is not well understood by the other. The opposite situation, full collaborations, sees both disciplines establish the research questions and participate in answering them. However, as Peralta and Moultrie showed (2010), despite the wealth of studies about interdisciplinary collaborations involving science or design, we currently lack studies that focus on the relationship between design and biology, and, more specifically, on the specific roles played by designers and biologists in collaborative projects. Chiesa and Ginsberg (2018) also argue that defining new roles for designers alongside biologists would help foster innovation in the emerging field of bio-design. This approach focusing on roles has been used, for example, by Balmer et al. (2015) to understand the multiple and complex patterns of interaction between science and technology (STS) researchers and synthetic biologists. Therefore, in the long term, studying the roles that emerge in current collaborations will help us better prepare designers and biologists who want to engage in such

collaborations. This paper therefore addresses the following research questions: what roles biologists and designers play in collaborative projects (RQ1), how do they evolve during the projects (RQ2) and how this role distribution affects the materialization of the projects (RQ3)?

Case study and methods

Case Studies

[Figure 2 near here]

To answer our research question about the roles of designers and biologists in interdisciplinary collaborations, we selected seven collaborative projects (Figure 2) with designers and biologists in two different universities. In the following paragraphs, we present the case studies, their characteristics and their outcomes to define the scope of our study.

Three collaborative projects took place at Tokyo University in three volunteering biology research labs over the course of eight weeks. Researchers in the first participating lab work on living and electronic sensors to detect environmental chemicals. The second lab is dedicated to regenerative medicine and the culture of living tissues. The third is a neuroscience lab experimenting on lab grown neuron bundles.

Participants included five industrial designers recently graduated from the Royal College of Art (London, UK), three master students from the University of Tokyo and three biology professors who supervised the projects. One designer had trained as a scientist before enrolling at the design school. Over the course of the collaboration, the biologists and designers broke into three teams of two to four students. At the end of the collaboration, all three projects have been exhibited in the university as well as at the National Art Center, Tokyo. One project directly led to

a new research direction and a second project led to a new collaborative project by the same team, this time aiming at developing a product based on the research developed by the laboratory. Both of these projects are being developed at the time of writing.

Five collaborative projects took place at the CRI in Paris in one volunteering research laboratory focusing on research in synthetic biology, over the course of twelve weeks. The cohort included eleven masters level product design students from Ecole Boulle, five masters level biology students from Paris Diderot and Descartes Universities, and two Post-Doctoral researchers in synthetic biology who supervised the projects. None of the participants had worked across disciplines, but one biology student had a bachelor's degree in art. Over the course of the collaboration, the biology and design students broke into five teams of three-to-five students. As part of the program, the students were introduced to fundamental concepts in biology and exposed to hands-on laboratory work. At the end of the collaboration, all the projects were exhibited in museums in Paris and New York as part of the Biodesign Challenge program. One of the projects is being developed as a research project in the CRI laboratory at the time of writing and two other projects have been exhibited at several science and design fairs.

In all of the projects, no explicit methods or tools were imposed on the participants. To see how the different collaborators were naturally developing their own methods, they were free to arrange the collaboration in the way that suited them the best. Teams also had to collaboratively come up with their own brief from the research. While no specific outcomes were required, participants knew that their projects would be displayed in exhibitions.

[Figure 3 near here]

Methodology

The purpose of the study is to understand how collaborations unfold in multi-disciplinary teams of designers and biologists. In an initial phase, one author acted as a participant observer in the projects conducted in Paris. These initial observations revealed that the roles were not fixed but instead constantly evolved throughout the process. These initial insights guided the creation of the semi-structured interview process that was then carried out with all the participants. We conducted 21 post-hoc semi-structured interviews (Breakwell 2006; Denzin 1994) with 5 master's-level biology students, 12 designers as well as the 4 mentors (biology professors). 10 individual interviews were performed in Tokyo and 8 interviews were performed in Paris, individually with biologists and with designers' teams for each project. Each interview lasted from 1-1.5 hours. Specifically, we first asked participants about how the collaboration unfolded, the roles and the concrete activities that they performed at the different moments of the project, their strategies for collaboration, and the frictions that arose during the collaborative process. The authors audio-recorded the interviews, took handwritten notes, and later transcribed the interviews in adherence to the transcribing methods described by Saldana (2015). Each participant has been attributed a code according to their profession, their institution and their project (see Figure 3).

We analysed the interviews using the approach to thematic analysis developed by Clarke and Braun (2014). We identified the roles in an inductive manner and we regularly met to discuss the data, the coding and our interpretations, to ensure that they were coherent, comprehensive and reflective of the actual data in both the Paris and Tokyo projects. We grouped codes into categories and went back again to the interviews to consistently apply these emerging categories (see Appendix A).

Dynamics of designers and biologists' roles in the project

We observed the emergence of strong role dynamics between designers and biologists during their collaboration. In our analysis we found that all the projects followed a similar path that could be divided into four distinct phases: discovering, defining, developing, delivering, during which designers and biologists played very distinct roles. We should note here that the different phases and roles were never formally defined within the teams but our analysis revealed that they consistently emerged throughout the course of the projects in all the teams. We present them below in chronological order and we detail the specific roles performed during each phase by both designers and biologists.

Discovering

Designers as guests

Designers started the project with their own desires and interests, mostly materials or thematic, as external elements that they wanted to confront the biological matter. They initially perceived the laboratory as a playground, a place to explore, especially due to its 'exotic' tools and a strict 'scientific method' (P₂Des_b). As P₂Des_b explained, they assumed that working with biologists would involve creating and manipulating biological material. For example, P₁Des_b came with the idea of working with ceramics and DNA while P₄Des_a already knew that he 'wanted to design a clock with an organic display'. In contrast, biologists arrived with no preconceived ideas about the project. Even more, at first P₁Bio didn't know 'what [he/she] could bring to the project and didn't understand [his/her] role in such competition'.

Biologist as guides

Biologists found their first active role in the project as tutors to guide designers in their discovery of a biology laboratory. At first, biologists did not know what or how they should present their research to an audience of designers. Some biologists, like T₁Bio_b, had the impression that ‘designers would not be interested in their daily research activities’. T₁Bio_b and T_{2,3}Bio both explained how they tried to focus on the visible and tangible aspect of their research, especially the materials and visuals that they use. For example, T₁Bio_b tried to describe the material qualities of neurons to designers: ‘I also showed that we can stretch it if you attach it to a small pin’. Nevertheless, biologists had an instinctive sense of which part of their research would be interesting starting points: for project P₁, the mentors M₁ and M₂ encouraged the designers to focus on a DNA detection process even if designers ‘didn’t see at first the point of working on it’ (P₁Des_b). The designers later admitted that ‘she was right to show us that it was the right subject, the right direction’. T_{2,3}Bio demonstrated the different colour lenses that she can use to observe her samples, thinking that designers could find this colour change interesting. T₁Bio_b also ‘focused more on how to do the experiment’, rather than her current research on proteins that regulate the morphology in the brain because she thought that ‘it’s not very interesting for them’. In a similar manner, at the beginning of the T₁ project, designers were initially interested in the genetic aspect of professor’s T₁Bio_a research, but he thought that it would be ‘too difficult for designers to edit genes by themselves in the laboratory’ so he argued against it.

Defining

Biologists as influencers

The way biologists presented information to designers had a very strong impact on the generated concepts. For example, in the case of T₃, designers reified the metaphor that professor T₃Bio used to describe her research: ‘We already had the idea at the microscopic scale, they did it at a macro scale’. In the case of P₁ project, M₂ explained that while they were using a sophisticated machine to duplicate DNA ‘[they] could as well be heating with a candle’. As a result, designers took this statement literally and developed their project based on a tealight candle. P₁Des_b explained that they would not have arrived at this idea on their own because it could have appeared as a dilettantism, as if they did not respect the science. Beyond the discourse, biologists’ concrete practices and gestures also inspired designers: P₁Des_a explained that the DIY approach of her project was inspired by the biology student M₂ who ‘hacks his own tools to do his project’. The laboratory and its numerous unknown artefacts were also a source of inspiration for designers who could understand the research from a different perspective, by inquiring about when and how they were used and if they were disposed after use or not.

Designers as ‘elastic minds’ (Antonelli 2008)

One of the main strategies used by designers to ideate from scientific research was to extrapolate a specific research finding. In the case of project T₂, professor T₂Bio managed to create a bio-hybrid device to detect a molecule from sweat. Designers posited that this research finding could be extended and applied to sense every molecule. In project T₁, professor T₁Bio_a was also very surprised at first when designers came up with the idea of using the armpit to incubate neuron but he realized that ‘they came up with the armpit, because we said neurons are fragile and need a

good environment at 37°C with nutrients’. In P₁, students also chose to extend the purpose of a technology that was already created in the laboratory. Originally, biologists had devised a technique to test food for Genetically Modified Organisms (GMOs). P₁Bio explained that ‘it was only usable in a specific case, when the food is based on corn or soy’. Adding, ‘the challenge led us to think about turning it into a more universal project that can be used by anybody [...]’.

Biologists as ‘bridges between ideas and reality’

However, we observed that it was difficult for biologists to engage with this type of ideation, because they know the current limitations of their research and how hard reproducing experiments can be. In the Tokyo lab, when designers proposed to work on an artificial brain made of thousands of the organoids created by professor T₁Bio_a, the latter felt that it was too far from his research: ‘We already have issues with connecting two together for now’. Similarly, T₁Bio_b explained her difficulties to propose design ideas during the brainstorming sessions with designers because ‘researcher on the field are really restricted by the difficulty of the experiment’. In the beginning, biologists were sometimes at a loss for how to respond to designers when confronted with designers’ ideas that seemed currently impossible on a scientific level. However, as T₁Bio_b came to reflect during the interview, biologists gradually found their place by becoming ‘the bridge between the reality and the idea’. She explained how she established her role in setting up a scientific roadmap with the different ‘obstacles to overcome’ in order to make the idea a reality: ‘Thinking about the process to make the thing and not trying to deny it’.

Developing

Practice: designers as apprentice

As first ideas were emerging, designers in all the groups wanted to experiment, to get their hands dirty in the lab, even if they did not directly work with the suitable material. For example, P₂ group ‘did a lot of tests, but not using the real data’ (P₂Des_a). P₃’s designers ‘experimented with bacteria but it wasn’t the one that produces indigo’ (P₃Des_a) while in the T₁ project, T₁Des_a explained that, in the first phase, they broadened the ideas and did not research the actual academic content: ‘We didn’t set any restrictions so that we could come up with any idea’. After the first autonomous experimentations, as all attempts of growing biological matter were failing, designers realized that they had to learn the rigor of scientific experimentation from the biologists ‘to be able to really start the project’ (P₃Des_c).

Practice: biologists as supervisors

In this phase as well, biologists came to the rescue: they started to lead the experimental part and designers took on the role of scientific assistants. They gradually learned the experimental gestures through observation and imitation. As P₄Des_b explains, ‘P₄Bio was doing the experiments, but we tried to understand, we were observing over her shoulder’. Designers were ‘taking notes’ and also ‘took a lot of pictures to be able to understand and reproduce the same thing’ by themselves (P₃Des_c). Another strategy explained by P₃Des_b was to ‘always manage to be in the lab at the same time as P₃Bio when she was working on the project, so we could watch her and learn’. Repetition was also crucial for designers to learn how a scientific protocol is carried out through micro-variations until ‘it had become very familiar.’ (P₃Des_a). After a few sessions ‘it was like holding a paintbrush’ for her.

Theory: designers as amateurs

Alongside their apprenticeship of experimental biology, designers also looked for more theoretical scientific knowledge to enrich the projects. P₂Des_a explained that they first turned to second hand sources, looking at popular science journals and visiting local Science Museums. However, P₂Bio was sending designers scientific articles and diagrams because ‘according to him, our websites were not scientific enough’ (P₂Des_a). The original asymmetry in knowledge was reinforced by the fact that only biologists knew where to find and how to read original sources. Indeed, journal articles are written for scientists in the field and can be extremely hard to understand for outsiders. Biologists needed to act as mediators and provide a translation from scientific content into information usable by designers. As P₄Des_a explained, ‘When P₄Bio was finding a website with interesting information, she would show it to us, but the information did not come across to us, whereas she would understand it right away’. However, even if designers were looking for information, they also thought that ‘going too deep into scientific details was slowing the project sometimes’ (P₂Des_a). According to P₂Des_a, ‘there is a paradox between fully understanding something and knowing what is necessary for design’. At the end of the project, after having spent several months growing bacteria, designers P₃Des_c admitted that they ‘still don’t know how bacteria worked but we didn’t need to know this for the project’ and P₂Des_b had reached a deep level of understanding of the functioning of DNA ‘but nothing in what’s around it’.

Theory: biologists as librarian

Biologists felt that it was their role to teach theoretical biology to designers, in order for them to understand the experiments they were conducting. Biologists used diverse strategies to transmit their knowledge, from ‘explaining to a 5 year-old’ (T₁Bio_b) to using drawings and diagrams. Biologists also became knowledge referents even though they themselves did not always have the

knowledge. Designers expected scientists to do the ‘validation step with [their] knowledge’ (P₄Des_a) by answering their questions. Thus, biologists were being used to find resources outside of the laboratory to develop the project. Biologists had access to a network of colleagues to whom they could directly ‘send the question via email’ (P₄Des_a) and who could refer to the relevant sources to solve problems or confirm hypothesis. For designers, this role distribution felt natural: ‘It was simpler for [biologists] to contact researchers. It’s also a matter of scientific language.’ (P₄Des_b). Interestingly, while designers gradually managed to learn and master the art of experimentation, they never managed to become autonomous on the theoretical side of the project.

Delivering

Designers as lone makers and biologists’ exclusion

Despite the original desire to set up a perfect environment for a hybrid project between design and biology, all design students wanted to work first on the biology part, and as they came to master it, they wanted to shift to the design part. Biology had become the means to an end, or as P₃Des_a puts it: ‘the scientific tool to create’. As a result, biologists were mostly evicted from this phase. This eviction of biologists during the design phase of the project was also justified by designers as a matter of planning and timing, as they had ‘only little time to do the project’ (P₄Des_a), and were ‘under pressure to make the project happen’ (T₂Des). P₂Bio_a explained that ‘designers conducted the fabrication process while P₂Bio was there as a fact checker, or manual help, but he was not involved in the design process’. In that sense, biologists became tokens of truth. On the other side, biologists were looking for interactions that designers were not spontaneously offering them. They had suggestions on the design and also had their own opinions but they had to use strategies to have their voice heard by designers, such as ‘whispering new ideas’ (P₂Des_b). At the end of the

project, some designers expressed regrets about the fact that they had not involved biologists in the design process and that ‘If we had to do it again, we would integrate her more into the design of the object’ (P₄Des_a).

Designers wanted to visually demonstrate their concept: ‘doing something that give the impression that it’s working and that will show people the potentialities’ (P₄Des_a) while scientists wanted to develop functional prototypes. The difficulty to produce functional prototypes with biological matter as a design material had a strong influence on the resulting design. In T₂ project for example, they represented the function of the object literally: ‘every dot represents a specific chemical, there are 50 of them on a sheet of 1cm’ (T₂Des). Because they could not produce a functional prototype, they needed to convey the function through the object shape and visual detail. They therefore used biology as an aesthetic reference to design the object. In T₃ project as well, designers decided to print images of blood vessels to illustrate what the sheets could look like and added jelly on top of it to make it ‘looks more like bio’ (T₂Bio).

Designers and biologists as collaborators

The projects had a short time span from a biology perspective but all had to produce outputs that would be displayed at exhibitions as well as in the Biodesign Challenge for the projects developed in Paris. A strong emphasis was therefore put on presenting and communicating the research behind the objects. The very end of the project and the finalization phase was the only moment when ‘roles got completely mixed and there were no designers and no scientists anymore.’ (P₂Bio). For scientists, this mission was seen as a natural continuation of their teaching mission during the whole project. They crafted the stories that back-up the projects and the design choices at the end. Science was thus used for its authority and as a justification mechanism for design and allowed teams to ‘build the story while building the product’ (T_{2,3}Des).

Discussion

We observed the emergence of strong role dynamics between designers and biologists during their collaboration. In our analysis we found that all the projects followed a similar structured during which designers and biologists played very distinct roles. In the initial discovery phase, designers acted as guests while biologists were acting as guides in the laboratory. In the defining phase, biologists became influencers and tried to bridge the gap between designers' ideas and reality. In the developing phase, designers acted as apprentices and amateurs while biologists acted as supervisors and librarians. Finally, in the delivering phase, while biologists were evicted from the design process that was carried out by designers, both disciplines collaborated on equal terms for crafting the reasoning that supported the projects.

In this study, we identified a novel type of interdisciplinary collaboration dynamic that differs from the ones observed by John-Steiner (1998). Our analysis revealed the strongly asymmetrical collaboration roles performed by designers and biologists during the projects. More than collaborations on equal terms, roles were instead strongly enforced and the two disciplines were mobilized in very different ways in the project. This asymmetry cannot accurately be described as tokenism (Reich et al. 2006) nor can it be seen as simply one sided (Dawson 2009). It is asymmetrical in that designers were leading on the process while biologists were leading on the content. Specifically, in the projects we analysed, we observed how designers take the lead on organizing the project time and activities. This can also be seen in the fact that the four phases of the projects we identified echo traditional divergence-convergence phases in the design process as described by Cross (2000). If those phases appear familiar to designers, we found that they also closely match the four key stages of scientific collaboration defined by Sonnenwald (2007) in her

literature review: ‘foundation, formulation, sustainment, and conclusion’. This might explain why both designers and biologists, in all the projects we studied, managed to organize the collaboration implicitly and did not question it during the interviews.

Despite having designers leading on the process during the collaboration, our analysis also revealed the critical role played by biologists in almost all the steps. As we have seen in our analysis, because designers first get access to the biological matter through biologists’ eyes, hands and knowledge, their vision and their possibilities are enabled and shaped by biologists. We also observed how biologists were constantly redefining their role and adapted their practices to support the projects, while designers mostly performed traditional design activities. In that sense, biologists played the design game: they adapted to designers’ ideas and tried to make them viable, taking on the role of bridge between designers’ ideas and the biological practices and knowledge needed to achieve the projects. Biologists also had a reflexive approach on their work and their tools that helped designers question and appropriate biology. Biologists were also gatekeepers: designers were always seeking confirmation and validation and relied on biologists’ ability to interpret their ideas and adapt them to the scientific reality and constraints. Callon (1984) observed how scientists find their place and mobilize different partners through a process called ‘interessement’ in which they translate the concerns of the non-scientists to their own terms. In the collaborations analysed here, we observed a similar movement, but, this time, performed by designers as they made biologists their allies in the development of the project. In the later phases especially, we observed how designers translated the biologists world into their own, by appropriating their aesthetic for example. Thus, designers treated biology as a material to design, more than a scientific field or discipline in its own right.

Conclusion

Through seven use cases of design and biology collaborations in two different universities, we explored the roles played by both disciplines in the collaboration, how they evolved (RQ1) and how they impacted the projects (RQ2). Informed by participant observation, our 21 post-hoc interviews with both designers and biologists revealed strong asymmetrical collaboration patterns: designers and scientists took on complementary roles that strongly shaped the projects. Biologists performed the roles of guides, influencers, bridges between ideas and reality, supervisors and librarians. Designers acted as guests, apprentices, amateurs and lone makers. It is only at the end of the ‘delivering’ phase that both designers and biologists became peers. We also found that the projects followed a mostly traditional design project structure despite their interdisciplinarity and access to laboratory equipment. Biologists led on the content of the projects, but designers framed the projects based on their methods and processes. Designers mostly developed an instrumental relationship to biology, eagerly adopting its materiality but seldom including biologists in the design process, until the final stage of the project. Finally, we looked at how this roles’ distribution affected the materialization of the projects (RQ3): We show biologists’ decisive influence on early project ideas and how, in later phases, we show how designers treated biology as a material to design and as an aesthetic, more than a scientific field or discipline in its own right.

This study also has some limitations we would like to acknowledge. In such collaborations, differences of seniority and expertise can strongly influence the collaboration patterns; we need more studies to understand how different expertise level can influence collaborations. While the use case selected in this study were diverse in terms of topics explored by the teams, they all happened in a university context and were relatively short projects when compared with traditional

biology projects' timeframe (Ginsberg et al. 2014) that usually last for several years. They were, however, closer to traditional design project timeframes. Collaborations happening in the long run may lead to different roles and collaboration patterns that should also be studied.

As the interest in bio-design is growing and more and more design and biology collaborations are being set up, this research shows that we need to carefully consider the environment of bio-design projects to fully explore the potential of working with biologists. Revealing and making explicit the roles that can spontaneously emerge in the collaboration can help both designers and biologists to reflect on their roles in the collaboration. Taking advantage of their outsider position on scientific knowledge, designers could look at it differently and eventually 're-conceive both the object(s) of research and the relations between research subjects and objects' (Barry et al. 2008). Using this work, we plan to develop tools and methods that encourage designers and biologists to explore other patterns of collaboration.

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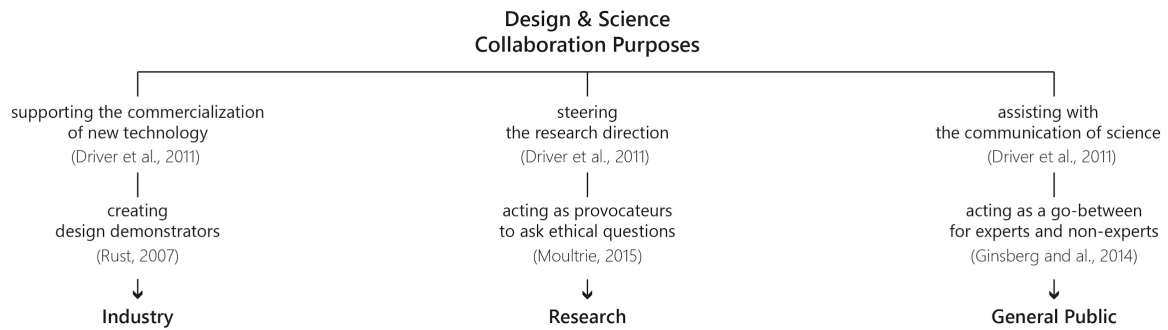
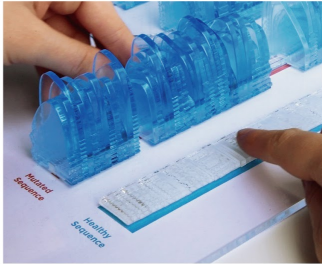


Figure 1. Design and science collaboration purposes, as identified by previous research, can be classified in three categories: projects for the industry, for research and for the general public.

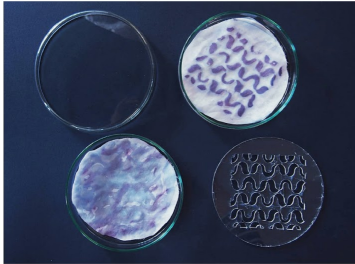
Paris



Minima, the elementary
biology lab
P₁



Tactile Micro Landscape
P₂

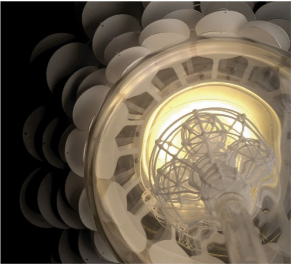


IndiCo
P₃



Bio-Clock
P₄

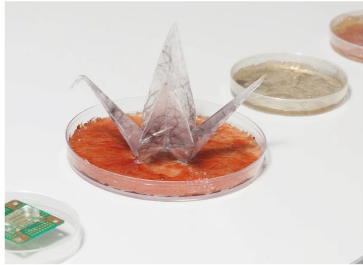
Tokyo



Aura
T₁



Chemical Synchronisation
T₂



BIOrigami
T₃

Figure 2. Resulting artifacts from the seven collaborative projects studied.

Paris projects P	Minima, the elementary biology lab P ₁			Tactile Micro Landscape P ₂		IndiCo P ₃			Bio-Clock P ₄			
Designers Des	P ₁ Des _a		P ₁ Des _b	P ₂ Des _a		P ₂ Des _b		P ₃ Des _a	P ₃ Des _b	P ₃ Des _c	P ₄ Des _a	P ₄ Des _b
Biologists Bio	P ₁ Bio		M ₁ <i>(post-doc researcher)</i>	P ₂ Bio		M ₂ <i>(post-doc researcher)</i>		P ₃ Bio		M ₂ <i>(post-doc researcher)</i>	P ₄ Bio	M ₂ <i>(post-doc researcher)</i>
Tokyo projects T	Aura T ₁			Chemical Synchronisation T ₂		BIOrigami T ₃						
Designers Des	T ₁ Des		T ₂ Des	T ₂ Des		T _{2,3} Des		T _{2,3} Des				
Biologists Bio	T ₁ Bio _a <i>(professor)</i>	T ₁ Bio _b	T ₁ Bio _c <i>(professor)</i>	T ₂ Bio <i>(professor)</i>		T _{2,3} Bio		T ₂ Bio <i>(professor)</i>		T _{2,3} Bio		

Figure 3. Participants' naming scheme according to their profession (designers and biologists, including mentors), the home institution (Paris, Tokyo) and the project.