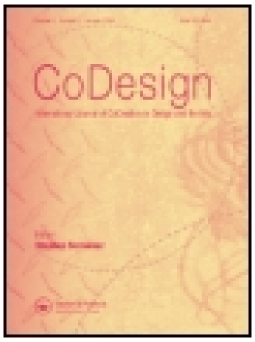

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Supporting collaborative biodesign ideation with contextualised knowledge from bioscience

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ABSTRACT

The objective of this work is to support co-creation of novel ideas in biodesign during fast-paced and facilitated workshops. We created a card-based tool which simultaneously provides knowledge on both 'science' and 'context'. The tool was used to trigger and inspire collaborative ideation in two biodesign workshops in which participants from scientific and design backgrounds produced ideas for healthcare-related innovations. To understand the perception of the tool and the mechanism of scientific knowledge integration in ideation, we conducted post-workshop interviews with 10 participants. Our qualitative analysis shows that the exposure to contextualised scientific knowledge provided by the tool enabled participants to generate ideas that cover a wide spectrum from the micro-scale of bioscience to the macro-scale of socio-political contexts, and thus supported the acceleration of ideation in biodesign workshops.

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Interdisciplinary design; design tool; biodesign; creativity; innovation

1. Introduction: interdisciplinary biodesign

Interactions and collaborations between different disciplines are growing increasingly, paving ways to new interdisciplinary industrial paradigms and biological production (Ginsberg and Chieza 2018). Entangling two or more disciplines is the essence of new knowledge and precondition of innovation (Dorst 2018; Oxman 2016). The paradigm shift towards more sustainable futures highlights the role of bio-sciences in creation of novel and useful technologies (Future Today Institute 2020). In the UK, the bioeconomy is estimated to double within 10–15 years (Department for Business Energy & Industrial Strategy 2018). Bioeconomy refers to all economic activity derived from bio-based products and processes which contribute to sustainable and resource-efficient solutions to the challenges humans face in food, chemicals, materials, energy production, health and environmental protection. For example, synthetic biology is expected to be at the forefront of such developments, illustrated by proliferation of hundreds of companies that produce chemicals, drugs, proteins, probiotics, sensors, fertilisers, textiles and food through application of engineering principles to organisms (Meng and Ellis 2020).

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2. Research objective

While interdisciplinary ideation across design and engineering is well supported by creativity support tools (CSTs) – for example, the TechCards (Ocnarescu et al. 2011), there is lack of tools and best practices for practitioners wanting to work with knowledge from biosciences, such as in the field of biodesign. This research aims at bridging this gap.

More specifically, the goal of this research is to explore how biodesign ideation can be supported in short-term collaborations and in the early stages of projects such as workshops and hackathons. We explore how biodesigners use novel bio-scientific knowledge to generate innovative ideas in a series of interdisciplinary co-creative ideation workshops. Our assumption is that ideation tools can support the process and facilitate collaboration.

3. Theoretical foundation

3.1. Emerging interdisciplinary knowledge spaces in biodesign (bridging science and design)

Biodesign is an emerging interdisciplinary paradigm crossing biology with design (Collet 2020). Biodesign is not a single method, but a methodology with many possible approaches (Gough et al. 2021) that combine interdisciplinary knowledge spaces. Interdisciplinarity offers several advantages such as dealing better with complexity and fostering creativity. Interdisciplinary projects are likely to be impactful and address larger sets of societal needs (Kääriäinen and Tervinen 2017). Interdisciplinary approaches provide novel insights about connections between technology and society but also envision new avenues in R&D (Agapakis 2014). Novel interdisciplinary entanglements in science and design fundamentally advance both domains (Ito 2016).

When designers and scientists collaborate from early phases of a project, designers can challenge research direction and future applications (Driver, Peralta, and Moultrie 2011; Benony and Maudet 2020), which goes beyond the popular understanding suggesting designers are most impactful at supporting scientists with communication. Instead, the role of design knowledge in interdisciplinary collaboration is multifaceted, ranging from being a catalyst for research (Sawa 2016) to stimulating creation of new knowledge through artefact generation (Driver, Peralta, and Moultrie 2011). This suggests there is untapped potential in entangling bio-science and design, particularly from early stages of research or ideation (Simons, Gupta, and Buchanan 2011). The challenge in unlocking this potential is caused by boundaries between practices and lack of mutual understanding (Bucciarelli 2003). Events such as the annual Design with the Living symposium at the Design Museum in London (4–5 November 2021) and Croiser arts, design et sciences pour enseigner autrement? – Intersecting Arts, Design and Science towards innovation in higher education – symposium at the Pompidou Centre in Paris (12–13 November 2021) highlight the growing prevalence of interdisciplinary biodesign and its democratisation.

Examples of interdisciplinary approaches in biodesign that entangle science and design illustrate the potentialities of a bio-based future. The development of Material Driven Design method addresses technical properties of novel materials and user perception (Karana et al. 2015). The CHEMARTS project has produced a series of innovative material demonstrators, which are results from cross-pollination of design and scientific research (Kääriäinen et al. 2020). At the intersection of synthetic biology and design, provocative and infamous projects speculate the future of science and design entanglement (Calvert and Schyfter 2017) (see also Ginsberg et al. 2014; Dunne and Raby 2013). Advancements in design processes for bio-inspired smart building systems (Park and Bechthold 2013) and establishing *livingness* as a material quality in design (Karana, Barati, and Giaccardi 2020) are some of the examples.

Practitioners in biodesign (domain based on science and design entanglements) are influenced by their disciplinary expertise which imposes asymmetric roles (Benony and Maudet 2020). Strategic tools and facilitation methods could probe the interaction dynamics, challenge role asymmetry and leverage outcomes. Tools have the potential to facilitate desired interactions through a process of ideation. A characteristic for emerging domains is lack of pre-existing tools (Peters, Loke, and Ahmadpour 2020), which is critical because tools play a key part in ideation, particularly at the fuzzy-front end of innovation (Inie and Dalsgaard 2017).

3.2. Challenges in interdisciplinary idea generation

A challenge with interdisciplinarity is its complexity and lack of established best practices that would be applicable across different contexts (Groth et al. 2019). Figure 1 illustrates the locus of this research by summarising an overview of disciplinary dimensions (Zeigler 1990; Groth et al. 2019) and clarifies our terminology.

A pivotal challenge in interdisciplinarity is misunderstanding. Misunderstandings in collaborative idea generation in biodesign originate from specialist language, but also from seemingly shared terminology that has different meaning in different contexts (Agapakis 2014). Similarly, lack of shared formal language leads to communication difficulties (Driver, Peralta, and Moultrie 2011; Rust 2007). Therefore, we assume that interdisciplinary biodesign ideation relies on effective tools and *translation* of core knowledge, ultimately leading to shared understanding (Kleinsmann and Valkenburg 2008), which supports creative idea generation.

A prevalent strategy to eliminate barriers related to terminology in bioscience and design collaboration is longevity. Long-term projects have a tendency to eliminate discipline-specific language barriers (Groth et al. 2020; Sawa 2016). When practitioners

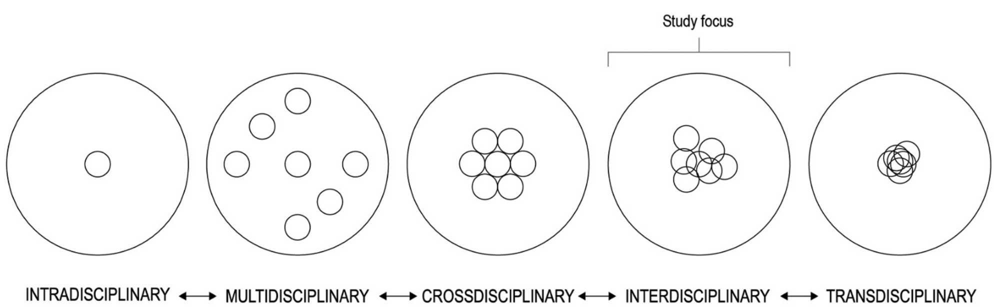

Figure 1. Disciplinary interactions (each circle represents a discipline) and study focus. Derived from Zeigler's original drawing.

from widely diverse backgrounds collaborate, the nature of co-doing is likely to induce learning and shared understanding (Kurtzberg and Amabile 2001), also explained with the concept of tacit knowledge sharing, which occurs naturally in long-term dialogues (Nonaka and Takeuchi 1995; Lave and Wenger 1991; Schindler 2015; Polanyi 1975). Well-defined and mutually understood goals in interdisciplinary projects can eliminate barriers (Kääriäinen and Tervinen 2017).

For short-term collaborations that aim at generating novel and useful ideas there is a lack of validated ideation tools and methods. Time sensitive workshop-based practices are affected by constraints, which may be alleviated by tools and methods that enable creative idea generation within boundaries of fast-paced environments. An example is research with Biocards, which found that higher levels of abstraction on scientific principles support bio-inspired ideation (Lenau et al. 2015).

Design tools could address some of the challenges in biodesign ideation, since they allow thinking through making – an exploration in which the practitioner 'plays around' with materials without knowing what will come out of it (Peters, Loke, and Ahmadpour 2020). Guided explorations facilitate 'thinking through making' in co-design and participatory design (Sanders and Stappers 2013). Tools can also be 'instruments of inquiry' in the creative design process, enabling perception, conception, externalisation, knowing-through-action, and mediation (Dalsgaard 2017); they can catalyse interactions, build relationships and enable diverse communities to innovate creatively by allowing framing of problems from multiple perspectives (Freach n.d.). Co-design tools can also be used to leverage communication about the intended experiences associated with living materials by providing a shared vocabulary (Ertürkan, Karana, and Mugge 2022). Narrative building in design can be an effective way for mediating collaborative activities (Dindler and Iversen 2007). Narrative theory and its use in design is well documented (Forlizzi and Ford 2000; Lloyd 2000), but lacks coherent definitions. However its common ingredients have been identified: chronological representation of events that involves characters and their agency (Grimaldi, Fokkinga, and Ocnarescu 2013).

3.3. Ideation cards supporting collaboration

Ideation cards provide inspirational materials (Haritaipan, Saijo, and Mougenot 2019), guide the process of ideation and negotiation (Halskov and Dalsgaard 2007) and incite co-discovery (Brandt, Messeter, and Binder 2008). Cards are tangible 'idea containers' that trigger creativity and facilitate collaboration (Aarts et al. 2020; Lucero, Halskov, and Buur 2016). They are useful for facilitating knowledge transfer from theory to practice (Tahir and Wang 2020). The format is popular because cards are easy to use, interpret and apply, evaluate, and redesign. Cards act as boundary objects-in-use by enabling knowledge sharing (Melville-Richards et al. 2020; Star and Griesemer 1989).

Ideation cards can impose unwanted effects as external stimuli, which may lead to fixation (Vasconcelos and Crilly 2016; Crilly and Cardoso 2017). Combining sources of inspiration in ideation can reduce fixation (Halskov and Dalsgård 2006) and provide process (Mora, Gianni, and Divitini 2017). Emergence of narratives (Dindler and Iversen 2007) through combination of inspiration sources and reflection (Schön 1991) may also alleviate fixation. Diversity and domain specificity of card contents are critical for their use. The KCC (Krebs Cycle of Creativity) proposes that creative transitions (Table 1)

Table 1. Transitions between domains in KCC (Oxman 2016).

Domain	What the discipline produces	Used by
Science	Knowledge	Engineers
Engineering	Utility	Designers
Design	Behaviours	Artists
Art	New perceptions of the world (granting access to new information and inspiring new scientific inquiry)	Scientists

depend on an interdisciplinary perspective by showing how disciplines (science, engineering, design, art) are interrelated (Oxman 2016). It provides a cartographic overview that implies the importance of communicating and utilising discipline-specific knowledge in interdisciplinary co-creation. Consequently, the contents of interdisciplinary ideation cards should aim at communicating diverse knowledge representing the four domains.

4. Literature summary and positioning of the study

The field of biodesign is rich in different terminologies and definitions, oftentimes described by overlapping and diverging constructs resulting in ill-defined boundaries of the field (Gough et al. 2021), suggesting that biodesign is inherently interdisciplinary. To better navigate the landscape of biodesign, which is often associated with terms such as biomimetics, bio-inspired design, bioscience-based design and biophilic design, we adapt a position that distinguishes between two main constructs which we base on existing literature. Firstly, design that is inspired *by* biology and secondly, design *with* biology (Table 2).

Example projects that embrace the entangled nature of design *with* biology include the Dynamic Robotic Fibres collaboration bridging HCI with design and materials science and CMD – a set of artificial ecosystems that share access to light based on their oxygen production (Figure 2).

The table illustrates the positioning of this study by showing a way to view biodesign as a landscape, instead of abiding by one predefined definition of biodesign. We position the paper within the area of biodesign that aims to design *with* biology. The two

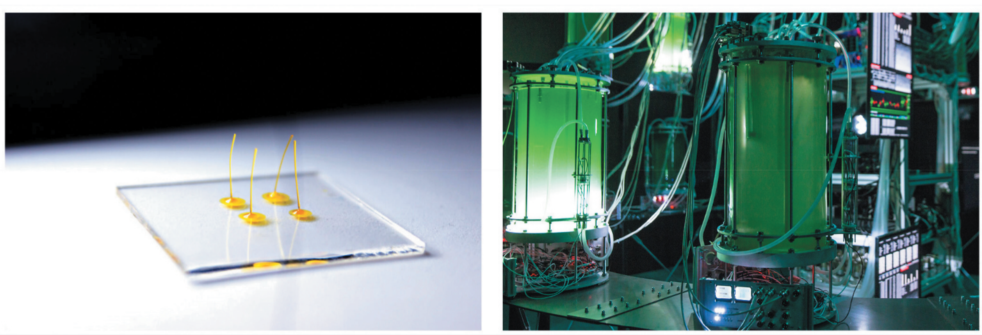

Figure 2. Dynamic Robotic Fibers by Amy Winters (left), CMD by Michael Sedbon and collaborators (right).

Table 2. Approaches in biodesign and their characteristics.

	Biodesign	
	Design inspired *by* biology	Design *with* biology
Scope	Intradisciplinary, multidisciplinary (Vincent 2009)	Interdisciplinary, transdisciplinary (Välk and Mougenot 2020)
Process	Knowledge adapting and transferring (Vincent 2009)	Knowledge integrating (Maudet, Asada, and Pennington 2020; Myers 2018)
Aim	Analogy-seeking (Yargın, Firth, and Crilly 2018)	Entanglement-seeking (Ramirez Figueroa 2018)
Aim	Stimulate creativity (Esat and Ahmed-Kristensen 2018)	Implement the living (Agapakis 2014; Ginsberg and Chieza 2018)
Approach	Problem solving (Lenau et al. 2015), addressing tame problems (Gough et al. 2021)	Problem finding (Driver, Peralta, and Moultrie 2011), sensemaking (Haidamous 2017; Sanders and Stappers 2014)
Focus	Engineering mechanics (Keshwani et al. 2013), form-giving, styling (Myers 2018)	Symbiosis, diverse knowledge (Oxman 2016)
Scale/ perspective	Human (Barati, Karana, and Hekkert 2019; Gough et al. 2021; Sayuti, Montana-Hoyos, and Bonollo 2015)	Alternative to human (Wakkary 2021; Ito 2016; Metcalfe 2015)
Subject	Inanimate matter (Collet 2020)	Animate living matter (Collet 2020)
Tools/ approaches for ideation	Individual (Lenau et al. 2015) Time consuming and incidental 'Treasure Hunting' (Maudet, Asada, and Pennington 2020)	Collaborative, fast paced and facilitated - ***focus of this paper***

approaches can both be applied simultaneously or sequentially; and they can be complementarity, but require different approaches, mindsets, and knowledge spaces.

The interdisciplinary approach of design *with* biology is underexplored in design research, albeit being capable for addressing open ended societal issues (Kääriäinen and Tervinen 2017), however, tools such as Biocards exist in design inspired *by* biology. Interdisciplinarity can address complex problems, however boundaries between practices and knowledge spaces pose challenges (Bucciarelli 2003) particularly in collaborations.

There are encouraging approaches in interdisciplinary biodesign. For example, residences where designers immerse in lab environments (Sawa 2016; Chieza 2018). The limitation of such approach is that it is time consuming. Similar approaches have been studied by looking at how industrial designers and scientific researchers can contribute to each other's work (Driver, Peralta, and Moultrie 2011) and investigating how experiential knowledge exchange (Nimkulrat et al. 2020) can facilitate research on new materials (Groth et al. 2019). Hands on activities in shared space have been found to support collaborative knowledge spaces across the sciences and creative practices (Groth et al. 2020). There are limited tools and approaches available to support interdisciplinary biodesign. Treasure hunting provides one collaborative approach and suggests that developing strategies for scientific knowledge representation for design is critical in interdisciplinary collaborative ideation (Maudet, Asada, and Pennington 2020). Collaborative fast paced and highly facilitated tools and methods are currently underexplored in the literature.

4.1. Research scope

Unlike existing interdisciplinary biodesign approaches that require a substantial commitment in time – such as residence (Sawa 2016; Chieza 2018) or treasure-hunting (Maudet, Asada, and Pennington 2020) - our approach is to focus on short and early

Table 3. Overview of the proposed 'designing with biology' ideation.

	Proposed format	Function
Approach	Workshop/ hackathon	Collaborative, fast paced and facilitated ideation (Flus and Hurst 2021)
Tool	Ideation cards	Supporting creativity and collaboration (Aarts et al. 2020; Lucero, Halskov, and Buur 2016)

phase collaborations – such as workshops and hackathons. This approach has been found to embody characteristics of divergent and convergent design (Flus and Hurst 2021), therefore it can be generalisable for the broader field. We assume that successful early stage biodesign ideation can incite extensive projects and create large scale impact.

The literature demonstrates it is unclear how collaborative biodesign ideation can be supported, hence our research questions: **How to support collaborative ideation in biodesign workshops? How can scientific knowledge be accessed and understood by biodesign workshop participants?** Our hypothesis is that introducing novel bio-scientific knowledge in ideation workshops can be effective if practitioners are provided with a combination of specific and generalisable knowledge about science.

5. Methodology

This research uses a case study that develops a set of novel ideation cards to explore support mechanisms for biodesign ideation in workshops. The proposed approach is outlined in Table 3.

Our case study consists of three phases: (1) developing an ideation tool (cards) for biodesign workshops, (2) running a series of workshops with the cards and (3) conducting interviews with workshop participants. While the cards are mainly intended to support ideation during the workshops, they are also used to elicit participants' reflection in post-workshop interviews.

5.1. Development of ideation cards for biodesign

While cards for general ideation aim at supporting collaboration, we developed ideation cards that aim at overcoming the specific challenges associated with the interdisciplinarity of 'designing with biology', i.e. interdisciplinary knowledge integration and narrative building. To that end, we developed two sets of cards – science cards and context cards, as described in Table 4.

The card layout for the science cards is inspired by TechCards (Ocnarescu et al. 2011), showing general information as well as detailed information (Figure 3). The cards (Figure 4) were developed collaboratively with experts in synthetic biology and bioengineering by discussing discipline specific literature (Villalba et al. 2021). We selected synthetic biology and bioengineering as both fit under the *biosciences* umbrella term. The criteria for identifying and synthesising contents targeted four key qualities described in the KCC (Table 1).

Table 4. Overview of the proposed content for the ideation cards.

Name	Science cards	Context cards
Function	Interdisciplinary knowledge sharing	Narrative building
Operationalisation	Facilitating the transition from scientific knowledge to broader social context through the 4 levels of KCC model (based on Oxman 2016)	Facilitating the emergence of a narrative which connects scientific knowledge with a societal goal (sustainable development goal)
Operationalisation structure	4 levels of operationalisation about the bioscientific method: knowledge (what is it?), utility (what can it be used for?), behaviour (how can it be used?), perception/context (example case)	Context (summary and visual representation of goal)
Topics	Synthetic Biology & Bioengineering *(CRISPR, Biosensors for Disease and Pollution prevention, Probiotics, DNA isolation, Fermentation, Genetic Engineering, Cell-free Systems; 3D/4D printing, Cellular agriculture, Organ on a chip, 3D/4D imaging, Biomimetic engineering, Synthetic morphology, Biological priming, Bio-architecture)*	United Nations Sustainable Development Goals *(Health & wellbeing, affordable & clean energy, clean water & sanitation, industry, innovation and infrastructure, reduced inequalities, sustainable cities & communities, responsible consumption/production, climate action, no poverty, zero hunger, quality education, gender equality, decent work, life below water, life on land, peace & justice, partnerships)*
Number of cards	16	17

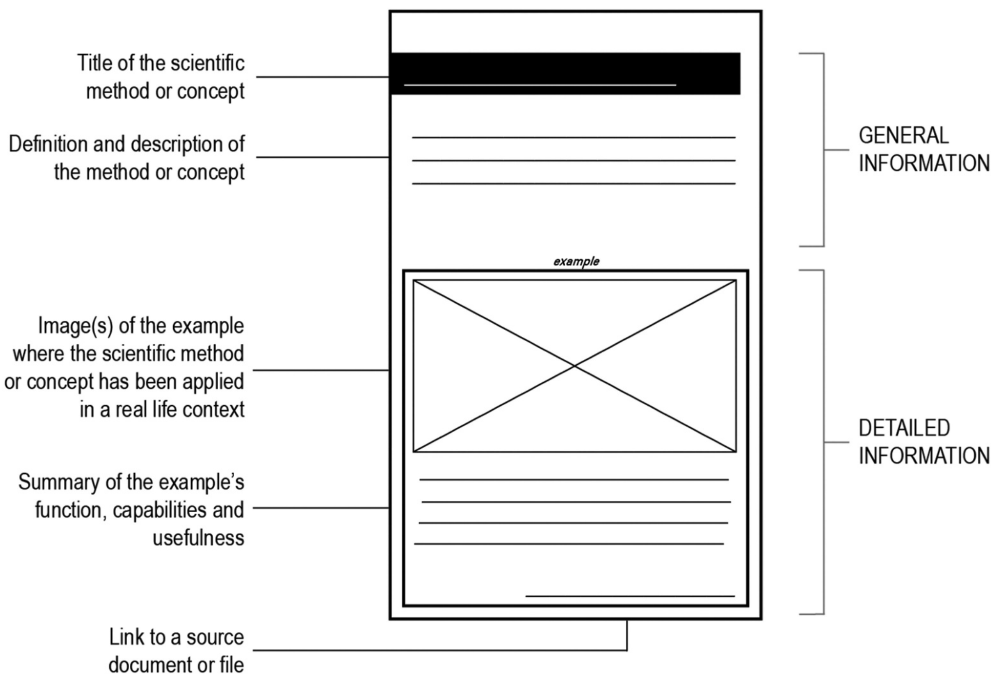

Figure 3. Science card layout.

We integrate UN SDGs (United Nations Sustainable Development Goals) in a card format so that they can be combined with science cards (Figure 5). The purpose of the context card is to allow collaborators to build a narrative based on predefined building blocks.

Figure 4. Example cards (left: science card; right: context card).

Based on the example in Figure 4 the KCC operationalisation structure on science cards is: CRISPR allows gene editing/correction (utility, scale), which can be used to improve malt for new taste experiences (behaviour and perception).

5.2. Case selection

We organised two online workshops in 2020, where participants and organisers used conventional tools such as video calls, group chat, file sharing, and virtual white boards (Figure 6).

Participants were post-graduate students in design (innovation design engineering) at Imperial College London/Royal College of Art and bioengineering at Imperial College London who were randomly assigned to groups of 2–4 people for the ideation workshop. Their courses involve interactions between students from diverse backgrounds and previous training in engineering, science, social sciences and arts. The motivation for selection is the interdisciplinary profile of participants and their interest in biodesign.

One workshop was in synthetic biology (2 h), the other one in bioengineering (5 h), both topics covering distinct areas of knowledge that can be used for designing with the living. In both workshops, participants tackled a general brief of generating novel and useful ideas for future of healthcare. Healthcare was chosen because participants from all disciplines can relate to it and UN SDGs are either directly or indirectly related to health and well-being.

Science cards and the context cards were provided in a virtual white board. Participants were asked to select one card from each category (see Figure 5) and use them simultaneously as references in idea generation.

In a given time frame, participants were asked to produce novel ideas related to the brief and to post descriptions of their ideas, sketches, and annotations in the virtual white board (see Figure 6).

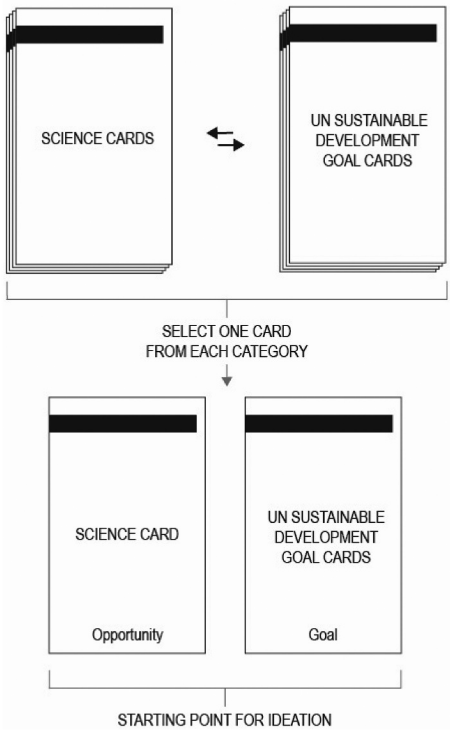

Figure 5. Card selection process in workshops.

5.3. Data collection

5.3.1. Post workshop interviews

The objective of the interviews was to gain an understanding of the biodesigners' (Table 5) perception on the use of cards and knowledge acquisition during the collaborative biodesign ideation workshops (Yargın, Firth, and Crilly 2018). We conducted semi-structured interviews (duration: 40–60 min) with questions that addressed the participant perception about the tools and the ability thereof to support ideation, clarity, understandability and relatability of bioscientific knowledge for ideation and value of generating biodesign ideas in the context of UN SDGs. Clarity, understandability and relatability are connected to design principles of CST, such as *low thresholds, high ceilings, wide walls* (Shneiderman et al. 2006). Interviewees were asked questions in the context of collaboration using Design and Science cards. Ten participants from various backgrounds (Table 5) were interviewed. They were selected from the pool of participants who engaged with the workshop from start to finish and who volunteered to be interviewed.

5.4. Data analysis

The content of the interviews was analysed through directed qualitative content analysis – an approach established for validating and extending existing theoretical frameworks

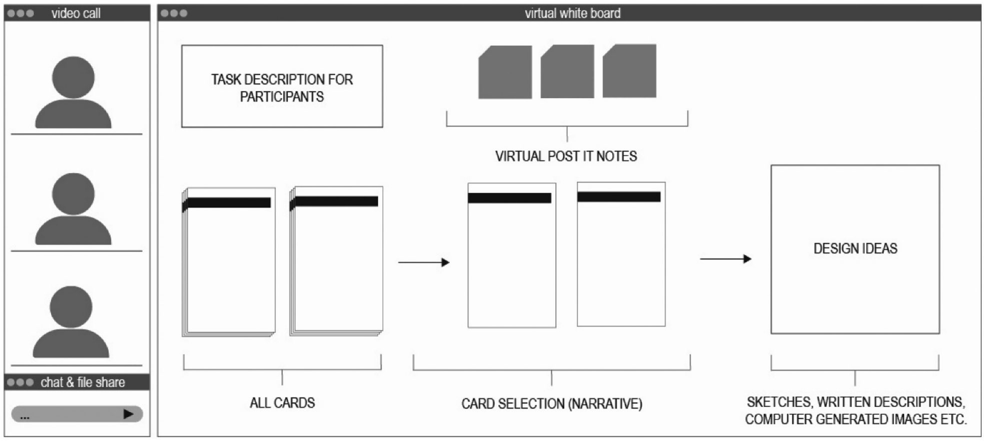

Figure 6. Schematic view of workshop setup as screenshot.

Table 5. Overview of 10 biodesigners participating in the study.

Participant	Naming scheme	Background	Level of expertise
1	SD-1	Materials science and engineering	MSc + MA
2	SD-2	Industrial design	MSc + MA
3	SD-3	Design engineering	MSc + MA
4	SD-4	Design	MSc + MA & MA obtained
5	SD-5	(Bio)Science	MSc + MA & PhD obtained
6	BE-1	Chemical engineering, biotechnology	PhD
7	BE-2	Bioengineering	BSc
8	BE-3	Biochemistry	MSc
9	BE-4	Biophysics	PhD
10	BE-5	Bioengineering	PhD

(Hsieh and Shannon 2005). The directed approach to content analysis enabled to determine preliminary coding scheme and relationships between codes.

Two researchers coded the data. Our analysis consisted of (1) transcribing the interviews and (2) highlighting relevant sections and then coding based on predetermined open ended interview questions. We followed the coding scheme described by Stompff, Smulders, and Henze (2016) and proposed by Valkenburg (2000). Interview data was divided into 305 segments of which 20% ($N = 61$) were selected randomly for assessing the inter-rater agreement score. Segments were coded into four categories: knowledge, effect, contextualisation and narratives by the first author and an independent researcher belonging to the same research group. The coding was compared and discussed, which resulted in inter-rater agreement score of 92% (56 out of 61). Disagreements were discussed and, if no agreement could be obtained, the data were not used.

6. Results

All participants stated that the workshops increased their interest for biodesign and integrating interdisciplinary knowledge into their projects. The interviewee reflections about their collaborative ideation revealed three emerging themes: the value of bioscientific knowledge representation, diversity of knowledge on the cards and contextualisation of ideas.

6.1. Bioscientific knowledge representation

The cards provided playful interactions for the workshops and were seen as useful components in idea generation, particularly for initiating the process. SD-2 said that bouncing back and forth between the scientific information and his design expertise was crucial for idea generation. BE-1 suggested that the cards initiated their thinking process by providing direction and a starting point. BE-3 said that knowledge on the cards helped the team to cover a wide variety of ideas to combine into directions later. BE-1 reflected that the cards made the creative process game-like, rather than an exercise and added that the process felt like a 'casual conversation' without losing scientific focus. He also claimed that he could not ideate in biodesign without the cards, given his lack of expertise.

Participants noted that their ability to understand the scientific knowledge was essential for collaborative ideation. Higher levels of understanding were related to better engagement in the workshop. BE-3 was able to quickly apply the cards: '*It was easy to start brainstorming because the **process** was in place*', referring to the narrative that emerged when combining different scientific methods with various contexts. BE-1 signified the use of language because the cards explained specialist topics without the use of specialist language: '*I appreciate that the cards are easy to understand even if you don't come from this area of expertise*'. BE-2 added: '*the cards are good to look at – this is important! Sometimes scientific information is very difficult to absorb*'. Knowledge that was relatable was more likely to find use in ideation. According to SD-2, being able to relate the science to ongoing projects was a driving force for ideation. Additionally, participants found that ideation could have been more fruitful if they were able to understand the science better. BE-1: '*The cards initiated our thinking process. Without the cards, coming up with ideas would've been difficult. They provided direction and starting point for the discussion which was very useful*'. BE-5 noted that the cards were useful for supporting creative and useful concepts: '*A lot of it is raw science and getting into papers, but this was more about reality and role of creative process. Bioengineers are used to solving clearly defined problems, but the real value is spotting things outside this space*'. Participants found that one of the key outcomes from using the cards were their ability to accelerate the creative process and minimise team misunderstandings about unfamiliar scientific opportunities. SD-1 said: '*The cards were perfect as an easy summary of a concept. I definitely felt they were successful in triggering creative thinking. The format was very useful for giving the main idea about the concepts to play with. Enables to quickly jump into brainstorming. No need to spend time on figuring it all out*'.

6.2. Knowledge diversity in biodesign ideation

Participants considered the diversity of knowledge presented on the science-based cards supportive of ideation. This was a result of participants being able to relate to at least some aspect of a card, making the knowledge actionable. BE-3 said: '*there was a good balance between specificity and generalisability of information on the cards*'. BE-4 reported there were '*several layers*' of knowledge on the cards, which enabled the ideation process:

'You can get the idea of the card really quickly and it allows you to harvest and gather more information later if needed'. The diverse contents of the cards were perceived logical and easy to understand because they explained scientific methods from multiple perspectives, leading to a wholistic overview. SD-3 stated: '*The best thing about Synbio cards is that they break down, in simple terms, the different areas of Synbio in chewable bits that can be worked with*'. However, it was mentioned that rigidity of knowledge provided to the biodesigners for ideation was challenging because selecting the narrative was limiting (selection of 1 science and 1 UN SDG card): '*There's no leeway, There's one card and nothing else.*' SD-5 preferred to see information about different scientific methods and concepts presented on the same level of abstraction. SD-4 suggested that the visual nature of knowledge representation accelerated ideation.

SD-1, SD-2 and SD-5 mentioned that extreme cases of scientific concepts applied in real life settings can support idea generation. SD-1: *'I'm interested in things that are extravagant and exciting, like CRISPR'* and SD-3: *'It was good to see down to earth and crazy examples'*. SD-3 highlighted the importance of user-related information on the cards: *'It is useful to have an image with the product in use'*. Contrastingly, SD-5 suggested that *'connection to human can sometimes be over amplified'*. When reflecting on information and knowledge representations on the cards, participants expressed a wide variety of individual preferences for knowledge that supported them or their team ideation process. SD-1 found that the summary of scientific concepts and their overview (as a set of cards) triggered creativity since it triggered knowledge contextualisation. SD-1 highlighted that the summary of scientific knowledge on the cards initiated a speedy process. SD-2 found that having a set of cards with diverse knowledge provided a shared knowledge base for team ideation process, eliminating misunderstandings about complex scientific phenomena. Similarly, SD-3 suggested that the card contents enabled a clear process and clarity about the scientific knowledge and its potential application areas. When discussing the format and knowledge representation, SD-5 said that the cards provided a useful overview and explanatory pictures increased understanding of the science. The pros and cons of each scientific method improved contextualisation.

6.3. Knowledge contextualisation

Despite some challenges in combining the Science and UN Goal cards, the respondents found combining sources of inspiration helpful for ideation because it explicitly put scientific opportunities into societal context. For example, BE-5 suggested that *'the UN cards helped a lot by adding guidance and structure'*. SD-2 said that bridging the scientific methods with design approaches for coming up with biodesign ideas can be difficult due to contextual differences. SD-1, SD-3, SD-4 said that combining the perspectives with UN SDGs was a natural, fun and quick process. SD-4 specified: *'Choosing the card combinations with the group was really holistic, the dynamic was really good, we were in a really good flow'*. According to SD-1 their group would have been lost during the ideation if there was no bridging of different perspectives (1 UN SDG card with 1 Science based card). Combining the cards provided clear process and surprising ideas according to participants. The ideas were described as surprising because the cards provided participants with new knowledge that they did not have before, nor knew they could use in ideation. SD-2 added that the story acted as a framework for brainstorming. BE-3 suggested that mixing and matching the cards was '*the best thing and irreplicable for us*' later suggesting: '*Combining the two cards together was quite concise. Really laid a good structure for us to start brainstorming*'.

SD-4 said that combining the science with broader context created an inspiring narrative to use as starting point: '*it was useful to have this story before ideation. It led us to having a good process. It took us to an idea that may or may not work but we felt it was magic*', SD-2 added: '*combining the cards was straightforward. UN cards were clear and relatable*'. SD-1 thought that making connections between cards enabled their group to access ideas that would otherwise have been unreachable. It was noted that sustainable development goals allowed participants to place their ideas into a broader context that has significance and meaning: '*it's good to know what's considered important in the world*'. (SD-5). Exposure to critical contexts raised participant awareness and encouraged them to envision ideas that directly address global issues. This exposure alleviated ambiguities of ideation and accelerated the team process.

BE-2 found that the UN cards enabled contextualisation of specific skills. According to SD-5 the challenge in combining different categories was mostly within the science-based card because there '*appeared to be an overlap between some of the cards, but the UN cards were very important and made us precise*'. BE-1: '*I think it's a helpful thing to combine cards together into a narrative – ideation can be fun! But in a lab meeting it looks like a task*'. When reflecting on their quick team process, SD-4 said that '*one of the cards was very relatable so that's why we chose so fast*' and SD-1 stated: '*the process was to pick and match where a lot was based on the feeling. Can I see it fit? Does it feel right?*' BE-5 found that the UN Cards and Science cards are most useful when planning new innovations.

7. Discussion

The results from a series of workshops demonstrate an approach for supporting collaborative biodesign ideation with utilisation of a conceptual interdisciplinary creativity model (KCC). We found that exposure to diverse bio-scientific knowledge presented in a standardised format (Design x Science cards) has potential to support ideation process in biodesign. Based on participant comments and our observations on the ideas generated, the prevalent effect of the cards was on the team process, rather than quality (novelty and usefulness) of proposals. This could be justified with the time-limited nature of the experiment.

When analysing the participant perception on the collaborative ideation, we found that contextualisation of scientific knowledge supported team process and enabled creating narratives prior to brainstorming. The results show that interdisciplinary biodesign ideation can be supported by tools that integrate a combination of science-specific and generalisable knowledge. The study expands design theory in combined sources of inspiration (Halskov and Dalsgård 2006) to interdisciplinary biodesign collaborations; and contributes to the development of CSTs in interdisciplinary biodesign. The main findings for interdisciplinary biodesign ideation are:

- Practitioners value diverse knowledge contents from/on CSTs;
- Contextualisation supports creativity and generation of innovative ideas;
- Narratives can act as accelerators and starting points for ideas.

7.1. Knowledge diversity and contextualisation with narratives

We found that biodesigners (irrespective of their background) prefer using general and specific knowledge to inform their ideation. The diversity of knowledge initiated divergent and convergent thinking. Our exploratory study found that Design x Science cards that were developed based on interdisciplinary and diverse knowledge (as described by the KCC and Table 1) were unanimously considered supportive of ideation because the cards incited thinking along unconventional thought patterns. The diversity of knowledge representation was considered twofold: firstly, the card deck provided a diverse selection of bioscientific inspiration. Secondly, each card was designed with diverse characteristics in mind (scientific knowledge and its utility, potential effect on behaviour and perceptions). The interviews showed that the cards supported ideation because of quick and easy access to summarised scientific knowledge, allowing speedy process and decisions making. A key characteristic of the cards was their affordance to imply process and guidance for discussions and ideation. Consequently, this was perceived as positive for the team process and the speed at which ideas could be generated.

The results show that combining the cards was an engaging process and participants considered this an important step in building team dynamics. It was found that combining UN SDGs (United Nations Sustainable Development Goals) and scientific methods helps to contextualise ideation. The contextualisation can be described as narrative building whereby different pieces of knowledge are put together. Participants in this study used the narrative as a creative input to inspire ideation.

7.2. Limitations

A methodological limitation of this study concerns directed content analysis, which is associated with researchers finding evidence that is supportive of a theory under investigation. During interviews, some participants may answer in ways that please researchers (Hsieh and Shannon 2005), however we mitigated this potential effect by explicitly asking participants to be critical. The card format can be a limitation and other forms of interventions that are based on the principles applied for making the cards could lead to valuable insights. The workshops used in this case study were conducted online, which is likely to have caused unwanted side effects on the quality of collaboration, although becoming a common format for ideation workshop.

7.3. Future work

This study found that interdisciplinary biodesign ideation can be supported with collaborative tools, such as ideation cards. The finding is relevant for advancing the field of interdisciplinary biodesign. The results with Design x Science cards indicate that designers prefer new information in standardised formats emphasising the role of facilitator as a moderator of inspirational content. A key challenge in facilitating the workshops was balancing generalisable and specific contents for the cards. This reflects on research describing how designers source ideas from science laboratories, whereby there is a 'sweet spot' for describing sources of inspiration (Maudet, Asada, and Pennington 2020). Further research could explore facilitation strategies of biodesign ideation. Understanding the role of various types of narratives (Grimaldi, Fokkinga, and Ocnarescu 2013) in biodesign ideation, including temporal narratives (Pschetz and Bastian 2018), could also provide insights for advancing the field. Future work could also address the ethical dimension of co-creative biodesign, for example by adapting existing frameworks for responsible innovation, such as Consequence Scanning (Brown 2019). Given the fast-paced nature of our workshops and focus on ideation, there was no emphasis on ethical consequences.

8. Conclusion

This paper explores how to support collaborative ideation in biodesign workshops. The exploration is necessary to accelerate biodesign processes and provide a complimentary approach to time consuming collaborations such as residencies. Using a case study with Design and Science cards based in a series of workshops, we found that biodesign ideation could be supported with tools such as ideation cards. Our results show that practitioners value tools which provide diverse interdisciplinary knowledge about bioscientific phenomena in ideation. The results suggest that combining bioscientific knowledge with large-scale contextual challenges such as the United Nations Sustainable Development Goals help biodesigners to contextualise their ideas and develop a narrative. The narrative building provided collaborators with process for creative ideation and co-creation.

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