IASDR 2019
International Association of Societies of Design Research Conference 2019
DESIGN REVOLUTIONS
Manchester School of Art
Manchester Metropolitan University
02-05 September 2019

Exploring How Boundary Objects Can Support Multidisciplinary Design and Science Collaboration

Välk, Sander*[a]; Maudet, Nolwenn[b]; Mougenot, Céline[a]

[a] Dyson School of Design Engineering, Imperial College London, London, United Kingdom
[b] Tokyo Design Lab, The University of Tokyo, Tokyo, Japan
* sander.valk@imperial.ac.uk

In order to solve complex issues, professionals from different fields of expertise increasingly collaborate across domains. These collaborations require meaningful and efficient processes, particularly when design approaches and scientific knowledge is combined. Based on the review of existing literature on the role of incidental learning in ideation and boundary objects in multidisciplinary team creativity, it can be proposed that knowledge sharing can support collective creativity. This approach was tested in a preliminary study of a collaborative creative task with pairs of design engineers and bio-scientists. Four pairs were asked to jointly discuss a healthcare-centred innovation brief, and generate novel ideas based on their own expertise. The findings show that boundary objects support knowledge sharing across disciplines in creative collaborations - in this case, design engineering and synthetic biology. While strong role asymmetry was observed, it has been found that boundary objects are instrumental in ensuring both parties participate effectively in the creative session. In the study, designers were found to be steering the conversations by generating boundary objects more frequently than scientists (66% of total number vs. 34%) and sharing knowledge on the design process with them. This initial study will later inform the development of a toolkit that aims to support science and design collaboration process.

Keywords: collaborative design; science; design protocols; boundary objects

1 Introduction

To address ill-defined and complex societal problems, innovators increasingly collaborate across disciplines, combining design approaches and scientific knowledge (Gero, 2000; Sawa, 2016; Schindler, 2015; Simons et al., 2011; Tsekleves et al., 2019) and try to entangle two or more disciplines among art, design, engineering and science (Oxman, 2016; Stark, 2009). However, cross disciplinary collaborations can lead to a lack of mutual understanding between collaborators due to “object worlds” and “thought worlds” presented by boundaries between practices (Bucciarelli, 2003). The context of science and design collaboration can be a rich ground for the generation of creative innovations, but the interactions, methods, processes for such collaboration are yet to be defined (Dunne and Raby, 2013). This research aims at improving collaborations in multidisciplinary

Copyright © 2019. Copyright of this paper is the property of the author(s). Permission is granted to reproduce copies of the works for purposes relevant to the IASDR conference, provided that the author(s), source and copyright notice are included on each copy. For other uses, please contact the author(s).

innovation teams and at understanding how to cross boundaries between disciplines such as design and science.

In this paper, a review of existing literature on the role of incidental learning in creative processes and exploration about the role of boundary objects in multidisciplinary teams is carried out. This is followed by a proposed approach for leveraging collective creativity through knowledge sharing. Ultimately, a preliminary study on knowledge sharing in collective ideation is explained. An analysis how boundary objects support knowledge sharing across disciplines – in this study, between design engineering and synthetic biology creative collaborations, concludes the findings.

2 Literature review

2.1 Creativity in Multidisciplinary Collaboration

Every advancement in humankind has resulted from creativity (Sternberg and Kaufman, 2018). Similarly, creativity is a key element for innovation in teams (Amabile, 1988). This study is concerned about exploring ways of enhancing creativity defined as “the production of novel and appropriate ideas” (Crilly and Cardoso, 2017) and as a process by which an agent uses its ability to generate ideas, solutions or products that are novel and valuable (Sarkar and Chakrabarti, 2008). Design studies generally examine external creativity triggers and fixation in the context of problem solving design tasks (Vasconcelos and Crilly, 2016). In a similar manner, scholars assume creativity can be triggered to tackle wicked problems (Rittel and Webber, 1973) and to innovate. However, in this context, the approach requires focus on intrinsic triggers of creativity (Amabile, 1988) and emphasis on incidental situated learning (Lave and Wenger, 1991).

2.2 Learning in Conceptual Ideation Phase

The first studies on creativity describe a process in four phases: preparation, incubation, illumination and verification (Wallas, 1926), and suggest that unconscious factors have a crucial role in the creativity process. More recent studies on idea generation propose that ideas originate from the knowledge base of a practitioner, which is explained in SIAM Model (Search for Ideas in Associative Memory) (Rietzschel et al., 2007). The model also suggests that creativity can be enhanced by inducing people to leave the path of least resistance by increasing depth and breadth of the process. This in essence is the core of any multidisciplinary collaboration because it stimulates and expands the knowledge base of practitioners through a process, which stretches boundaries between different knowledge spaces (Drach-Zahavy and Somech, 2001; Oxman, 2016). When developing innovations, the task is essentially complex and multifaceted, therefore it requires an element of mutual learning and co-doing, before truly novel and appropriate ideas are likely to be achieved (Amabile, 1988). Learning function can be defined as the extent to which team or group members overtly reflect on their objectives, strategies and

processes for the purpose of creating a team-level intellectual product that initiates change (Drach-Zahavy and Somech, 2001).

2.3 Four States of Knowledge

When analysing the importance of knowledge in creative processes, such as conceptual design phase in the existing literature, four states of knowledge, that can be leveraged in order to pave a way to innovative ideas have been identified (Figure 1). The first state is the natural knowledge base of the practitioner. In order to expand this state, collective learning-based activities can be conducted. Team learning is a phenomenon related to situated cognition. The theory of situated cognition rejects the assumption that learning is the reception of factual knowledge or information. Instead, it puts forward that learning is a process of participation in communities of practice, participation that is at first legitimately peripheral, but that increases gradually in engagement and complexity (Lave and Wenger, 1991). This type of learning can be intentional, but is never highly structured, which makes it incidental (Marsick and Watkins, 2001). Informal, also known as incidental, learning is always occurring, with or without the practitioner being aware of it. Marsick and Watkins characterise incidental learning as being integrated with daily routines, triggered by internal or external jolt, not highly conscious, influenced by chance, inductive of reflection and action, linked to learning of others.

As learning grows out of everyday encounters while working and living in a given context, it poses an important perspective for reaching the second knowledge state - upgraded knowledge. According to Christiaans (2002), ideas and creativity in designing originate from the practitioner's knowledge base, and more importantly, upgrading the practitioner's knowledge base within a given domain, will increase the chances of her or him coming up with an idea, that can be characterised as creative (Cross et al., 1992). The third knowledge state enables creation or emergence of a creative idea, by facilitation of preparation, incubation and illumination as described in Wallas' model. The fourth knowledge state proposes the emergence of an innovative idea, based on findings stating that creativity is a key element for innovation in teams or groups of practitioners (Amabile, 1988).

2.4 Boundary Objects in Creative Sessions

In order to innovate, new knowledge ought to be created and effectively shared between practitioners (Cairó Battistutti and Bork, 2017). The main challenge is converting tacit knowledge (described as valuable and highly subjective insights and intuitions that are difficult to capture and share) to explicit (defined as objective and transferable) (Nonaka and Takeuchi, 1995). This process can be facilitated through methods such as generation of metaphors. This type of knowledge creation and sharing is particularly difficult in communications between actors from domains far apart (Star and Griesemer, 1989) which is especially relevant for collaborations between scientists and designers, because new objects and concepts have different meanings in different domains. A potential way to explore collaborative knowledge creation and sharing, is to focus on boundary objects in context (Balint and Pangaro, 2017). Boundary objects can be described as a means of representing, learning

about, and transforming knowledge to resolve the consequences that exist at a given boundary (Carlile, 2002). Furthermore, boundary objects are objects which are both plastic enough to adapt to given needs and the constraints of the several parties employing them, yet robust enough to maintain a common identity across domains by enabling translation and transfer of knowledge. The creation and management of boundary objects is a key process in developing and maintaining coherence across intersecting social worlds (Star and Griesemer, 1989) such as collaborations between scientists and designers. However, currently there is little understanding about how designers and scientists concretely generate and use boundary objects to leverage incidental learning.

3 Research Question and Hypothesis

Based on this literature review, a new theoretical approach for leveraging creativity through incidental situated learning (Figure 1) can be proposed. The proposal is a result of finding structure and sequence between phases in creative conceptual elements of a design phase. According to this sequence, the conceptual design phase starts with a natural knowledge base, and there are steps, that can be taken to reach an innovative idea. The first step is to improve the knowledge base, which can be done by learning. New knowledge acquisition facilitates the emergence of a creative idea, which in turn is a precondition for innovation. This approach is supported by the emerging knowledge on creativity stimulation that emphasises ambiguity and unstructured sources of inspiration (Cheng et al., 2014). These qualities are also known to be preferred by designers when they compare and choose creativity triggers for their process (Kwiatkowska et al., 2014). In this context, the question is about understanding how the creativity process unfolds when, multidisciplinary teams collaborate in a field that is rapidly gaining momentum (Dunne and Raby, 2013). It can be argued that the way practitioners from different disciplines learn from each other is a key to creativity, which in turn is a much-needed quality in innovation-oriented ventures. It is hypothesised that incidental learning can be identified through boundary objects. Inspired by this, a proposal to explore the nature of learning in multidisciplinary context can be formed, by asking: *How does incidental situated learning occur in innovation aimed open-ended collaborations?*

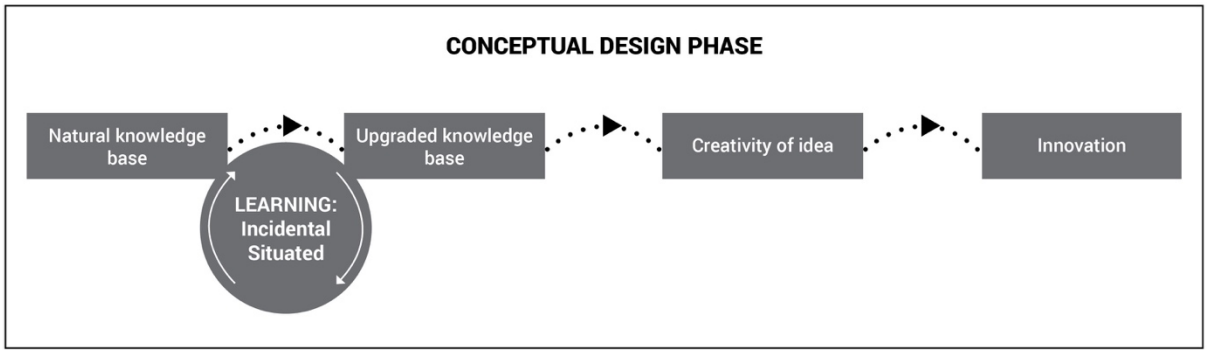


Figure 1 - Hypothetical approach to leverage creativity through knowledge creation

Limitation of this approach is that there are several facets to creativity, which are difficult to control or describe. A study on synergy and team-level creativity describes creativity as the intersection of individual's domain relevant skills, creativity relevant skills, motivation and diversity of the team (Kurtzberg and Amabile, 2001). Similarly, environmental factors can either promote or hinder creativity and innovation. These factors include freedom, appropriate resources, good project management, as well as practitioners' intrinsic motivation and lack of extrinsic constraints (Amabile, 1988). These factors can either work as creativity enhancers or reducers.
It is important to acknowledge, that this study contributes to an understanding about designing *for* creativity (and innovation) by providing a framework that explores the link between incidental situated learning through boundary objects.

4 Experimental Study

4.1 Objective and overview

To understand the effect of boundary objects in collaborations between designers and scientists, 4 ideation sessions were organised. Participants were asked to come up with an innovative (novel and useful) project proposal and illustrate potential outcomes of their proposal. The study entails a qualitative analysis of the use of boundary objects, focusing on how both physical as well as verbal boundary objects help us understand how mutual learning occurs. This is done with the long-term aim of exploring what kind of attempts can be made to enhance these types of processes, by introducing strategic design interventions that embody a boundary object, or inviting practitioners to create one, as part of the collaboration. In order to leverage the creation of such innovations, the following research questions are proposed:

- How does learning occur in multidisciplinary ideation sessions between designers and scientists?
- What is the significance of boundary objects in 'creative conversations' aiming at innovative ideas (defined as ideas that are novel and useful)?
- What is the effect of boundary objects in multidisciplinary ideation sessions: what positive and negative effects can be identified?

The analysis is contributing to the developing knowledge about understanding the reflective practitioner (Schön, 1991) and co-evolution of ideas in a collaborative multi-agent context. Stompff et al.,(2016) have demonstrated how surprises can be beneficial for inciting reframing in teams. Similarly, this analysis aims to uncover the significance of boundary objects in creative conversations.

4.2 Participants

8 participants were recruited for the purpose of conducting 4 creative sessions with 2 participants in each session - one designer and one scientist (Figure 2). All participants were postgraduate students. Designers were enrolled in MSc/MA Innovation Design Engineering program at Imperial College London / Royal College

of Art and scientists were enrolled in MRes Synthetic Biology program or PhD candidates in Synthetic Biology at Imperial College London. Every participant received a compensation for their time. All participants had interest about the domain of the partner they were about to collaborate with. Two participants had previously experienced collaboration between scientist and designer on a relatively brief design-led project. For the purpose of the session, subjects were randomly allocated into pairs (three pairs consisting of male participants and one of female participants).

4.3 Procedure

Participants were informed that the study was about applying their expertise in generating new ideas that can be useful in the future of healthcare domain. Participants were told that there are similar sessions running in the School and outcomes will be evaluated by a committee with potential for selected projects to be awarded or implemented at the college. The evaluation criteria are based on newness and usefulness of proposed solutions, as well as meaningful implementation of participants' own area of expertise in the project.

Phase 1 - Project proposal (45 minutes)

The session is divided into two phases. In the first phase the participants were asked to establish a theme for a hypothetical fully funded design and science collaboration project, which would take place over 6 months. The participants were advised to base the project on ongoing activities and themes currently relevant in their respective departments or related to their study program or research interests. Participants were required to produce a clearly defined title and short rationale for the proposed project by the end of the 45 minutes phase.

Phase 2 - Idea generation (45 minutes)

The participants were asked to generate preliminary ideas or solutions to the project proposal coined in Phase 1. The ideas should aim to illustrate the potential outcomes of the project and usefulness in the healthcare domain.



Figure 2 – Experimental setup and discussion about a user journey. Synthetic biologist is on the left, designer on the right

All information was represented on printed sheets and in case of questions, they were encouraged to ask the note taking conductor(s) in the room. The following tools were provided: A4 sheets titled: Project Proposal, A4 sheets titled Idea Title, post-it notes, pens, coloured papers, scissors, glue, whiteboard, markers, coloured stickers. The choice of tools is a reflection of conventionally used office supplies in design as well a science meetings.

4.4 Data collection and analysis

All sessions were recorded with two complementary video-cameras. One experimenter took notes during the sessions and interviews that followed. All artefacts produced during the sessions were collected in the end.

Qualitative content analysis is applied to divide text data into explicit categories with the aim to characterise contextual meaning and provide understanding about the nature of the collaboration (Hsieh and Shannon, 2005). The data is first coded by the first author and verified by the second author to ensure reliability. The applied coding process consists of the following steps: firstly, episodes with utterances where co-evolution takes place through learning are identified, which can be identified by an appearance of a boundary object. Secondly, we identify how learning or co-evolution starts by coding the phrases or activities that relate boundary objects. Thirdly, we add our interpretation about the type of boundary object identified next to the quote triggering it. We also aim to measure the time which is spent on being immersed with every boundary object.

The data analysis method is adapted from a study of co-evolution of ideas developed by Reyemen, Dorst and Snelders (McDonnell and Lloyd, 2009). The perspective for analysing the conversations, is to focus on aspects that indicate incidental situated learning through emergence of boundary objects. Similarly to this study, we identify verbal boundary objects in dialogue, predominantly in the form of references and summaries (McDonnell and Lloyd, 2009). These forms of communication indicate increased knowledge levels as well as emergence of mutual understanding regarding the subject under discussion. The qualitative aspect of the analysis reveals patterns and interactions (Clarke and Braun, 2013) that enable an understanding about knowledge sharing as a source of creativity.

In contrast to the study on co-evolution of ideas, where the focus is on identifying verbal boundary objects, physical manifestations of knowledge sharing are also included in this study. In the analysis, boundary objects that are reflected in sketches, drawings, prototypes and process maps are identified (Carlile, 2002) as these phenomena are indicators of incidental situated learning (Lave and Wenger, 1991). We have expanded the definition of process maps to include storylines, timelines, user journeys etc.

5 Results

5.1 Differentiated designer and scientist roles in collaborative sessions

The task provided in the beginning of the session emphasised the fact that proposals should stem from both designer's and scientist's own area of expertise. Nevertheless, a clear role division between designers and scientists was observed in all sessions. These roles can be summarised as design-explorer and scientist-treasury. This means that in majority of cases and utterances, the designer initiated a way forward in the conversation, by either asking a question or providing a summary or interacting with a boundary object. Concurrently, and due to designers' likelihood of taking the lead in steering the process, a tendency where designers continuously inquire the synthetic biologist about their expertise and approach them as sources of information was observed. In other words, scientists were acting as sources of information. Beyond questioning and answering strategy, tools and methods used in the collaborations were predominantly proposed by designers, who were driving the materialisation of ideas (see table 1).

Table 1. Coding examples of verbal transcripts of the ideation session between a designer and a scientist in session 3.

Start 00:43:38	End 01:27:44	Duration (s)	Quote/description (S) – Scientist (D) – Designer	Interpreted learning indicator (BO_N) – boundary object (R_N) – reframing
00:44:10	00:51:05	415	(D) 'Let's list all the things we talked about'	(BO_1) – list of stakeholders and their needs
00:54:50	00:55:17	27	(S) 'You could do a weird thing…?'	(BO_2) – product use scenario
00:57:44	00:59:44	120	(D) 'Give him a name…'	(BO_3) – persona Stephen/sketch
00:59:44	01:00:04	20	(S) 'There's a company following up on people'	(BO_4) – reference to an existing routine (for service touch points)
01:01:05	01:01:35	30	(D) 'How about personal stuff like an app…alarm clock…'	(BO_5) – service use scenario
01:01:35	01:01:55	20	(D) 'You know, like Monday Socks'	(BO_6) – reference to existing product
01:03:20	01:04:20	60	(D) 'You get it in the post...'	(BO_7) – product/service use scenario
01:05:25	01:05:40	15	(D) 'A month-long egg timer'	(BO_8) – sketch/reference to existing product
01:06:15	01:13:40	445	(D+S) 'Let's look at Stephen's month'	(BO_9) – sketch/timeline
01:13:45	01:14:42	57	(D) 'Let's summarise it'	(BO_{10}) – sketches
01:22:10	01:22:20	10	(D) 'I'm making a pill box'	(BO_{11}) – cardboard prototype

5.2 Boundary objects to record, explain and generate

A divide between the types of boundary objects initiated from designers and scientists was observed. Scientists mostly brought up references to existing products, technologies or research, while designers predominantly initiated boundary objects often associated with design process (Table 2). These include various forms of process maps like user journeys, timelines, personas, diagrams and charts. Generally, the more time practitioners spent on being deeply immersed with a single boundary object, the better the quality of the final idea, in comparison to the number of boundary objects in the discussion. This is the case when the quality of an idea that emerges from the boundary object is subjectively assessed by the authors.

Beyond the type of boundary objects, they can also be divided into three different categories based on their reason for being: to record an idea or milestone in the process, to generate an idea and to explain and externalise existing knowledge to others. These sub-categories in all their forms fall under the definition and rationale of boundary objects discussed earlier, but in addition, leverage the understanding about various boundary objects in collaborations between bio-science and design. To identify the source of a quote or boundary object, the following scheme is used in the analysis: D1-D4 for designers and B1-B4 for bio-scientist, where the number indicates one of the four sessions conducted.

Table 2. Number of boundary objects generated by designers and scientists

Type of Boundary Object	Generated by designer	Generated by scientist	Total count
Post-it note with a new idea	11	3	14
Sketch of a new idea	21	4	25
Reference to existing product, technology or service	19	25	44
Reframing (attempt)	8	1	9
Metaphor	0	1	1
Process map (journeys, timelines, personas etc.)	9	1	10
Prototype	1	0	1
Total	69 **(66%)**	35 **(34%)**	104 **(100%)**

The occurrence of a boundary object varied between different types of boundary objects. Explanatory boundary objects were more likely to emerge in the middle of conversations. These types of boundary objects are often related to participants trying to establish the so-called common ground, and often manifest themselves through references. These references were made about related projects or products

in the wider world, for example *'They managed to create an enzyme that could…'* (S1) or *'So, one of my colleagues at… worked with designers, to improve…'* (S4). These types of explanatory boundary objects demonstrated possibilities for solving the task at hand in the collaboration and paved the way for reaching a novel and useful idea. Most often, explanatory boundary objects formed a basis in the conversation and were expressed verbally, but in cases where one or both of the participants found the reference or explanation particularly insightful, it was also captured on a piece of paper (mostly post-it note).

The second type of boundary object observed in the collaboration recorded an element of the overall generative conversation, through writing or sketching. They were applied in the middle of the conversation when the participant(s) considered the shared information useful or relevant enough, for having potential to leverage the ideas. Oftentimes, boundary objects like this, were first expressed verbally, but eventually marked down and triggered by one of the participants announcing that *'I'm just writing down some focus areas'* (D1). Alternatively, boundary objects with the aim to record, can be initiated to summarise a previous episode in the collaboration. In this case, they were identified by either the designer or scientist suggesting making a note of the progress, for example by saying *'Let's list all the things we talked about'* (D3). In this instance, notes were usually made on post-its.

The third type identified in the collaboration was a boundary object which is generative in its nature by inciting a creation of an idea that can be made explicit and shared. Generative boundary objects were often followed by explanatory and recorded ones, which suggests that they appear once the participants feel knowledgeable or competent enough to create and propose solutions that are relatively concrete. Generative boundary objects were usually a physical manifestation of ideas, as opposed to explanatory boundary objects. They were brought to life in various forms, which usually originated in the design domain and related to activities usually embodied in the design process, e.g. *'Should we just jot some ideas for five minutes?'* (D2) or *'Should we write rough ideas on post-its?'* (D2). Generative boundary objects also included user journeys, sketches, personas, scenarios and taking another perspective on the issue at hand, for example *'If we think about the patient's perspective…'* (D3) and *'I'm trying to think about the journey...'* (D4) in conversations between synthetic biologists and designers.

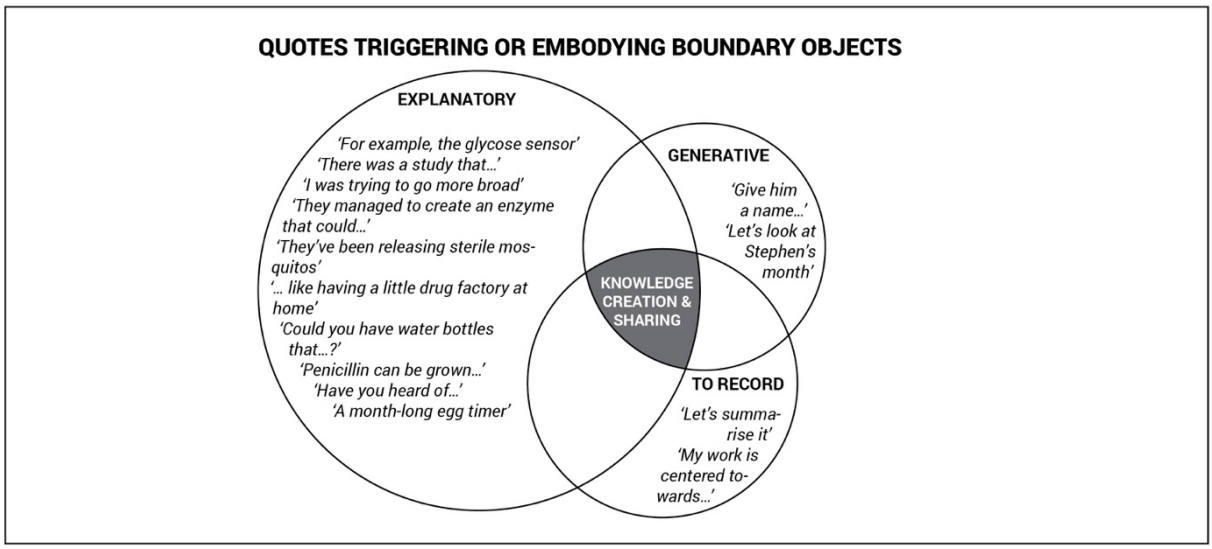


Figure 3 - Selection of quotes from collaborations between synthetic biologists and designer

6 Discussion

6.1 Understanding the role polarisation in design-science collaboration

Beyond the obvious knowledge gap between designers and synthetic biologists, the role polarisation phenomenon may originate from different approaches to leadership and practitioners' previous experiences with steering projects. This may be a reflection on designers being more accustomed to open-ended idea discussions and techniques, whereas synthetic biologists are driven by rigorous research findings. Comparatively few questions imposed by scientists to designers were observed. Despite this asymmetry, repeated question and answer sessions did not lead to one sided process because ideas themselves originated from designers and scientists collaboratively and indistinctly. This was also acknowledged by participants, for example in session 3 '*This felt like our project…It has met in the middle of our both fields'* (D3), followed by nonverbal confirmation (S3). These roles echo skills that each discipline can mobilise: designers are trained to inquire and probe, but scientists are accustomed to articulate potential research direction from existing literature. This is related to the observation that, in general, designers were driven by hypothetical futures and things that haven't been done before, whereas scientists search for proof of evidence as a precondition for feasibility.

6.2 Effects of boundary objects in multidisciplinary collaboration

Strong positive aspects associated with the use of boundary objects were observed. Most notably, they were instrumental in helping designers and scientist identify common ground. The recurrent use of references from scientists suggest that they were able to adapt the level of their discourse to that of the designers, by describing existing products and possible functionalities. Boundary objects also served as anchor points for both designers and scientists in helping the other understand their way of working. While scientists generally describe the process of research orally and explicitly, designers generally did not talk directly about the design process.

However, they indirectly explain the design process through different boundary objects they brought to the collaboration. For example, by introducing boundary objects such as user journeys, designers represented the process and provided guidance for what to discuss next and how to manipulate or formulate a boundary object. For instance, in session 3, the designer introduced a timeline of the user journey (Figure 4). The visual representation of the timeline helped the scientist understand how to participate in the conversation without requiring specific instructions from the designer. It can be assumed that in this case, the materialisation of the process helped scientists position themselves in the design process and actively engage with it. It is a manifestation of incidental learning about the design process. This is significant as designers generally introduce the boundary object by directly demonstrating how to manipulate or use it, for example, by filling the first step in the timeline.

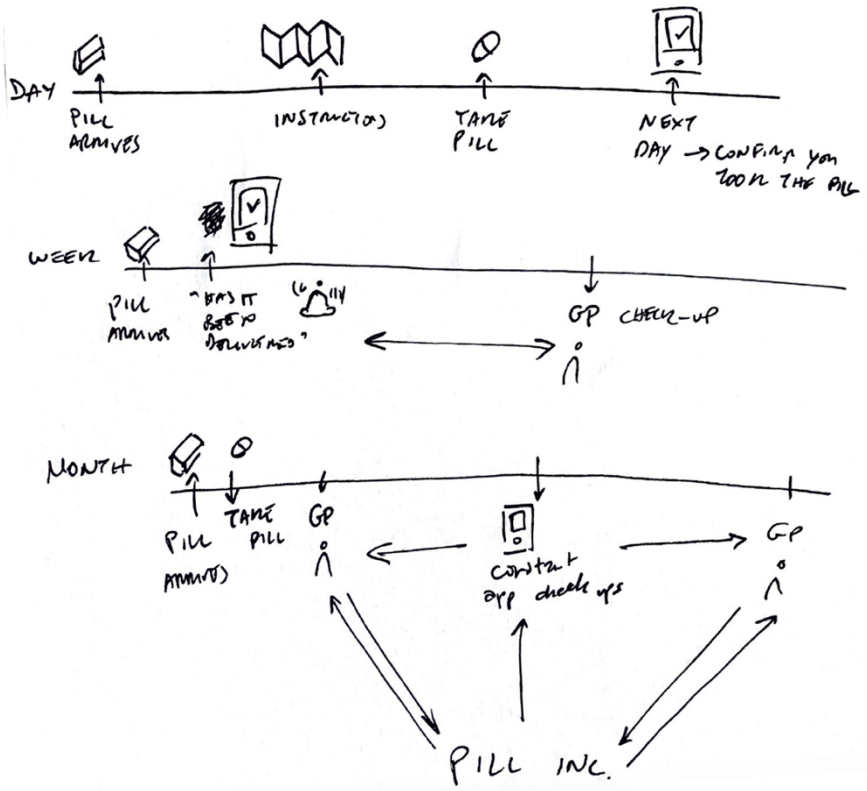


Figure 4 – An example of boundary object - timeline sketch from session 3

Contrarily, potential negative aspect boundary objects brought into the collaborative process, especially early on in the discussion have been identified. To some extent, this can be observed in all conversations and manifests itself as a decision to dedicate the collaboration on one specific application area of synthetic biology before discussing a broader set of potentialities within healthcare domain (as set out in the initial task). In this instance, biosensors or sensing mechanisms regarding illnesses or harmful bacteria became the drivers of the collaboration as observed through utterances such as *'I think it would be best to focus on sensing in our collaboration'*

(S1) in minute 13 and *'We use quite a lot of biosensors'* (S2) *'I love the word biosensor…'* (D2) in minute 6. Similar observations regarding decision making process were made in other sessions - *'There are many examples for using biosensors as application for diagnostics'* (S3), four minutes into the discussion. This effect can be described as unconscious focusing on a certain aspect regarding the task being solved, while leaving alternative options. In other words idea fixation (Crilly and Cardoso, 2017) has been identified in the collaborations between designers and synthetic biologists. This can be seen as a cognitive error and associated with low levels of creativity, which makes it consistently unfavourable (Vasconcelos and Crilly, 2016). It is assumed that fixation on one idea during the session is the result of participants being unable to leave the path of least resistance, once they have mutually found an idea that they can both agree on. Given the complexity and difficulties between practices, but also because of the limited time for the session, this may be considered inevitable. However, it can be suggested that efforts should be made to leverage leaving this path, in order to improve collaborations.

7 Conclusion

7.1 Significance of boundary objects in multidisciplinary collaboration

The findings of our study are multifaceted (Figure 5) and emphasise the significance of boundary objects in upgrading practitioner knowledge base, which is a precondition for creativity. This empirical study on collaborative innovation driven sessions combining designers and bio-scientists showed that boundary objects are of crucial importance, when complex information needs to be shared, in order to be meaningfully synthesised into a novel and useful outcome. The analysis has revealed three functions of boundary objects, which can be categorised as generative, explorative and to record. The evolution of ideas and concepts in collaborations relied on learning from one another, and on the ability to creatively form innovative solutions in healthcare domain. We found that boundary objects can be valuable indicators of learning and enable a deep understanding into the dynamics of multidisciplinary collaboration, when practitioners are faced with complex open-ended questions. Boundary objects served as anchor points in conversations, enabling progress. They also facilitated a common ground between practices far away from each other. It may be hypothesised that collaboration between design and science would benefit from tools and processes that purposefully intend to facilitate interactions, which leverage knowledge sharing and mutual learning.

7.2 Ambiguity in learning and role asymmetry

The learning process enabled by boundary objects was ambiguous in nature, which emphasises the benefits of incidental, situated and contextual learning in multidisciplinary innovation-oriented processes. The study found that one of the most valued aspects of the exchange was open-ended nature of collaboration. Ambiguity by design can lead to a pleasant cross disciplinary collaboration for the practitioners,

because it offers an experience of taking responsibility and finding approaches that are meaningful for the individual. Ownership of the problem at hand is related to bottom up approach and it can be suggested that it will aid the creation of meaningful ideas. Based on the experimental study, an implication for a design intervention that aims to improve such collaborations is to acknowledge the likelihood of one-sided interview-like process and to address the need for interactions where all parties and actors from various domains can experience responsibility and involvement.

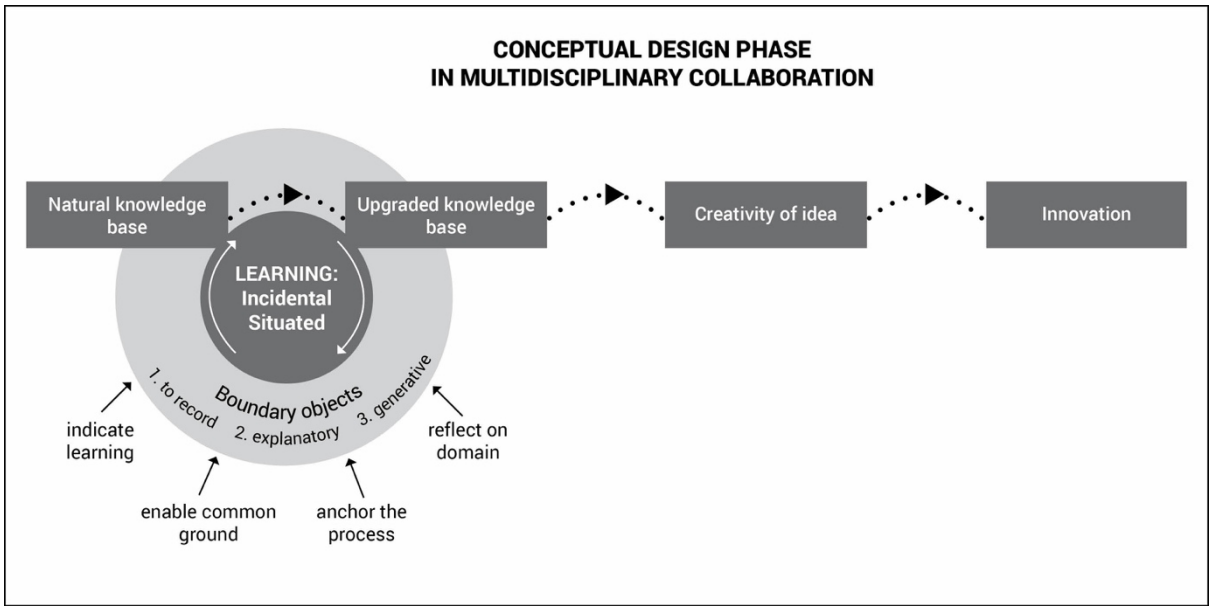


Figure 5 – Effects and types of boundary objects in multidisciplinary collaboration in the context of an approach to leverage creativity through knowledge creation

7.3 Future work

The long-term objective of this research is to understand the correlation between incidental situated learning and creative quality of ideas generated in collaborations. In the next phase, a design intervention will be introduced to the collaboration between designers and scientists. The aim is to assess the impact of the intervention on the creative quality of ideas generated in the collaboration. The expected outcome of the research is a new model of collaborative innovation, supported by a tool(kit), that will support creative conversations between multidisciplinary agents, with a particular focus on designers and scientist. The outcome is aimed to be useful in practice as well as in academia.

8 References

Amabile, T.M. (1988), “A Model of Creativity and Innovation in Organizations”, *Research in Organizational Behaviour*, Vol. 10 No. 1, pp. 123–167.

Balint, T.S. and Pangaro, P. (2017), “Design space for space design: Dialogs through boundary objects at the intersections of art, design, science, and engineering”, *Acta Astronautica*, Elsevier Ltd, Vol. 134 No. January, pp. 41–53.

Bucciarelli, L.L. (2003), “Designing and learning: A disjunction in contexts”, *Design Studies*, Vol. 24 No. 3, pp. 295–311.

Cairó Battistutti, O. and Bork, D. (2017), “Tacit to explicit knowledge conversion”, *Cognitive Processing*, Vol. 18 No. 4, pp. 461–477.

Carlile, P.R. (2002), “A Pragmatic View of Knowledge and Boundaries: Boundary Objects in New Product Development”, *Organization Science*, Vol. 13 No. 4, pp. 442–455.

Cheng, P., Mugge, R. and Schoormans, J.P.L. (2014), “A new strategy to reduce design fixation: Presenting partial photographs to designers”, *Design Studies*, Elsevier Ltd, Vol. 35 No. 4, pp. 374–391.

Christiaans, H. (2002), “Creativity as a Design Criterion”, *Creativity Research Journal*, Vol. 14 No. 1, pp. 1–16.

Clarke, V. and Braun, V. (2013), *Successful Qualitative Research: A Practical Guide For Beginners*, *Successful Qualitative Research A Practical Guide for Beginners*.

Crilly, N. and Cardoso, C. (2017), “Where next for research on fixation, inspiration and creativity in design?”, *Design Studies*, Elsevier Ltd, Vol. 50, pp. 1–38.

Cross, N., Dorst, K. and Roozenburg, N. (1992), “Research in Design Thinking”, Delft University Press, pp. 111–118.

Drach-Zahavy, A. and Somech, A. (2001), “Drach-Zahavy, Somech - Understanding team innovation the role of team processes and structures.pdf”, *Educational Publishing Foundation*, No. Group Dynamics: Theory, Research, Practice. 5(2):111-123, June 2001., available at: https://ovidsp-dc2-ovid-com.iclibezp1.cc.ic.ac.uk/sp-3.33.0b/ovidweb.cgi?&S=FFIEFPBCDKEBOOEGJPCKFFBFFNECAA00&Complete+Reference=S.sh.22%7C1%7C1&Counter5=FTV_complete%7C00066945-200106000-00005%7Covft%7Covftdb%7Covfte.

Dunne, A. and Raby, F. (2013), “Speculative Everything”, *Design, Fiction and Social Dreaming*.

Gero, J.S. (2000), “Computational Models of Innovative and Creative Design Processes”, *Technological Forecasting and Social Change*, Vol. 64 No. 2–3, pp. 183–196.

Hsieh, H.-F. and Shannon, S.E. (2005), “Three approaches to qualitative content analysis.”, *Qualitative Health Research*, Vol. 15 No. 9, pp. 1277–88.

Kurtzberg, T.R. and Amabile, T.M. (2001), “From Guilford to Creative Synergy: Opening the Black Box of Team-Level Creativity”, *Creativity Research Journal*, available at:https://doi.org/10.1207/S15326934CRJ1334_06.

Kwiatkowska, J., Szóstek, A. and Lamas, D. (2014), “(Un) structured Sources of Inspiration : Comparing the Effects of Game-like Cards and Design Cards on Creativity in Co-design Process”, *Pdc ’14*, No. 2010, pp. 31–39.

Lave, J. and Wenger, E. (1991), *Situated Learning: Legitimate Peripheral Participation (Learning in Doing: Social, Cognitive and Computational Perspectives)*, *Learning in Doing*, available at:https://doi.org/10.2307/2804509.

Marsick, V.J. and Watkins, K.E. (2001), “Informal and Incidental Learning”, *New Directions for Adult and Continuing Education*, Vol. 2001 No. 89, p. 25.

McDonnell, J. and Lloyd, P. (2009), “About Designing:Analysing Design Meetings”, 1st ed., CRC Press/Balkema, pp. 67–82.

Nonaka, I. and Takeuchi, H. (1995), “Knowledge-Creating Company”, *Harvard Buisiness Review*, available at:https://doi.org/10.1016/S0969-4765(04)00066-9.

Oxman, N. (2016), “Age of Entanglement”, *Design and Science, MIT Media Lab*, No. MIT Press, pp. 1–11.

Rietzschel, E.F., Nijstad, B.A. and Stroebe, W. (2007), “Relative accessibility of domain knowledge and creativity: The effects of knowledge activation on the quantity and originality of generated ideas”, *Journal of Experimental Social Psychology*, Vol. 43 No. 6, pp. 933–946.

Rittel, H. and Webber, M. (1973), “Dilemmas in a General Theory of Planning”, *Policy Sciences*, Vol. 4 No. December 1969, pp. 155–169.

Sarkar, P. and Chakrabarti, A. (2008), “The effect of representation of triggers on design outcomes”, *Artificial Intelligence for Engineering Design, Analysis and Manufacturing: AIEDAM*, Vol. 22 No. 2, pp. 101–116.

Sawa, M. (2016), “The laboratory life of a designer at the intersection with algal biotechnology”, *Architectural Research Quarterly*, Vol. 20 No. 1, pp. 65–72.
Schindler, J. (2015), “Expertise and tacit knowledge in artistic and design processes: Results of an ethnographic study”, *Journal of Research Practice*, Vol. 11 No. 2, pp. 1–23.
Schön, D. (1991), *The Reflective Practitioner - How Professionals Think in Action*, Routledge of Taylor & Francis Group, New York, available at: https://www.taylorfrancis.com/books/9781351883160.
Simons, T., Gupta, A. and Buchanan, M. (2011), “Innovation in R & D: Using design thinking to develop new models of inventiveness, productivity and collaboration”, *Journal of Commercial Biotechnology*, Vol. 17 No. 4, pp. 301–307.
Star, S.L. and Griesemer, J.R. (1989), “Institutional Ecology,Translations and Boundary Objects: Amateurs and Professionals in Berkeley Museum of Vertebrate Zoology, 1907-39”, *Social Studies of Science*, Vol. 19 No. 3, pp. 387–420.
Stark, D. (2009), *The Sense of Dissonance*, Princeton University Press, available at:https://doi.org/10.1515/9781400831005.
Sternberg, R.J. and Kaufman, J.C. (Eds.). (2018), *The Nature of Human Creativity*, *The Nature of Human Creativity*, Cambridge University Press, available at:https://doi.org/10.1017/9781108185936.
Stompff, G., Smulders, F. and Henze, L. (2016), “Surprises are the benefits: reframing in multidisciplinary design teams”, *Design Studies*, Elsevier Ltd, Vol. 47, pp. 187–214.
Tsekleves, E., Darby, A., Ahorlu, C., De Souza, D., Pickup, R. and Boakye, D. (2019), “Combining design research with microbiology to tackle drug-resistant infections in different home environments in Ghana: Challenging the boundaries of design thinking”, *The Design Journal*, Vol. 22 No. sup1, pp. 347–358.
Vasconcelos, L.A. and Crilly, N. (2016), “Inspiration and fixation: Questions, methods, findings, and challenges”, *Design Studies*, Elsevier Ltd, Vol. 42, pp. 1–32.
Wallas, G. (1926), “The art of thought”, *Book*.

About the Authors:

Sander Välk: PhD candidate in design research at the Imperial College London and product experience designer. Sander’s primary research interest is to understand and develop human interaction centred methods and interventions for improving multidisciplinary collaborations.

Nolwenn Maudet: Interaction designer and design researcher at the Tokyo Design Lab. She obtained her PhD in Human-Computer Interaction from the University of Paris-Saclay. As a design researcher, she studies how designers work with their digital tools and with other communities of practice.

Céline Mougenot: Senior Lecturer in Engineering Design at Imperial College London. Her research interests are in Design Cognition and Collaborative Design, investigating socio-cognitive aspects of innovation processes. She examines what conditions favour innovation in multidisciplinary collaborations (Design / Engineering / Science / Art) or multicultural contexts (Europe / Asia). She was previously an Associate Professor at Tokyo Institute of Technology from 2011 to 2018.

Acknowledgement: This research is partially supported by an EPSRC Doctoral Training Program studentship to the first author.