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GENERATIVE BOUNDARY OBJECTS AS INTEGRAL PARTS OF FRAMING IN DESIGN AND BIOSCIENCE COLLABORATIONS

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Abstract

Collaborations between design engineers and bioscientists offer novel opportunities that could help solving some of the biggest challenges organisations and societies are facing. Combining design and bioscience has the potential to create responsible and desirable products/services, however such ventures come with challenges rising from boundaries between practices. This research explores boundary objects as sources of framing in multidisciplinary collaborations. The results are based on a descriptive study with synthetic biologists and design engineers working on an innovation-driven task.

Keywords: collaborative design, boundary objects, multi-/cross-/trans-disciplinary approaches, design creativity

1. Introduction – why collaborate?

Our society is faced with (man-caused) challenges that call for radical change in the way disciplines work together. It is acknowledged that responses to these challenges can rise from combining different disciplines with the aim of creating socially, environmentally and ethically responsible innovations. This is particularly relevant in the age where living organisms become a subject of design and synthetic biologists aspire to create so-called living machines (Szymanski and Calvert, 2018). At the same time design (research) is shifting focus from object and user to more organic, biological, systems-based and sustainable approaches.

Scholars have tried to untangle the essence of science and design as independent disciplines for a long time. Increasingly it is acknowledged that distinctions between basic and applied sciences (including design) are becoming irrelevant in the age of multidisciplinary research (Driver et al., 2011; Webster, 1991). Simon (1997) describes the basic sciences as being concerned with how things are. Design, on the other hand, is concerned with how things ought to be. Christopher Alexander has claimed that scientists try to identify components of existing structures whereas designers try to shape the components of new structures (Cross, 2001). These (seemingly) fundamentally opposing perspectives in science and design illustrate where some of the challenges for working together effectively come from; however with appropriate tools, strategies, mindsets and approaches success can be achieved (Välk and Mougenot, 2019). Various collaborative projects that have allowed open-ended approaches and experimentation reveal aspects of successful multidisciplinary team work with creative and innovative outcomes (Agapakis, 2014; Bernstein, 2011). The outcomes of these projects rely on effective knowledge sharing, knowledge transfer and knowledge activation between disciplines far apart from one another.

The aim of our research is to leverage teams of bio-scientists and design engineers towards creative and innovative collaboration outcomes. Such collaborations are yet to make a significant and positive impact. The objective of this particular study is to find novel insight for the design of a strategic intervention. This insight will be developed by characterising boundary objects that emerge in the context. The intervention (boundary object) will be designed to facilitate team interactions that support framing the problem and solution space in collaborations between bio-scientists and design engineers.

2. Lack in understanding framing in multidisciplinary collaboration

Numerous studies and projects demonstrate the potential of bio-science and design collaboration in generating creative and innovative ideas (Calvert and Schyfter, 2017; Chieza, 2018; Sabin and Jones, 2018; Sawa, 2016). It is widely agreed that creativity and innovation are vital to the realisation of the potential of human ingenuity and are the essence of design (McMahon et al., 2013). Creative ideas are significantly influenced by practitioners' knowledge base (Rietzschel et al., 2007) and how new knowledge can be obtained. The aspect of collaborative framing process in multidisciplinary teams has been linked to learning and generation of innovative ideas (Stompff et al., 2016). This link suggests that understanding how teams and organisations generate guiding frames for their activities is crucially important when the aim is to innovate. Schön (1988) describes framing in a following way:

> *"In order to formulate a design problem to be solved, the designer must frame a problematic design situation: set its boundaries, select particular things and relations for attention, and impose on the situation a coherence that guides subsequent moves".*

It may be inferred that in concept-level collaborations between bio-scientists and designers, practitioners from each discipline act as designers. This claim can be made because everybody who devises courses of action aimed at changing existing situations into preferred ones is a designer (Simon, 1997). Dorst and Cross (2001) have found that defining and framing the (design) problem is the key aspect of creativity and novel approaches. A model of co-evolutionary design (Maher, 2006) describes interactions between the problem space (where the problem has not been formulated yet) and the solution space (where different solutions are proposed). An integrated co-evolution model describes how manifestations (sketches, models, prototypes) are crucial indicators that trigger interactions between the problem space and the solution space (Storm et al., 2019). This model also highlights the convergent nature of the problem and solution space (Figure 1). An evaluation of Storm's model which was conducted with students found that visualising the design process with the refined model can lead to frequent reframing of the problem space. Concurrently, reframing the problem space leads to more solution opportunities (Storm et al., 2019).

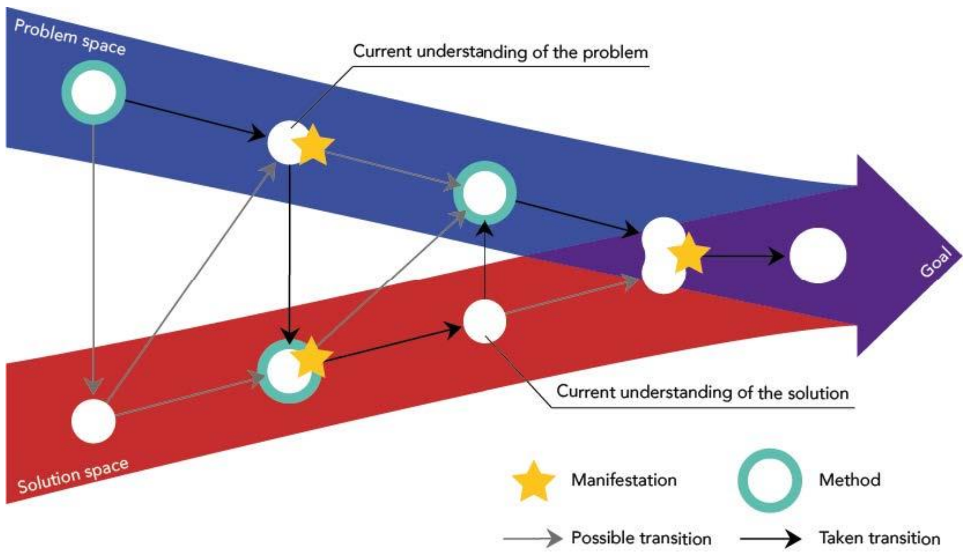

Figure 1. Refined model of framing by Storm et al., 2019

There are different ways to support framing in the design process. Framing can be understood by phenomena such as manifestations, surprises (Stompff et al., 2016) and knowledge sharing (Cash and Gonçalves, 2017) when designing. Another way to support framing is to understand how co-evolution takes place in multidisciplinary collaborations. Co-evolution of the problem and solution space can be identified in two ways: learning in conversations (reflections, agreed solutions, summaries in dialogue) and boundary objects (cognitive bridges between practitioners) (Reymen et al., 2009). The essence in both cases is the nature in which new knowledge is being delivered, understood and acted upon. Studies have found that knowledge can create good collaborative teamwork in contexts that entail multidisciplinary practitioners (Keshet et al., 2013). However, understanding how to share knowledge between multidisciplinary collaborators (such as bio-scientists and designers) in a meaningful and effective way can be further improved. One effective way to explore multidisciplinary collaborative knowledge creation and sharing could be to focus on boundary objects in the process (Balint and Pangaro, 2017).

3. Categories of boundary objects in multidisciplinary collaborations

Boundary objects are defined as:

> *"...objects which are both plastic enough to adapt to local needs and the constraints of the several parties employing them, yet robust enough to maintain a common identity across sites...These objects may be abstract or concrete. The creation and management of boundary objects is a key process in developing and maintaining coherence across intersecting social worlds." (Star and Griesemer, 1989)*

A way to interpret and apply the theory of boundary objects is to identify knowledge sharing between multidisciplinary practitioners. This knowledge sharing can be facilitated by *abstract or concrete objects*. The challenge is in understanding these objects because there is no clear structure in which they emerge. Instead, it has been suggested that meaningful and effective knowledge is obtained organically. For example, engineering designers prefer to source knowledge and information through informal interactions with their colleagues and databases (Aurisicchio et al., 2013). These preferences suggest that unplanned and unpredictable interactions are crucial (and little understood) when dealing with complex problems that require learning and collaboration (Aurisicchio et al., 2013). 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 and linked to learning of others. Exploring the role and qualities of incidental boundary objects in relation to framing in collaborations may have useful implications for teams that aim to produce creative and innovative ideas.

Multidisciplinary collaborations can produce boundary objects that are not understood in the same way between practitioners because of boundaries between practices (Bucciarelli, 2003). Literature on boundary objects suggests that boundary-spanning activities (including multidisciplinary idea generation) can lead to conflict and confrontation rather than collaboration. This can be the case when meanings attached to objects are not shared (Melville-Richards et al., 2019). Literature studying bio-science and design collaborations has found that misunderstandings can arise not only over specialist language but also over shared terms that have different meanings in different disciplines (Agapakis, 2014). These misunderstandings suggest that boundary objects can have positive as well as negative consequences in bio-science and design collaboration. The emphasis of wide majority of existing research on boundary objects investigates favourable qualities and/or consequences, however a more nuanced understanding about boundary objects is required for informing design interventions that aim to leverage bioscience and design collaborations. A study on multidisciplinary healthcare project identified a taxonomy of boundary objects. According to the taxonomy there are four categories of boundary objects: Repositories, Standardised methods and forms, Objects and model maps, Symbolic objects (Melville-Richards et al., 2019). Furthermore, a characterisation of boundary objects has been suggested on the basis of two concepts: boundary objects-in-theory and boundary objects-in-use. Boundary objects-in-theory are things, ideas or concepts that have the potential to be boundary objects. They embody qualities that in principle lead to knowledge sharing and emergence of common ground but in reality, fail to do so. On the other hand, boundary objects-in-use are things, ideas or concepts that meaningfully operate as boundary objects to facilitate multidisciplinary knowledge sharing and mobilisation (Melville-Richards et al., 2019). Boundary objects-in-use have implications for courses of action in the framing process and influence the evolution of ideas. An additional categorisation from a study exploring boundary objects in bioscience and design collaborations suggests three main functions. Firstly, boundary objects to record a milestone or manifestation in the collaboration process, secondly boundary objects that explain a concept or idea and thirdly boundary objects that are generative and facilitate co-creation (Välk et al., 2019). Based on the existing categorisations of boundary objects in multidisciplinary collaborations a research question can be proposed: *what are the characterisations of boundary objects-in-use versus boundary objects-in-theory in open ended creative collaborations between bio-scientists and design engineers?*

4. Approach

When taken together, boundary objects in bioscience and design collaborations can be described in the framework of existing categorisations. This framework includes indications on whether the boundary object has a theoretical or practical nature and whether boundary objects can be categorised by three meanings: to record, explain and generate. The role of boundary objects for framing in design and bioscience collaborations can be further explored. This is important because understanding about boundary objects that facilitate framing will enable implementation of strategies and interventions in teams that aim to produce creative and innovative ideas. One way to deepen understanding about framing in multidisciplinary collaborations is to analyse the relationship between different characteristics of boundary objects. Table 1 illustrates the data categorisation definitions used for verbal protocol analysis.

Table 1.

Phenomenon	Definition	Indication in protocol	Reference
Framing	A creative event occurring as the moment of insight at which a problem–solution pair is framed	Information linking, surprise, identification of coherence, transformation of problem into solution	Dorst and Cross, 2001
Boundary object-in-use	Things, ideas or concepts that operate as boundary objects	Convergence, co-production (engagement)	Melville-Richards et al., 2019
Boundary object-in-theory	Things, ideas or concepts that have potential to be boundary objects	Divergence, failure to engage	
Boundary object to explain	Things, ideas or concepts that aim to explain	Emergence of common ground, example	Välk et al., 2019
Boundary object to record	Things, ideas or concepts that aim to record (part the process)	Establishment of common ground, summary, interpretation	
Boundary object to generate	Things, ideas or concepts that aim to generate (something new)	Demonstration of common ground, visual, immersion	

The limitation of this analysis is that information exchange that does not lead to immediate framing is classified as boundary object-in-theory. In other words, boundary objects-in-use are only identifiable within the timeframe of the experiment. In reality these may turn out to be boundary objects-in-use after practitioners have had time to reflect and contemplate on the newly obtained information.

5. Method

5.1. Experimental study

To understand the effect of boundary objects on framing in collaborations between designers and bio-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 data analysis method is adapted from a study on co-evolution of ideas (Reymen et al., 2009). The perspective for analysing the sessions, is to focus on different types of boundary objects and their relation to framing. The qualitative aspect of the analysis reveals patterns and interactions that enable an understanding about knowledge sharing as a source of creativity. Particular focus when identifying boundary objects is on verbal and physical manifestations. Physical boundary objects are artefacts such as sketches, drawings, prototypes and process maps (Carlile, 2002). This also includes storylines, timelines and user journeys. Verbal boundary objects include metaphors, analogies and summarised answers (Reymen et al., 2009).
Qualitative content analysis is applied to divide text data into explicit categories with the aim to characterise contextual meaning. The applied coding process consists of the following steps: firstly, episodes with knowledge sharing through boundary objects are identified. Secondly, we identify how learning starts by coding the corresponding phrases. If the learning episode results in framing, this is noted. Thirdly, interpretation about the type of boundary object is added by allocating meaning: *to record*, *explanatory*, *generative* (Välk et al., 2019). We also aim to measure the time which is spent on being immersed with each boundary object. The data is coded by the first author and verified by the second author to ensure reliability. Figure 2 further describes the process.

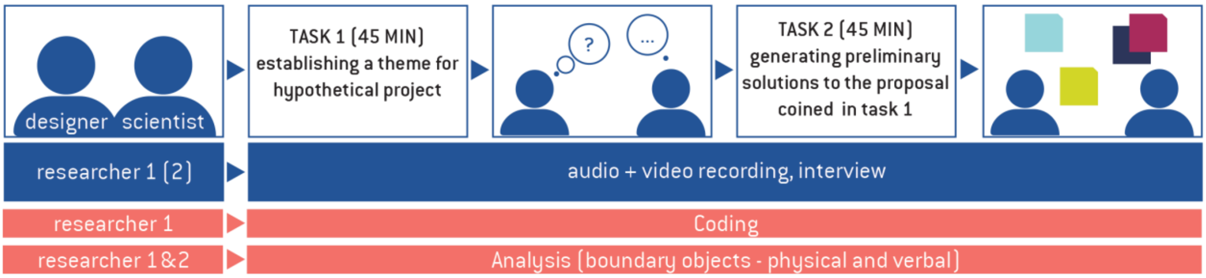

Figure 2. Experiment overview

5.2. Participants

Four pairs of participants were asked to take part in the study (Figure 3). Each pair combined a postgraduate student in design engineering with a student in synthetic biology. All design engineers were enrolled in MSc/MA Innovation Design Engineering program at Imperial College London/Royal College of Art at the time of the study. All bio-scientists were enrolled in MRes Synthetic Biology program at the Imperial College London or they were PhD candidates in the same department. All eight participants were compensated for their time in the study. Everyone who took part in the study had some interest in multidisciplinary collaborations that include scientist and designers, but none of them had extensive experience in the domain. The collaborating pairs were allocated randomly.

Figure 3. Experiment setup with a pair of participants

5.3. Procedure

Each pair of bio-scientist and design engineer was told that the study is about applying their expertise in generating new ideas. These new ideas should be relevant for the domain of future healthcare. The criteria given to the participants included key aspects of creativity in teams: newness (novelty) and usefulness. Additionally, the participants were asked to generate ideas that would be meaningful in their domain of studies and related to their personal experiences.

The experiment was divided into two 45-minute-long phases with a 15-minute break in between. In the first phase the participants were asked to collaboratively come up with a hypothetical bio-science and design engineering project. The project would take place over 6 months. The expected outcome of the first phase was a clearly defined title and short rationale for the proposed project.

In the second phase of the collaboration the pairs were asked to come up with preliminary ideas or solutions which would illustrate the project they had worked on in phase 1. The pairs were asked to illustrate the potential outcome of their proposed project. The outcome criteria for the second phase was novelty and usefulness of the idea in healthcare domain.

Paired participants received information sheets about the task. In case of questions, they were encouraged to enquire the experiment conductor(s) in the room. Collaborators were provided with conventional office supplies used in meetings: A4 sheets titled: *Project Proposal*, A4 sheets titled *Idea Title*, post-it notes, pens, coloured papers, scissors, glue, whiteboard, markers, coloured stickers. The sessions took place in a design faculty.

Two video cameras were used to record each session. Experimenter(s) took notes during sessions and 10-minute-long debriefing interview. All notes and sheets were collected in the end of the session.

6. Results

In total 84 different verbal and non-verbal boundary objects were identified when analysing the data. The total duration of sessions was 6 hours and 8 minutes. Time found to be allocated on discussing questions central to boundary objects was 1 hour and 21 minutes. Table 2 shows all identified boundary objects (abstract and concrete) from one session. All four sessions were analysed using the same framework. Table 3 shows the breakdown of all boundary object from four sessions. Firstly, all boundary objects have been identified as either practical or theoretical. Secondly, an indication whether the boundary object incited framing in the process is noted. Lastly, boundary objects are divided into categories that demonstrate their main function.

Table 2. All identified boundary objects from session 2

	Boundary object					framing
	Description	Identifier	-in-theory	-in-use	category	
17	sketch	"let's write it on…"	X		generate	Yes
18	reference	"we use quite a lot of…"		X	explain	No
19	reference	"we did a project in…"	X		explain	No
20	new angle	"…is an interesting topic"		X	explain	Yes
21	analogy	"it's like having … at home"		X	explain	No
22	reference	"someone was talking about"	X		explain	No
23	reference	"there's something in…"		X	record	Yes
24	reference	"there was this example"	X		explain	No
25	reference	"I read somewhere…"	X		explain	No
26	sketch/idea	"let's put it down"		X	generate	Yes
27	new angle	"it can be broad"		X	generate	Yes
28	reference	"I did a project in…"		X	explain	No
29	note	"so it could be like…"		X	generate	Yes
30	analogy/ref	"you could have bottles like…"	X		explain	No
31	reference	"I've been interested in…"		X	explain	Yes
32	sketch	"jot some ideas…"		X	generate	No
33	reference	"Do you know…?"	X		explain	No
34	reference	"A project called…"	X		explain	No
35	sketch	"let's keep them like.."		X	record	No
36	sketch	"Do you have these post cards?"		X	generate	No
37	reference	"they throw a lot away"	X		explain	No
38	reference	"It'd be good to have like a…"	X		generate	No
39	sketch	"It would be like this..."		X	generate	Yes
40	sketch	"You could have it…"		X	generate	No
41	sketch/ref	"It could be like…"		X	generate	No
42	reference	"It's like a pregnancy test"	X		explain	No

Table 3. Summary of categorised boundary objects

Boundary object	-in-theory		-in-use		
	framing	no framing	framing	no framing	Total
to record	0	2	3	5	10
to explain	0	30	6	11	47
to generate	0	2	16	9	27
					84

7. Discussion

The results of the study show that boundary objects play an important role in multidisciplinary collaborations between bio-scientists and design engineers. Approximately one quarter of the overall duration of idea generating session was spent on boundary objects. The most commonly occurring boundary objects were explanatory boundary-objects-in-theory (30). This finding is predictable because of the open-ended nature of the collaboration and practitioner's aim to find out more about their colleagues' background before starting the idea generation process. There was also a significant focus on explanatory boundary objects-in-use (17), however these types were not significant in terms of leading to framing (6). Surprisingly the majority of generative boundary objects (27 in total) had the capability to lead to framing (16). 25 generative boundary objects-in-use illustrate the significance of co-creation as part of the knowledge sharing process in multidisciplinary collaborations.

The limitation of this study is the relatively small sample size of 8 participants. This does not allow to make conclusive implications, however it is sufficient to illustrate the significance of generative boundary objects-in-use as key elements in framing process. Another limitation of the study is the subjective nature of allocating boundary objects into categories. In order to minimise errors, the results were reviewed by the second researcher and amendments made where necessary. The current analysis does not consider the role of explanatory boundary objects and *boundary objects to record* as prerequisites for ultimately creating generative boundary objects. Such analysis could offer a valuable insight for understanding knowledge sharing and transfer in collaborations between design engineers and bio-scientists. In other words, future research could investigate how framing occurs as a process that has multiple inputs, such as boundary objects-in-theory that are first explanatory and gradually evolve into boundary objects-in-use and generative boundary objects.

In the next phase of this research, an in-depth analysis on boundary objects will be carried out by including details about interaction characteristics that each boundary object facilitates. These characteristics will describe the interactions between practitioners as well as between practitioners and boundary objects. The findings will be used as a source of information for designing a strategic design intervention for leveraging collaborations between bio-scientists and design engineers towards creative and innovative project outcomes.

8. Conclusion

Framing is a key aspect of creativity and innovation in teams and organisations. This study explored the nature of boundary objects that support and incite framing in multidisciplinary collaborations. The research focused on characterisations of boundary objects-in-use and boundary objects-in-theory in open ended innovation-driven collaborations between bio-scientists and design engineers. Results of the descriptive study carried out with synthetic biologists and design engineers indicate that generative boundary objects-in-use are integral components of framing when compared with boundary objects that aim to explain or record a milestone in the process. This finding can support the creation of strategies and design interventions for multidisciplinary teams aiming at innovative project outcomes. The findings of this study contribute to the existing research on taxonomies of boundary objects by providing insights from a synthesis of existing frameworks.

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