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Learning from creative biology: Promoting transdisciplinarity through vocabularies of practice

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Abstract: Transdisciplinary ways of collaborating are considered essential to support new approaches to tackling societal and environmental "wicked" problems. But how can collaborations take place in ways that reach this envisioned state? In this work, we look for cues of transdisciplinarity in the experience of those with a successful track record of working across disciplines. We interviewed 38 practitioners and researchers working in "creative biology", an umbrella term that we use to address work that incorporates biology-related methods and research outside purely scientific realms. The interviews provide insights into how language can be used to support strategic shifts of positionality and nudge others to step out of their disciplinary realms, which contributes practical advice for those who are looking to collaborate with other disciplines. They further provide examples that can help expand the discussion of transdisciplinarity in design practice and education.

Keywords: creative biology; transdisciplinarity; biodesign; collaborations

1. Introduction

Transdisciplinary approaches are often considered essential for understanding and responding to societal and environmental "wicked" problems (Buchanan, 1992). They allow researchers and practitioners to frame problems differently and access aspects of reality that often cannot be seen within the realms of single disciplinary domains, therefore offering ways of understanding issues from multiple, sometimes conflicting, angles (Nicolescu, 2010). Current literature provides insights into the potential for design to operate and provide a bridge across disciplines (Dorst, 2018; Bremner & Rodgers, 2013; Blevis & Stolterman, 2009), as well as opportunities and challenges of design-driven transdisciplinary education (Constantino, 2018; Chew et al., 2020; Blevis et al. 2014, 2015). Our work contributes to this discussion by looking at the experience of those working at the intersection of biology and so-called creative disciplines as compelling examples of collaboration across disciplines.

We use the term “creative biology” as an umbrella to encompass different approaches, allegiances and forms of working with biology outside strictly scientific realms. As part of a bigger effort to map the landscape of creative biology, we carried out 38 semi-structured interviews with researchers and practitioners from the fields of arts, design and HCI, as well as collaborators from humanities, social and biological sciences, engineering, and synthetic biology. The interviews focused on their strategies and experiences of stepping out and working beyond their own disciplines to generate new spaces of practice and research. The aim was to draw practical advice from successful cases of collaborations across disciplines, which could support other researchers and practitioners working in the field.

As we will discuss, the interviews were particularly relevant to revealing the ways participants instrumentalised language to negotiate collaborations and find new possibilities across disciplinary boundaries. Such strategies can help decentre established dialogues within a discipline and provide useful advice for opening up space for transdisciplinary processes and new spaces of knowledge to emerge within a particular context or project. The interviews also provided examples that can help expand the discussion of transdisciplinarity in design practice and education.

2. Creative biology and transdisciplinarity

Our interest in exploring the intersection of biology and other fields is due to both the emergent landscape of bio-related initiatives, and their rich potential in suggesting new ways of working with other disciplines (Gough et al., 2020). The integration of biology in other disciplines is indeed a growing trend, which has led to the emergence of innovative areas of exploration (Ramirez-Figueroa & Hernan, 2021). Although these areas have their own agendas, they share a common interest in incorporating living organisms into their practices. Some of the most prominent areas include: *Biodesign,* an emergent design community interested in creating applications that integrate living systems in the process of fabrication or its interaction with human users (Myers, 2012); *DIY-bio,* a field defined by an ethos of democratising science and opening it up to the scrutiny and enjoyment of citizens (Landrain et al., 2013; Kuznetsov et al. 2012, 2015); *Biological HCI,* which seeks to investigate the relationship between human, computer and biological systems by redefining biological materials as design elements (Pataranutaporn et al., 2018). Examples from these areas range from exploration of bioluminescent surfaces (Barati et al., 2021; Ofer et al, 2021) and incorporation of living materials in computer systems (Weiler et al., 2019), products (Moisy & Pschetz, 2017), buildings (Ramirez-Figueroa & Beckett, 2020), material fabrication processes (Camere & Karana, 2018, Ramirez-Figueroa & Dade-Robertson, 2013), to soft actuators (Ramirez-Figueroa et al., 2016), applications of DNA (Pataranutaporn et al., 2018; Kim et al., 2021; 2022) and gut biota visualisation (Boer et al., 2020).

The integration of living organisms outside scientific realms requires a deep level of collaboration across often disparate disciplines (Hamidi et al., 2021, Szymanski & Calvert, 2018, Ramirez-Figueroa, 2018), which makes them prone to evolve from multi and interdisciplinary

perspectives to a position of transdisciplinarity. In our work, we departed from Blevis & Stolterman's (2008; 2009) perspective of transdisciplinarity in design practice, which strongly draws from Nicolescu's (2002) theory. According to Nicolescu (2010), multi, inter and transdisciplinarity are differentiated by the extent to which collaborative work steps out of single disciplines towards larger goals. Multidisciplinarity is seen as the study of a research topic by several disciplines in a way that exclusively enriches a single home discipline (Nicolescu, 2010), while Interdisciplinarity sees the transfer of methods from one discipline to another. Transdisciplinarity, in contrast, 'concerns that which is at once between the disciplines, across the different disciplines, and beyond all disciplines' (Nicolescu, 2010, p.20). It involves an understanding of reality as being formed by levels that are delimited by a degree of "resistance" in human experience. Different disciplines are able to access these levels individually, producing fragmentary views of this reality. Through transdisciplinarity, however, people are able to go beyond their usual resistance and engage several levels at once, which allows them to uncover "hidden" aspects of reality (McGregor & Gibbs, 2020).

Researchers in the social sciences and humanities have expanded on aspects of this definition. Gibbons & Nowotony (2001) point to how transdisciplinarity is inherently transgressive and often difficult to negotiate, Brown talks about the need to develop "the full capacity of the human mind to remain open to all possibilities," (2014, p.209), and McGregor (2015) approaches transdisciplinarity as an educational process: as people engage with transdisciplinary work, they grow into complex problem-solvers, and become more complex themselves.

Further approaches, particularly from what could be called the "Zurich" school (McGregor, 2015a) conceptualise transdisciplinarity as an emergent form of research, which stresses "diverse disciplinary perspectives that have to be reorganised for societal problem solving" (Pohl et al., 2021, p18). The nuanced difference is that, within these approaches, work may be considered transdisciplinary and still remain within a disciplinary realm (McGregor, 2015a). Nevertheless, the focus is still on the transformational aspect of such work: through reorganisation of problems and solutions, researchers and practitioners would better understand the plurality of ways that abstract and case-specific knowledge can interrelate - and, they are forced to confront the systems of power that can empower or inhibit domain-specific knowledge production as they seek to problem-solve for a perceived "common good" (Hadorn et al., 2008).

Given the importance and potential of transdisciplinary approaches, and the potential for creative biology to provide examples of them in practice, we embarked on a study to understand ways of working and communicating within what could be seen as successful collaborations across disciplines.

3. Study

This paper draws from insights from interviews that we carried out with 38 participants (45% females, 55% males). The interviews were divided into four sections, where we asked partici-

pants about: 1) their **work**, and specific practice and/or research; 2) insights and/or challenges faced in **collaborations** with people from other disciplines; 3) **vocabularies**, or terms and analogies employed or related to their work; and finally their 4) **visions** for the future of creative biology. Interviews lasted between 20 and 30 minutes. Complementary to the interview, we asked participants to fill in a questionnaire where they situated their practice on a five-point scale, sitting closer to science or creative disciplines, and to locate themselves in relation to movements within creative biology (see Figure 1). Responses were thematically analysed by two researchers.

Participants' selection aimed to include creative biology collaborations within a wide range of disciplines including molecular, plant and synthetic biology, human-computer interaction, medical sciences, engineering as well as arts, design, humanities, and social sciences. A second factor in inviting participants was their visibility and impact in the community. We assessed work produced in the field in the last five years and invited participants who were particularly visible and whose work was disseminated in a way that highlighted their transdisciplinary nature. We were also careful to balance backgrounds and career levels, including established artists and scientists, as well as emerging researchers and designers.

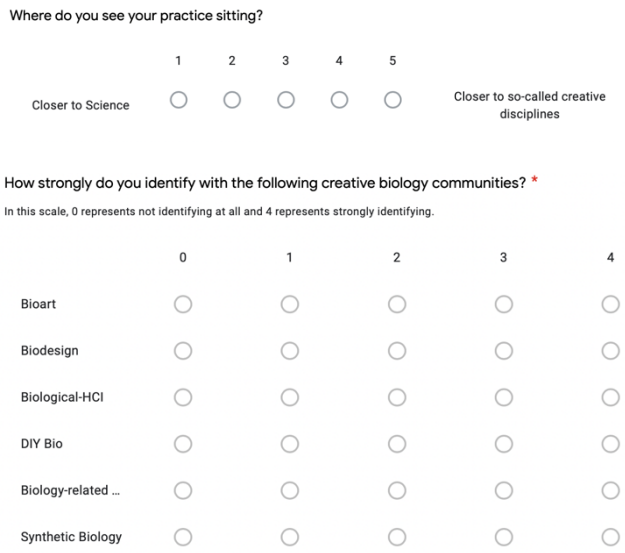

Figure 1. Questionnaire where we asked participants to identify where they saw their practice sitting

4. Responses

The highest proportion of interviewees (34.2%) positioned themselves between the sciences and creative disciplines, 26.3% leaned slightly towards the sciences, 18.4% towards the creative disciplines, with 13.1% placing themselves firmly in the creative disciplines, and only 7.9% firmly in the sciences. The distribution of how participants saw themselves as belonging to different movements was largely balanced. 52% identified themselves more strongly (scales 3 and 4 of Figure 1) as part of biodesign; 50% as biology-related research, 50% bioart, 47.4% synthetic biology, 31.6% DIY-bio, and 21% biological-HCI.

4.1Language

Through thematic analysis we identified four key aspects regarding the use of language and vocabularies:

Working across vocabularies and tactical use of language

Participants reiterated the prevalence of different ways of referring to themes, and the importance of learning the language of collaborators across and within disciplines: *"I think that having the tools to understand the language, the scientific language does contribute to your freedom as a designer, freedom of thought*" (NA).

The responses also showed that once vocabularies were mastered, they were used tactically to demonstrate knowledge of other fields: "*When I speak to scientists, I try to drop some key words, so they will see that I understand.*" (NA). By identifying vocabularies of practice, participants were able to place their work and, eventually, shift their own positions across fields: "*it's very hard to position where their work comes from, but if you have a certain category of words, it really helps*" (RK). Vocabulary was also tactically used to convey a certain message or create meaning through a generative critical approach. For instance, participants would strategically avoid a term in order to open space for emergent themes: "*One stipulation was to basically not use the word 'nature' in this project for two years. What that means depends on what language we need to construct to fill that gap*" (EB).

Participants would also use terms to create different connotations: "*Things like using the word 'interaction' I suppose (in contrast) to 'infection' [...] because firstly it has a connotation of a positivity if you say something is interactive, whereas infection is more of a negative connotation.*" (RK). Naming would then become a method to suggest new connotations to a particular practice "*a curiosity to then define it, to then interrogate [a name or title], is something that we use a lot in our practice.*" (AN2). Figurative use of a word was seen as creating ambiguity and potentially fruitful misunderstandings: "*we can use transversal tropes that cut across disciplines, but this reveals misunderstandings and ambiguity of terms [...] which means that both sides can engage in different alternative knowledge production*" (JH).

Metaphors would be brought to another area so that different meanings could surface, and a dialogue can be established "y*ou'd like to see it, to bring that work into another domain so that the metaphors are negotiated, and you find the similarities and most of the time the problems so that you can work with them*" (OT). Metaphors would be used to "*bring up the beauty of what we're doing when it can seem so simple*" (LC) and juxtaposed with other terms to create meaning: "*when I take those metaphors, I juxtapose them against other possibilities that are not things that I just invented, but things that I see when I'm in the lab, what I would call operational metaphors that cohere with practise but don't dominate the literature [...] I think if I just presented one of those things by themselves, it wouldn't have the same effect as being able to juxtapose them*" (ES).

Artists and designers often expressed that they would use terms to enhance engagement: "*from a designer's point of view, there's a certain amount of enjoyment in taking the terminology and the vocabulary of the scientific world [...] and playing with it a little bit, it gets a certain degree of interest and a certain degree of partial description in the resultant word and terminology which then requires a little bit more of the engagement*" (SP). They would create vocabularies to assign meaning to their work: "*These added meanings are based on artistic licence, intellectual work. It's not necessarily a vocabulary that is aimed at common use [...] I tend to avoid certain weighty words used by other practitioners or thinkers*." (MS) and would ultimately endeavour to constantly change their vocabularies to generate new possibilities: "*I do not think I have a fixed vocabulary and if I do, I try to continuously change that. How to think and practice living bodies without giving fixed categories that would define things as given is another challenge*" (AW).

Generative power of metaphors

Participants acknowledged the generative power of metaphors: "*by using this language, we basically bring something also into the world, on how we interact with our environment. Also, what it enables, but also what it prevents us from*." (EB), and language more broadly: "*I wanted to try and have a slightly more animated quality to the language. I think often, the language could do with being looked at and thought about in different ways, because as soon as you do, it gives you a different perspective on the material that you're working with.*" (LM). For instance, a simple exercise in a science class would invite students to think differently about their practices: "*We do an experiment [...] which is 'fill in the blank'. Cell as 'blank'. Cell as factory, of course, cell as church, cell as religion, cell as government, cell as poetry, cell as whatever you want. Suddenly, what does it mean? It's very interesting, especially with biologists and engineers, it's like, 'Oh, my gosh, wait. Wow, I could really think about this thing differently.'*" (DE).

Limiting aspects metaphors

Metaphors were however also seen as limiting: "*if you use metaphor and you don't quickly move past it, it's like you're drowning and you hold on to that buoy and you won't learn how to swim.*"(DE). The use of computing analogies to explain biological organisms, which are characteristic of synthetic biology, was seen as particularly limiting as it could lead to an "*objectification of the microbial world*" (NC), as explained by MP: "*I am sceptical about the organism-machine analogies, they are misleading. Organisms and machines are just different stuff*". However, many compared current developments in biotechnology with developments in computer systems a few decades ago, in terms of "*heading down a similar direction*" (PG) of becoming more democratised and therefore able to integrate different groups and voices.

The need for new forms of expression

Although the value of vocabularies was recognised, participants also acknowledged often being lost for words: "*What do you call that? What do you call a uniform dye that has texture? We've never seen that before outside of this context. Even the tools that you are building to be able to make the thing, they're very bespoke*" (NTA). There was also a discussion of the usefulness of other forms of expressions as vocabularies: "*there is a certain amount of visual vocabulary as well, which is of interest*" (SP), and the need to use different forms of expressions to "*engage with biology in ways that we don't have words or cultural words to deal with*" (OC), as explained by ES: *"words are part of a larger ecosystem of tools, and sometimes don't produce as visceral a means of asking questions as other, more creative approaches. I don't want to say creative because words are creative too, but as multimodal approaches, I would say. Things that involve, or are more, very sensorial*".

4.2 Visions of the Future

Looking towards the future, they focused on the ethics of working with living organisms, which was seen as directly connected to handling living organisms: "*it's about the ethics of the interaction with life that can only be fulfilled through direct engagement and taking responsibility for it*" (OC), and to the awareness of what happened locally, around them, in practice, rather than to abstract models of nature: "*That global vision also means to be really grounded somewhere in particular. It's not only about abstract views*"(JH). In other words, ethics would create a "*probing space, the space between the laboratory enquiry and everyday life.*" (MS). Ultimately, creative biologists would be trained to work with the material of life while being able to ask complex questions: "*What does it mean to make a better world with biology? What does it mean to try and make nature better? Who is it better for? Creative biology just opens up this whole subset of complex questions and issues. If we're training people to think in those ways, it has to be as nuanced and complex as the material that they're working with*" (ADG).

Creative biology was seen as a drive to transcend current knowledge systems and institutions towards a common set of values: "*We have to be quite vocal - I think - about what we are for, and what we are against. We have to build new networks that transcend the institutions that have held us running in one spot for too long [...] I'm very interested in globalised networks of practitioners who are brought together by not necessarily a common vision, but a common set of values*" (NAS) - values that are indeed what drives transdisciplinary collaborations.

Scientists talked about the need for more speculative thinking: "*For me, we need more 'what if' thinking in science and engineering [..] because our norms are no longer there. We need solutions or like, 'Oh, we didn't think about that kind of solution.*'" (NN), and to foster more empathy and imagination: "*The learning to learn, the learning to have empathy for what*

people wish for when we don't know how to wish [...] Most of biotechnology hasn't been imagined, let alone made true. [...] and so who are the people who are professional at imagining?" (DE).

There were concerns "*about the future wherein biology is directed toward producing commercially viable and valuable outcomes*" (ES), and, again, a desire to keep creative biology complex and nuanced: "*the creativeness of biology, regardless of human intervention or not, the fact that it's messy, unpredictable, and extremely complex, is what I would like to see coming out of creative biology*" (OC) while also keeping it open to possibilities: "*synthetic biology is becoming less weird, is becoming more commercialised, more industrialised, more military funding and more closed. Keeping it weird, which involves also keeping it open, partially requires letting people in. Yes, letting people come in and contribute in ways that might not necessarily happen in a normal scientific field*" (JC).

5. Discussion

5.1 Using language to cross disciplinary boundaries

The responses showed that language plays an important role in generating new spaces of knowledge, which in turn helps to re-frame understanding and shape interactions. Vocabularies were used to demonstrate knowledge from a particular field, to position their practice, to potentially allow participants to gain "access" to a field or discipline (NA), and shift position as appropriate (RK). In parallel to an interest in mastering vocabularies and finding ways to better communicate, practitioners and researchers used language to incite new thoughts and ideas, while artists and designers used it to enhance their practices (SP, AN2, MS) while looking to maintain a sense of authorship for particular words. Vocabularies were therefore used to connect, provoke, and individualise.

Participants stressed the need to move past abstractions and metaphors into reality. The insistence on metaphors specific to particular disciplines, which were seen as "accelerants into the mind" (DE), was considered limiting. There was also a suggestion that metaphors should be demystified to allow the reality to emerge. Once transferred to another field, however, metaphors could help generate discussion, by becoming "negotiated" (OT), and suggest new ideas.

Participants proposed strategies to move beyond field-specific metaphors, for instance, by omitting usual terms (EB), running through several meanings of taken-for-granted terms (DE), using "transversal tropes" (JH), or "juxtaposing" metaphors with others (ES). While these tactical uses of language were often carried out by one individual, others were agreed between collaborators - such as the omission of a common word (EB) as a way to force collaborators to reflect on their own use of language and connected ideas when they filled the gap of the missing word. Artists and designers were particularly prolific in using language and metaphors to generate meaning and gain a "different perspective" (LM) on the context, material, theme, or object of the collaboration. For instance, they used words that are not

often applied to a particular context as a way to provoke different ways of thinking about it, using "naming" as a creative "method" (AN2) or taking "artistic license" to employ terms according to personal theoretical or aesthetic interests (MS). They would use, for instance, a term that had different connotations to invite collaborators to rethink established ways of thinking and doing things.

Research has looked at the way metaphors influence the way people think, make decisions (Lakoff and Johnson, 1980) and structure their experiences (Kovecses, 2010). Psychology (Thibodeu & Boroditsky, 2011) has also shown that the ways in which we talk about complex and abstract ideas are permeated with metaphors that influence the way we look for further information about these ideas. Metaphors therefore are not only "accelerators of the mind" but accelerators towards a particular outcome, one that is in line with the sets of beliefs and values of a discipline. This is something that practitioners and researchers have identified and challenged to guarantee freedom of thought and the ability to transcend their disciplines. In the interviews, both scientists and designers revealed making use of experimental vocabularies and linguistic tactics such as metaphors, to challenge their own thinking and tease others to cross fields of knowledge and access what Nicolescu would call a zone of non-resistance. While research in design has looked at the multiple ways designers use metaphors to approach design problems (Casakin, 2007, Cila, 2013; Hey et al., 2008), the insights above suggest that metaphors and linguistic tactics could also be powerful tools to provoke, mediate and facilitate transdisciplinarity.

5.2 Opening up and keeping it weird

The insights above also indicate that there are spaces which seem inaccessible to current ways of expressing ideas. Participants mention the lack of "cultural words" (OC), the need to resort to new means of expression through "visual" (SP, OT), "multimodal" or "sensorial" (ES, AN3) formats. In this search for new forms of expression, they created a "probing" space "between the laboratory enquiry and everyday life" (MS), a space to approach questions of creativity, ethics, and the kinds of worlds we would like to live in. The value of working across disciplines was characterised not as trailblazing a new path to be followed by others, but to create examples of practices that would help to form a landscape geared toward particular values that can give insights into new realities.

Areas traditionally seen as creative disciplines were considered able to introduce a new level of "critique", "subjectivity", "experiences" and "voices" to the realm of biological sciences, and opening up access to biology-related knowledge and tools was seen as enabling new practices that would potentially change who is in control of these practices, and therefore the ways and kinds of knowledge of biological systems.

Participants drew attention to ways exchanges across fields would allow the emergence of discussion on how to deal with the complexity, messiness, and unpredictability of working with biology (RK, OC). Such collaborations would open up new ways of referring to biology, which would in turn allow its domains to become more multifaceted, and potentially

“messy” (OC), “weird” (JC), and perhaps independent from practical outcomes (ES). This was seen as particularly relevant, given that scientific fields are perceived as becoming more commercialized (ES, JC), industrialised (ES, JC) and militarised (JC), which could restrict creative possibilities. It was the crossovers of disciplines that participants saw as able to lead to ways of working that are more “nuanced and complex” (ADG), and to create an “emerging form of critique” (JC) that would lead to ideas and concepts that are unimaginable (TG, DE) now.

While linguistic strategies were used to entice collaborators to step out of their ways of thinking and open up new spaces of knowledge, ultimately collaborators needed to find new methods, tools and formats to express and place new practices. Such expressions were “never seen before” (NTA), were hard to place within existing fields and hard to describe to existing audiences (e.g. ES mentions “I end up with things that are unconventional no matter where I try to publish them”). Therefore, their origins and outcomes cannot not be determined at the start of the process.

This brings up the complexity of attempting to foster transdisciplinarity or planning for transdisciplinary-focused curricula. For example, a curriculum might focus on “skills training in design frameworks, values, and ethics, and design for important themes such as sustainability, equity, adaptation, justice, and social responsibility.” (Blevis et al 2014, p37), which are truly relevant, but leaves the question of how such curricula would remain open to support the unexpected, e.g. considering avenues for dissemination when there is no adequate space to publish / exhibit / talk about an emergent work, the production of new equipment to support an emergent method, or integration of new expertise when the course itself transcends the discipline within which it was created.

5.3 Uncovering new realities and identities

In what could be seen as a manifestation of transdisciplinarity, participants suggested that creative biology collaborations should focus on the bigger goal of developing ethical approaches to thinking about and working with living organisms (ND, OC, ADG, MDR, NAS). There was an awareness that networks and collaborations should “transcend institutions” (NAC) and should be brought together based on “a common set of values” (NAC). From a place of collaboration, researchers and practitioners would ask questions such as “what does it mean to make a better world with biology? [...] Who is it better for?" (ADG) “what else can I do as an individual that contributes to the greater good, and who are my allies?" (NAC). By trying to answer these questions they would get closer to the complexity of issues in the world which involves not only the social, cultural, and human, but also the full biological realm. The answers to ethical questions were seen as only achieved through direct engagement with organisms (OC), and grounding ideas “somewhere” in particular (JH). All of this connects to the transdisciplinary precept of engaging disciplines towards goals that go beyond disciplinary boundaries.

Participants drew attention to how pairing people with different backgrounds would invariably lead to something new - and if one party was to be replaced with another with a similar background, the new pairing would still generate something new (EC). The encounter of these individuals was seen as representing an encounter of worlds, providing a way into different levels of reality. When participants were asked to place their practice in relation to the sciences and creative practices, most located themselves in the middle, or leaning slightly towards one or another. Similarly, most saw themselves as belonging to several movements simultaneously. Engaging with other disciplines ultimately changed their identities. Scientists became designers, critics, artists, and the other way around, integrating methods and lessons learned from other disciplines into their research practices and teaching.

This echoes McGregor's (2015) argument that transdisciplinary practices change not only outcomes and disciplines, but the individual themselves. Despite being at different points in their careers, participants in our study had all achieved a level of success in creative biology. They had actively engaged with other disciplines, and were able to move across methods and practices, engaging in what Nicolescu would describe as a zone of non-resistance.

When we analyse discussion on how design could support transdisciplinary practices and education (Constantino, 2018; Chew et al., 2020; Blevis et al., 2014, 2015), we notice a lack of discussion on the challenges of preparing people as individuals to engage in such practices. Negotiating transdisciplinary practices can challenge core beliefs and ways of making sense of the world, which, according to McGregor (2015), could bring issues of identity and expertise that risk blocking people's engagement. Ways of assessing individual openness and gradual integration of challenges and collaborations could therefore help prepare the transdisciplinary subject to engage in this zone of non-resistance, supporting the emergence of unexpected outcomes.

6. Conclusion

Through a search for, and the tactical use of language, participants gave new meanings to practices and created work that accessed new ways of seeing the world, or new levels of reality, in Nicolescu's terms. Through their collaborative work, they attempted to express concepts that were considered hard to translate, particularly because cultural references to them did not seem to exist. New methods, tools, and formats therefore needed to be created to fill these gaps of expression, which were key to generating new knowledge, but could not be predetermined. Finally, the collaboration across disciplines changed not only the outcomes but the individuals themselves. These are useful lessons for both design practice and education. Linguistic tactics could be useful for designers to reflect on their own practice and tease other disciplines into a space of non-resistance. If design is to become a bridge that can connect disciplines and support moves towards transdisciplinarity, we need

to address not only challenges, methods, and outcomes, but also the individual, while staying open not only to unexpected formats and ideas, but also to the possibility of letting go of the very principles of design that might sustain our beliefs.

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7. References

Barati, B. et al. (2021) 'Living Light Interfaces and Exploration of Bioluminescence Aesthetics', in Designing Interactive Systems Conference 2021. New York, NY, USA: Association for Computing Machinery, pp. 1215–1229. doi.org/10.1145/3461778.3462038 (Accessed: 6 September 2021).

Boer, L. et al. (2020) 'Gut-Tracking as Cultivation', in Proceedings of the 2020 ACM Designing Interactive Systems Conference. New York, NY, USA: Association for Computing Machinery, pp. 561–574.doi.org/10.1145/3357236.3395588 (Accessed: 6 September 2021).

Bremner, C., and Rodgers, P. (2013). *Design without discipline*. Design Issues, 29(3), 4-13.

Brown, V. A. (2015). Utopian thinking and the collective mind: Beyond transdisciplinarity. Futures, 65, 209–216. https://doi.org/10.1016/j.futures.2014.11.004Buchanan, R. (1992) 'Wicked Problems in Design Thinking', Design Issues, 8(2), pp. 5–21. doi:10.2307/1511637.

Budinger, K. and Heidmann, F. (2019) 'Our Symbiotic Life: An Exploration of Interspecies Relations', in Proceedings of the 2019 on Designing Interactive Systems Conference. New York, NY, USA: Association for Computing Machinery (DIS '19), pp. 1349–1362. doi:10.1145/3322276.3323698.

Blevis, E., & Stolterman, E. (2009). Transcending Disciplinary Boundaries in Interaction Design. Interactions 16, 5 (Sept. 2009), 48–51. https://dl.acm.org/doi/10.1145/1572626.1572636

Blevis, E., & Stolterman, E. (2009a). The confluence of interaction design & design: From disciplinary to transdisciplinary perspectives.

Blevis, E., Koskinen, I. K., Lee, K. P., Bødker, S., Chen, L. L., Lim, Y. K., ... & Wakkary, R. (2015). Transdisciplinary interaction design in design education. In Proceedings of the 33rd Annual ACM Conference Extended Abstracts on Human Factors in Computing Systems (pp. 833-838).

Blevis, E., Chow, K., Koskinen, I., Poggenpohl, S., & Tsin, C. (2014). Billions of interaction designers. *interactions*, 21(6), 34-41.

Casakin, H. P. (2007). Factors of metaphors in design problem-solving: Implications for design creativity. *International journal of design*, 1(2), 21-33.

Camere, S., & Karana, E. (2018). Fabricating materials from living organisms: An emerging design practice. *Journal of Cleaner Production*, 186, 570-584.

Chew, J., Lee, J. J., & Lehtonen, M. J. (2020). Towards Design-Driven Transdisciplinary Education: Navigating the Challenges and Envisioning the Role of Design as a Facilitator.

Cila, N. (2013). Metaphors we design by: The use of metaphors in product design. Thesis: TUDelft.

Costantino, T. (2018). STEAM by another name: Transdisciplinary practice in art and design education. *Arts education policy review,* 119(2), 100-106.

Dorst, K. (2018). Mixing practices to create transdisciplinary innovation: A design-based approach. Technology Innovation Management Review.

Dorst, K. (2019). Design beyond design. She Ji: The Journal of Design, Economics, and Innovation, 5(2), 117-127.

Gibbons, M. and Nowotny, H. (2001) 'The Potential of Transdisciplinarity', in Klein, J.T. et al. (eds) Transdisciplinarity: Joint Problem Solving among Science, Technology, and Society: An Effective Way for Managing Complexity. Basel: Birkhäuser (Schwerpunktprogramm Umwelt / Programme Prioritaire Environnement / Priority Programme Environment), pp. 67–80. doi:10.1007/978-3-0348-8419-8_7

Gough, P., Pschetz, L., Ahmadpour, N., Hepburn, L. A., Cooper, C., Ramirez-Figueroa, C., & Catts, O. (2020). The Nature of biodesigned systems: Directions for HCI. *In Companion Publication of the 2020 ACM Designing Interactive Systems Conference* (pp. 389-392).

Hey, J., Linsey, J., Agogino, A. M., & Wood, K. L. (2008). Analogies and metaphors in creative design. *International Journal of Engineering Education*, 24(2), 283.

Hadorn, G. H., Hoffmann-Riem, H., Biber-Klemm, S., Grossenbacher-Mansuy, W., Joye, D., Pohl, C., ... & Zemp, E. (Eds.). (2008). *Handbook of transdisciplinary research* (Vol. 10, pp. 978-1). Dordrecht: Springer.

Hamidi, F. et al. (2021) 'Turning the Invisible Visible: Transdisciplinary Bioart Explorations in Human-DNA Interaction', in *Proceedings of the 2021 CHI Conference on Human Factors in Computing Systems*. New York, NY, USA: Association for Computing Machinery (CHI '21), pp. 1–15. doi:10.1145/3411764.3445408.

Kim, R., Linehan, C. & Pschetz, L., (2022). DNAmons and Fossilopoly: Navigating Imaginaries of DNA-Based Digital Data Storage. *In Proceedings of the 2022 CHI Conference on Human Factors in Computing Systems: CHI'22*. ACM

Kim, R., Pschetz, L., Linehan, C., Hee Lee, C. & Poslad, S., (2021), Academic Mindtrek: Proceedings of the 24th International Academic Mindtrek Conference. Archives in DNA: Exploring implications of an emerging bio-digital technology through design fiction. ACM, p. 102-105 4 p.

Kuznetsov, S., Taylor, A. S., Regan, T., Villar, N., & Paulos, E. (2012). At the seams: DIYbio and opportunities for HCI. In *Proceedings of the Designing Interactive Systems Conference* (pp. 258-267).

Kuznetsov, S., Doonan, C., Wilson, N., Mohan, S., Hudson, S. E., & Paulos, E. (2015). DIYbio things: open source biology tools as platforms for hybrid knowledge production and scientific participation. In *Proceedings of the 33rd Annual ACM Conference on Human Factors in Computing Systems* (pp. 4065-4068).

Landrain T, Meyer M, Perez AM, Sussan R. Do-it-yourself biology: challenges and promises for an open science and technology movement. Syst Synth Biol. 2013 Sep;7(3): pp. 115-26. doi: 10.1007/s11693-013-9116-4. Epub 2013 Aug 2. PMID: 24432149; PMCID: PMC3740105.

McGregor, S.L.T. and Gibbs, P. (2020) 'Being in the hidden third: Insights into transdisciplinary ontology', *Transdisciplinary Journal of Engineering and Science*, 11, pp. 142–157.

McGregor, S. L. (2015). Transdisciplinary knowledge creation. In *Transdisciplinary professional learning and practice* (pp. 9-24). Springer, Cham.

McGregor, S. L. T. (2015a). The Nicolescuian and Zurich approaches to transdisciplinarity. *Integral Leader-ship Review,* 15(3).

Myers, W. (2012). *Bio Design: Nature, Science, Creativity*. United Kingdom: Museum of Modern Art.

Moisy, A. & Pschetz, L. (2017), Designing with living organisms. In: *Proceedings of Research Through Design Conference RTD'17*.

Nicolescu, B. (2002). *Manifesto of Transdisciplinarity*. Translation: Karen-Claire Voss. Albany, NY: SUNY Press.

Nicolescu, B. (2010) 'Methodology of Transdisciplinarity–Levels of Reality, Logic of the Included Middle and Complexity', *Transdisciplinary Journal of Engineering & Science*, 1. doi:10.22545/2010/0009.

Ofer, N., Bell, F. and Alistar, M. (2021) 'Designing Direct Interactions with Bioluminescent Algae'. In *Proceedings of Designing Interactive Systems Conference 2021*. New York, NY, USA: Association for Computing Machinery, pp. 1230–1241. doi.org/10.1145/3461778.3462090.

Pohl, C., Klein, J. T., Hoffmann, S., Mitchell, C., & Fam, D. (2021). Conceptualising transdisciplinary integration as a multidimensional interactive process. *Environmental Science & Policy*, 118, 18-26.

Pataranutaporn, P., Ingalls, T. and Finn, E. (2018) 'Biological HCI: Towards Integrative Interfaces Between People, Computer, and Biological Materials', in *Extended Abstracts of the 2018 CHI Conference on Human Factors in Computing Systems.* New York, NY, USA: Association for Computing Machinery (CHI EA '18), pp. 1–6. doi:10.1145/3170427.3188662.

Ramirez-Figueroa, C., & Dade-Robertson, M. (2013). *Adaptive Morphologies: Toward a Morphogenesis of Material Construction.* ACADIA 2013: Adaptive Architecture.

Ramirez-Figueroa, C., Hernan, L., Guyet, A., & Dade-Robertson, M. (2016). *Bacterial Hygromorphs: Experiments into the integration of soft technologies into building skins.* ACADIA 2016 - Posthuman Frontiers: Data, Designers and Cognitive Machines, 244.

Ramirez-Figueroa, C. (2018). *Bio-material probes: Design engagements with living systems* [PhD Thesis, Newcastle University]. https://ethos.bl.uk/OrderDetails.do?uin=uk.bl.ethos.765309

Ramirez-Figueroa, C., & Beckett, R. (2020). Living with buildings, living with microbes: Probiosis and architecture. Arq: Architectural Research Quarterly, 24(2), 155–168. doi.org/10.1017/S1359135520000202

Ramirez-Figueroa, C., & Hernan, L. (2021, October 1). Bio-revolutions: Radical change, design cultures and non-humans (Proceedings Paper No. 7). Design Culture(s). Cumulus Conference Proceedings Roma 2021, Volume #2; Cumulus (the Global Association of Art and Design Education and Research). https://cumulusroma2020.org/proceedings/

Szymanski, E., & Calvert, J. (2018). Designing with living systems in the synthetic yeast project. *Nature Communications*, 9(1), 1-6.

Weiler, J. et al. (2019) 'Mycelium Artifacts: Exploring Shapeable and Accessible Biofabrication', in Companion Publication of the 2019 on Designing Interactive Systems Conference 2019 Companion. New York, NY, USA: Association for Computing Machinery (DIS '19 Companion), pp. 69–72. doi:10.1145/3301019.3325156.

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