TU/e
Industrial Design
Sensory Matters Squad

SENSORY SYMBOLSIS

Supporting the multi-/inter-disciplinary collaboration of bio-related design projects through tangible tools

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ABSTRACT

Having experienced bio-related projects in the biology and design fields, the author foresees more combinations of the two types of projects in the future and has begun to think about integrated issues, including the biological application aspect and the practical design, and the collaboration aspect. If team members can quickly recognise the common issues and then communicate and iterate, they can solve problems instead of being stuck with extended emotions. However, bio-related design beginners usually need more experience in multi-disciplinary collaboration and often realise the issues at almost the end of the project. Therefore, a set of suggestive tools was designed to help novices become more aware from the beginning of a collaborative bio-related design project. The team will be primed to know each other better, visualise the design process, and touch the combination of knowledge. With the building-up process of a new common language, team members have the shared fundamental of thinking and communicating. Next, they could have more trust and confidence to exert their dominant functions and be able to deal with complex knowledge further.

'Symbiosis' is the interaction between two different organisms living in close physical association, typically to the advantage of both. Sensory Symbolsis aims to facilitate symbiosis in a multi-disciplinary team through multiple sensory developments using signs and symbols.

INTRODUCTION

This project, Sensory Symbolsis, was inspired by the author's difficulties in cross-disciplinary collaborations, which include biology elements. In recent years, bio-related design is receiving more and more attention because biology brings fresh perspectives and material possibilities to innovators. The subcategory includes biomimicry or bio-inspired design, green design, biodesign, etc. No matter what kind of bio-related designs, we must collaborate with others and integrate biological knowledge to learn from Nature, consider ecological factors or implement living materials in the design. As a result, two main difficulties in the collaborative bio-related design project are **collaboration conflicts between diverse participants** and **complicated application of scientific knowledge**.

A project team of bio-related design primarily consists of participants from two fields: biology/science discipline and art/design discipline. The differences in innate characteristics and acquired training between the two kinds of people cause communication and working behaviour conflicts. Common communication problems come from their deep-rooted mindset, intention, expectation, and usage of words and expressions. Moreover, the discrepancy in working mode arises from their different preferable medium, tool and starting points for action.

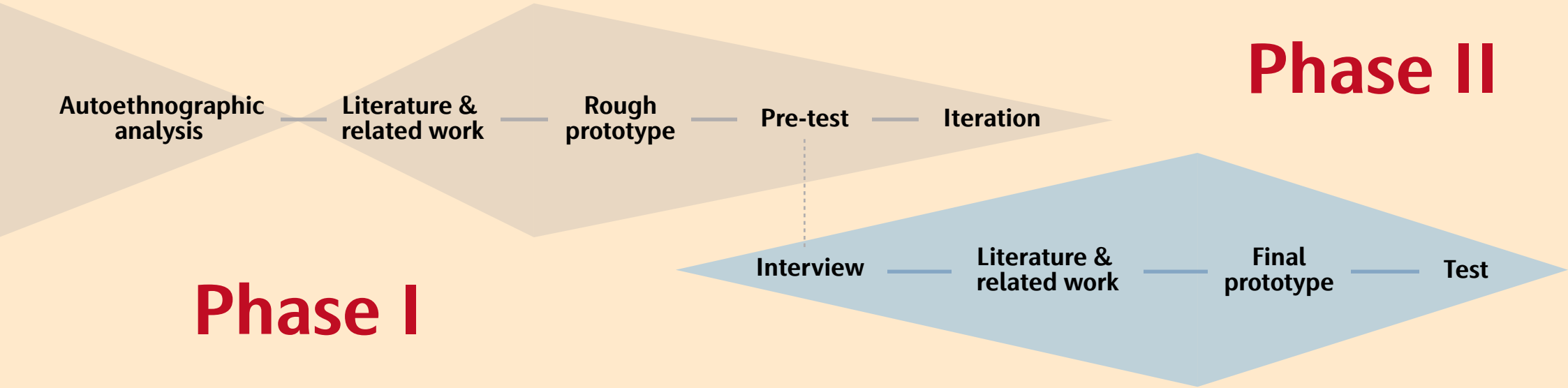
During applying scientific knowledge, the most common problem is the gap in understanding the terms. It takes work to let every member on the same page quickly, especially when everyone's learning way is different. Moreover, when there is a noticeable gap in background knowledge in the team, the expert often becomes the boss, and members with less knowledge also limit themselves from understanding more. Therefore, both the level of knowledge application in the project development and the potential of each individual get restricted.

Currently, well-known bio-related design works are executed by people who have experience in both fields or have several multi-disciplinary collaborative experiences, which makes them build integrative ability on their own. With a growing number of multi-disciplinary environments emerging, the needs for collaboration and related contests and courses for students are increasingly widespread. However, beginners often get frustrated in the collaborative process and give up diving more into this field. Consequently, this project aims to look into the common issues that beginners have experienced in collaboration and knowledge application and create a design to improve them.

DESIGN PROCESS

This project originated from the author's continuous reflection on her previous learning experience. Therefore, autoethnographic research was used to present insights into Phase I of the design process. In Phase II, interviews with others would be the primary design approach. Literature and related work review were involved in both phases.

During the first phase, rough prototypes would be made and tested in the interviews for part of the design items after the personal experiences were analyzed. Afterwards, the iteration coming from the test results, other significant findings in Phase I, and the analysis of interviews in Phase II led to the production of the final prototype. In the end, a focus group was used as the testing approach.



Phase I

Autoethnography is an approach to writing from the first perspective to analyze personal experience and seek correspondence with the research contexts. Below are two sections of self-reflection which first introduce the background of projects and the attitude of roles involved. All the content was retrieved from the author's journal. The information in Reflection - 1 was not much because the author was unaware of reflection-in-action at the beginning of this learning journey. The information in Reflection - 2 includes three kinds of format: **the observation of fact, conversation, and personal thoughts**. Then, the findings of reflection were commented on the content.

Reflection - 1

The first section contains two bio-inspired design projects in which the author has been involved in the Bio Inspired Innovation programme at Utrecht University. The first course, Integrative Bio-inspired Design, aims to design a renovation of the building and surrounding from the biomimicry perspective. Each group dealt with a topic in the renovation case. At the end of the course, they tried to achieve a systemic integration. The approach was developed based on the Nature Inspired Design method offered by the Nature Inspired Design team from TU Delft. Our group was responsible for biodiversity, and all members had a biology background. The goal of the second project, the Global Biomimicry Design Challenge, was to design a solution from object scale to system scale for a problem regarding SDGs in the world. The approach we used was the Biomimicry thinking method offered by Biomimicry Institute. All members have a biology background as well.

I have more experience in both projects in learning design and practising design thinking. Therefore, the perspective I adopted was relatively different from a biologist's eyes. Instead, I identified myself as a third role in-between biology and design discipline. Apart from the communication problems originating from the unfamiliarity with the online mode in the COVID era, the issues I have observed and others have expressed can also be divided into collaboration and knowledge problems.

/ Neglect of noticing the process and structure

My teammates from both projects have minimal experience in design. They usually do not look back and forth on the process and overview of the project, which leads to unclear or incomplete logic. Moreover, they are unfamiliar with using design tools and the typical chaos in the design process. Therefore, the lack of a design mindset makes them prefer discarding the method and also be scared of learning new tools.

→ As a beginner, practising noticing the process and structure is essential, especially in a multidisciplinary design like biomimicry design.

/ A gap in transforming the biological knowledge

Although every member has a biology background, each person is familiar with different topics. When a member holds much more knowledge on a particular subject, the voice in the group is unequal. However, most of the time, others will compromise with the expert's opinion rather than add new ideas after understanding and trying to transform them in their ways. Moreover, the aspects that can be discussed in one biology model are broad. And we often overlook other possibilities or extend the discussion without a focus. Nevertheless, if the knowledge is used to be transformed into the design, it is essential to differentiate the application level and range.

→ Knowledge is neutral. Interdisciplinary creation seeks to gain novel meanings from knowledge by switching mindsets. Hence, adding miscellaneous thinking and an evident transformation regarding the application levels is significant.

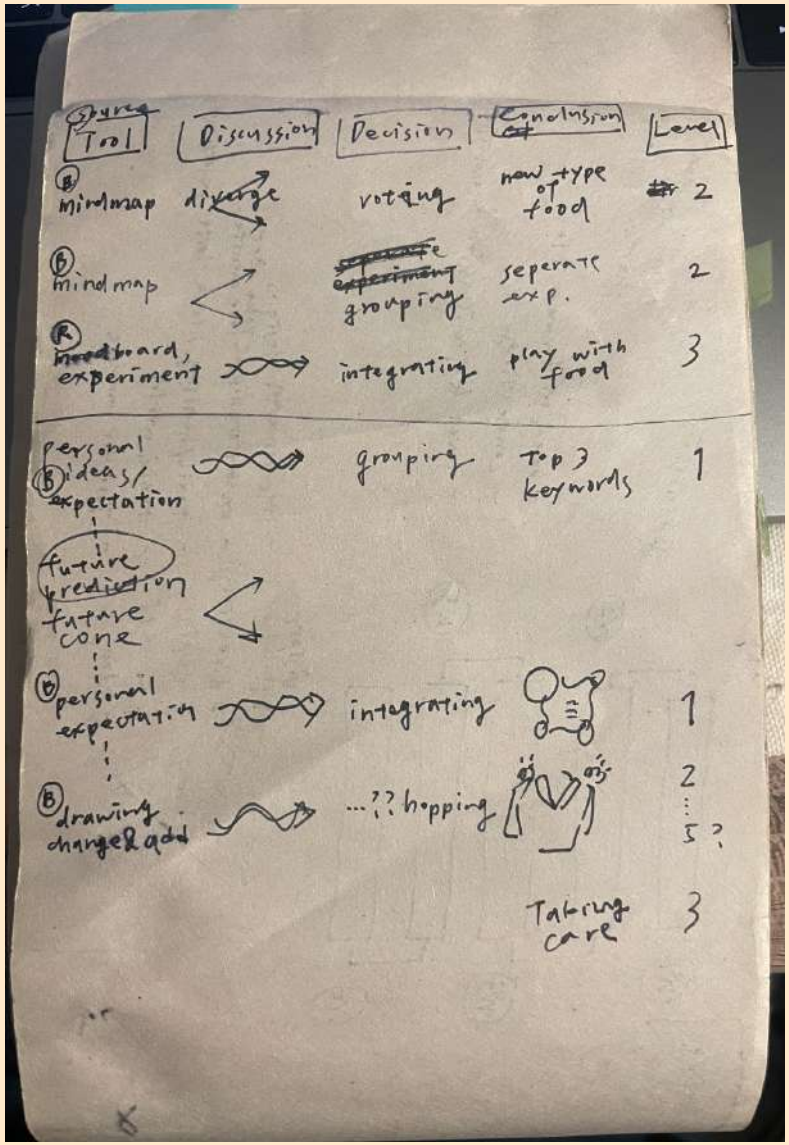


Figure 1: A page of analysing the meeting process and structure in my working journal.

Reflection - 2

TThe topic of this group project was the possibility of future food. Biological knowledge was involved in the discussion of food and agriculture. This project was conducted under the scheme in the department of Industrial Design. Hence, physical prototypes and various ways of expression and exploration were emphasized. In the beginning, a lo-fi prototype was required to represent the design process that week.

Team members in this project came from multiple backgrounds, member P1 from industrial design, member P2 from industrial product engineering, and member P3 from mechanical engineering. As the only person with a biology background, I was regarded as a biologist most of the time. Although I was more of a biologist in the team, I was aware of the role problem and tried not to deliver the knowledge too firmly.

Below, the content was divided into three parts- observation, conversation, and my thoughts at that time. Personal thoughts were the reflection-in-action retrieved from my journal. Few dialogues were documented in the project process, so only some impressive ones were shown.

/ DOCUMENTATION WAY /

An assigned place can noticeably help all members use the same way to keep the notes.

After we built up a basic structure in the Miro board, everyone automatically opened it during an online meeting instead of using their ways to take notes (e.g., Word, memo app, Google doc, Google slide, etc.)

Observation

If it's not specified, we seldom use a piece of large paper, which is good for 3-4 people table work, to just drop down some ideas and discussion.

We kept some thoughts in personal notes because the large paper seemed more official and intended for a complete mind map.

In physical meetings, we took notes and draw mind maps on A3/A4 paper.

- They were scattered and lost in order quickly.
- A large sheet of paper is helpful for physical group meeting

We use paper to take notes whenever a more formal discussion happens, like brainstorming. But many random ideas were gone in the talking. In the online meeting, someone who is free will type it down on the Miro board. What if we use visual notes in the physical meeting?

It's really a pity because sometimes those random ideas and jumping dialogue are where the inspiration is.

1/ Even though we had an online team board, paper notes in physical meetings were still needed.

2/ Unified paper can lighten the burden of organizing.

3/ A3 is more suitable for 4 people at the table to see and write together.

Conversation

'I usually don't bring my laptop to the physical meeting, and I prefer to discuss things on paper. If I have to use it, I will close it up after I finish the search because I think it is a barrier between people.'

Digital work with laptop is not always for everyone and sometimes it interferes with the creativity process.

'Sorry for the organized person here, my thoughts jump easily and I am also not good at structuring the notes.'

Better documentation way should be more inclusive and every kind of person can use it.

'I think we need more colours in this place.' 'I totally agree with you. It's not inspiring at all now.'

Visual stimulants like colour and shape are essential elements for some people to get inspired.

'Let's print all the information out and make a collage of ideation. By doing so, we can touch and move them.'

Even though the information is found on the Internet, paper note offers other functions than online note.

Personal thoughts

There's a need of having tools to assist the visualization of thinking.

My teammates were amazed by the way I deconstructed our discussion chaos. I wonder what the difference between us is. I think it relates to the visualization of thinking. I saw the links after I organized them in a structure. If we do not 'see' the thoughts in a direct way, we will have to make an effort to let them make sense in our head first, not to say exchanging the details with others quickly.

Format design is a kind of mechanism for processing information.

A subtitle or hashtags are helpful when I am reviewing past notes.

1/ Explaining visually can help communication.

2/ The way that one uses visual elements can be learned and developed together into a way of communication on the paper.

Keep doing: visual notes. - I tried to draw more geometric shapes to help me explain the idea today, and it was much more straightforward and effortless for them to understand quickly. And they even added their ideas to the figures.

The format that you use to bring out the information would affect the way you deal with it.

I feel clear about my thoughts when I use the bullet point symbol, while I remember to make things actionable when I use the to-do list symbol. The transition from a passage to a bullet list or even a numbered/ to-do list simply makes things move forward.

Observation

In a project without a specific framework, it is likely to have several types of discussion happened in a short period.

In the beginning, our exploration ways switched among brainstorming, problem analysis, and personal vision. There is no specific step to start.

The mood board and lo-fi prototype concretize our discussion in some ways.

Different types of work in visual and physical are also ways of communicating.

The structure assists us in thinking.

People have a fear of giving out opinion if the structure seems solid.

A proper structure can effectively help the discussion without limiting too much.

We used various ways to explore the project topic, but we lost the order and reason for jumping from one perspective to another in the discussion. The title of each sub-session helps us remind of the process.

The links between subtopics in the discussion are easily missed if it's not noted, especially in a meeting which has diverse discussions.

A real design process is not linear and can't be put in a fixed framework. However, a suitable structure is still a helpful reminder.

'It's chaotic but that's also how the design process works.'

'Yeah ok, well, I know that iteration is needed but I tend to know the logic or steps behind the outcome.'

'I think we need to try to keep with the framework as last time. It did help.'

'One of my learning goals in this project is doing the work in a more structural way and I learn so much from you.'

Conversation

To deconstruct the mess of our previous meetings, I think we have to list out the discussion in these aspects

1. Source of thoughts
2. Discussion tool and discussion type
3. Way of decision making
4. Conclusion/next direction and its level

I always have to organize the meeting notes first and then I can think deeper. The items that impact the organization if missing

1. Subtitles
2. Chronological order
3. Conclusion/next action

I am easily stuck in a messy structure or layout. My brain will shut down and can't execute more if the information is categorized well.

Personal thoughts

After today's meeting, I was thinking whether I need the structure and method too much.

- This was the first time I felt like I was actually a person who studies science.
- I am used to thinking with the help of a toggle list, not a mind map.

People are willing to learn new tool and mindset if they realize it's helpful.

After they realized the importance of having a structure, they made one today and followed it rigorously.

However, I felt weird filling in those questions in the format and couldn't focus on thinking of some real idea.

I wonder: How can we balance/mediate the influence of structure and process in a design project? Is choosing a methodology a vital thing?

Observation

Overall, we spent more time developing the concept than making prototypes.

Visual is an important sensuous stimulation for people in the design field.

When I showed the mould pictures, they sparked and instantly brainstormed many ideas around those figures.

Drawing and playing with colour pens were the ways of relaxation during our meeting break.

We found much research to contemplate the concept topic. However, it also made communication harder.

Conversation

'Shall we close our laptops and discuss with printed pictures?'

'I think we spent too little time on making.'

'I need to know the knowledge behind it to get convinced.'

(When we were stuck and I proposed that we could review our previous design process) 'You need to review it, but I don't.'

1/ Everyone has their preferable way to work. It might be very different from what we used to but it might also brings new possibilities.

2/ Physical contact with them can give people new inspiration.

Personal thoughts

A brain that tends to rationality needs logic and hierarchical relationship, while a brain that tends to sensibility needs sensuous elements like colour and image.

Our discussion rushes into 'what' only for preparing weekly demos. But it doesn't really link to and help with the development of the concept.

The demo session helps people complete the imagination of a concept.

Both concrete and abstract parts are crucial in a design project. Instead of arguing about which to be valued more, it's more important to see the developing route and keep trying to be balanced.

Although some approaches are not how we are used to working, or we guess they won't work, it's still meaningful to experience it together as a group. The results would tell us what we still need.

Observation

The discussion flow and direction are usually led by someone who holds more information.

Unequal amount of information leads to unequal discourse power.

The level at that everyone translated the biology research can be very different.

Conversation

'I am not sure if I am able to understand that. My biology knowledge is only at the level of junior high school.'

Many people are afraid of knowing more about the knowledge that they are not familiar with at the very beginning.

Personal thoughts

The perspective of a member without a biology background can give an out-of-box insight. However, the gap between two fields is still there and 'a ladder of knowledge' is needed.

How might I offer more imagination to teammates who have low knowledge of biology to extend the possibility together in a short period? How could we create an environment for pro/semi-pro/non-pro people?

People who want to do bio-design without a biology background usually only learn from the DIYbio. How could they learn and do more than that?

I believe it is important to integrate our opinions to create things together. This is the meaning of a collaborative group project.

Based on the documentation and reflection, several findings which indicate potential improvements in multidisciplinary collaboration have been shown in the following aspects.

A better note-taking way on the table can increase the retention of discussion in the physical meeting. In the case of an online meeting, the behaviour of the whole team changed just by simply setting up a digital collective board. Conversely, we never had the same awareness of the physical meeting and tended to document all the precious information separately and disorderly. Considering the benefits of physical interaction and the preference of various people, designing a medium to collect group notes and pop-up thoughts can influence how we discuss and record in a face-to-face meeting.

Suggestions implied from the case

- Large sheet
- Unified
- Explicitly designated
- A fluid note-taking way that can contain random ideas
- Can encourage the appearance of visual elements and boost 'visualization' becoming the team language
- The format can prompt the effectiveness of dealing with information

A moderate structure can improve the consistency and rationality of thinking in everyone's mind. The evidence above shows that a basic structure benefits thinking and then discussing. However, emphasizing the format too much hinders team members who are not used to thinking coherently from speaking out their ideas. Moreover, not every part of the design project is suitable for a fixed structure. Therefore, I propose that a fluid and harmonious structure for discussing and recording should be designed.

Suggestions implied from the case

- Visualization and concretization are also ways of communication
- Providing the structure in a non-limiting way helps, including the structure for the whole design process and for the documentation
  - Whole design process
    - Multiple discussions interweave
  - Documentation for a subtopic discussion
    - Title
    - Chronological order
    - Conclusion
- The subtitle of the discussion can assist in connecting the diverse and changing process
- A format that people from both scientific and design backgrounds can accept and be inspired by will be better

A balanced working mode can show team members' characteristics and carry out the completion of a whole design project. Based on our experience, the outcomes of one-sidedly emphasizing either research or prototype were not good. It is unfeasible for each member to implement their accustomed working mode directly in a new multidisciplinary collaboration. If the participants can discriminate and adjust the percentage of stages they have gone through in the design process, recognize each other's thinking tendencies and work habits, and try new activities opportunely, it is more likely to achieve balance among members and also for the entire project development.

Suggestions implied from the case

- Do not emphasize desk research at the expense of practical work and vice versa
- Both thinking logic and sensory experience should be included
- Touch and visual activity can be random stimulations
- Know the difference between each other and know others' preferable working tendency
- Try the activity that you are not used to doing (More helpful under the lead of the person who is familiar with it)

A disassembled way of sharing information can popularize scientific knowledge, which fosters a scientific method of thinking and communicating among people. The difficulty of applying scientific knowledge derives from the high complexity of content, the invisible pressure given by the deliverer, and the undeclared resisting mindset that the receiver might own. This general problem can happen when people from different disciplines communicate in depth. Nevertheless, if it can be improved, the advantage is that thinking from various perspectives can bring novel insights and application possibilities based on the same knowledge. In terms of multidisciplinary and interdisciplinary collaborative design, it is much more valuable than having an expert who gives definite opinions to the team.

Suggestions implied from the case

- Clarification of the content levels → Let people with different levels join to think
- Spreading out on the table → Break the unequal hold of knowledge
- Gamification → Diminish the feeling of resistance

Literature & related work

/ Multidisciplinary, interdisciplinary and knowledge sharing

Multidisciplinary work involves participants from different disciplines who "remain conceptually and methodologically anchored in their respective fields" [1]. In contrast, interdisciplinary work will "integrate knowledge and modes of thinking in two or more disciplines or established areas of expertise to produce a cognitive advancement—such as explaining a phenomenon, solving a problem, or creating a product—in ways that would have been impossible or unlikely through single disciplinary means" [2]. In this report, the word 'multidisciplinary' is used mainly since some project cases in the following context do not reach the level of interdisciplinarity, and many collaboration problems of beginners happen in the multidisciplinary situation. However, several issues in the reflection analysis present common difficulties in interdisciplinary projects, including ineffective communication and a lack of mutual understanding of epistemological frameworks in the team [3].

Many researchers agree that interdisciplinary methods, knowledge diversity and the linkage between different types of knowledge are crucial to innovation and collective creativity [4]. Although some research looks into the interdisciplinary framework or experience between two science fields [5], between natural sciences and social sciences [6], or between research and practice [7], there is still a lack of and a need for interdisciplinary methodology, especially between science and design.

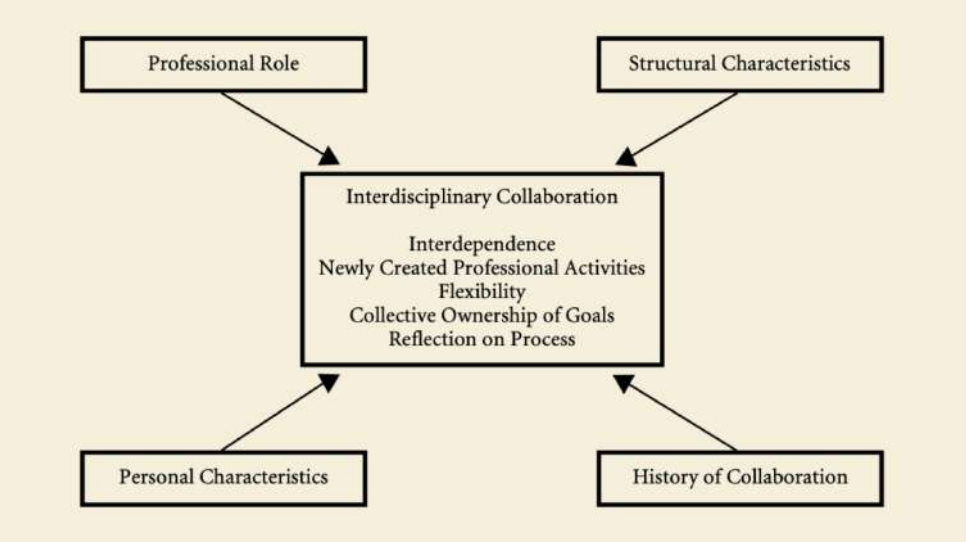
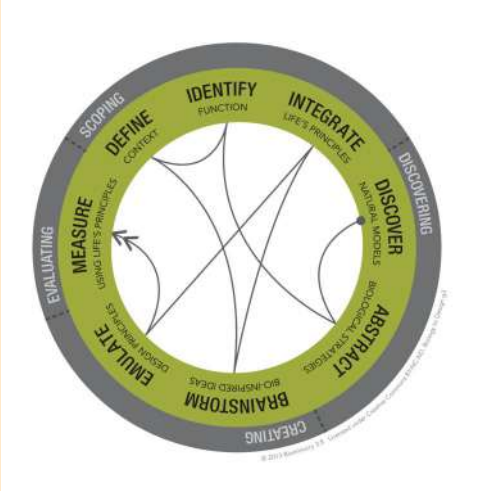


Figure 2: Influences on interdisciplinary collaboration [22].

/ Biomimicry Thinking Method

The consultancy Biomimicry 3.8 has developed Biomimicry DesignLens [8], a thinking structure assisting the biomimicry design process. The steps can be assembled in an ordered fashion depending on the project's aim. The "Biology to design" route can be used when the initiating point is a biological model. The other path, "Challenge to biology," is suitable for projects starting with a problem and calling for a solution. Besides the thinking method, they suggest a fundamental concept differentiation between biomimicry and other bio-approaches. Instead of consulting organisms, the bio-assisted approach accomplishes the needed function with the help of organisms, while bio-utilization harvests the product from organisms. Another essential categorization is the level of application. In biomimicry thinking, three mimicking levels are considered—form, process, and ecosystem. From a broader perspective of bio-approaches which also integrates the design language, four levels: material, form, mechanism, and system are taken into account.



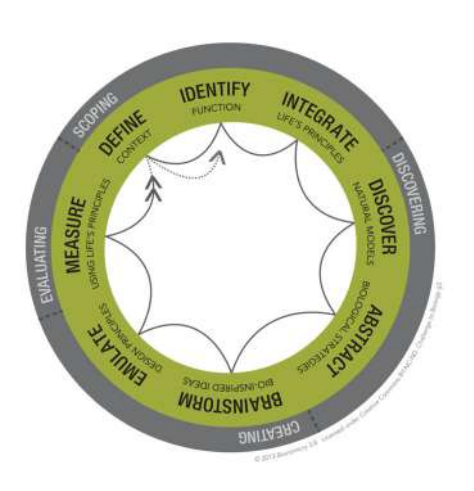


Figure 3: Biomimicry DesignLens [8]. Left: Biology to Design. Right: Challenge to Biology.

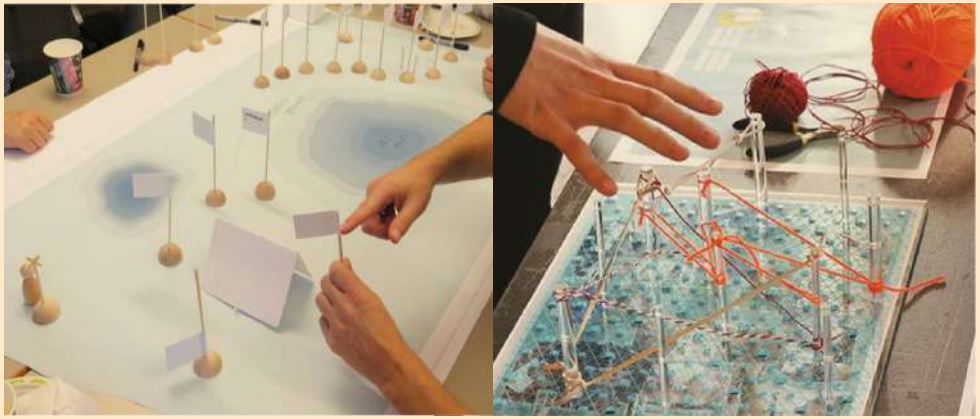


Figure 4: Tangible tools on the table [10]. Left: Actor Mapping Flags. Right: Multi-sensory relational tool.

/ Tangible Collaboration Tool

In cross-disciplinary collaborations such as healthcare services, co-design is increasingly used to support the development of creating processes between designers and people not trained in design [9]. Tangible tools play an important role in co-design because the physical form can help establish a shared language by switching focus from the jargon problem and misalignments in verbal communication to common physical reference points [10, 11]. Besides, tools can facilitate knowledge exchange, the negotiation of differences, interests alignment among stakeholders and generating new ideas under a playful atmosphere [11, 12].

Actor Mapping Flags uses a metaphorical map as the basis to show the innovation process and flags to represent the diverse actors. The multi-sensory relational tool from Aguirre-Ulloa & Paulsen visualized the relationships in complex public services through hemp and wire. Hall et al. have mentioned that using tangible tools with wires improved participants' discussion level than just using maker pens on paper because they had put more effort and concentration when attaching the cables.

Prototype

The design purpose of the prototype was to test part of the insights suggested by the self-reflection analysis. Because three interviewees have attended the Bio Inspired Innovation programme courses, the test items would be the two insights from Reflection - 1, which was based on the same courses, plus the main direction implied in Reflection - 2—tangible collaboration tools on the table.

To extend its value, the aim was to design additional tools on the table for the existing method in the biomimicry field, Biomimicry Thinking Method. There were two parts to this set of the prototype:

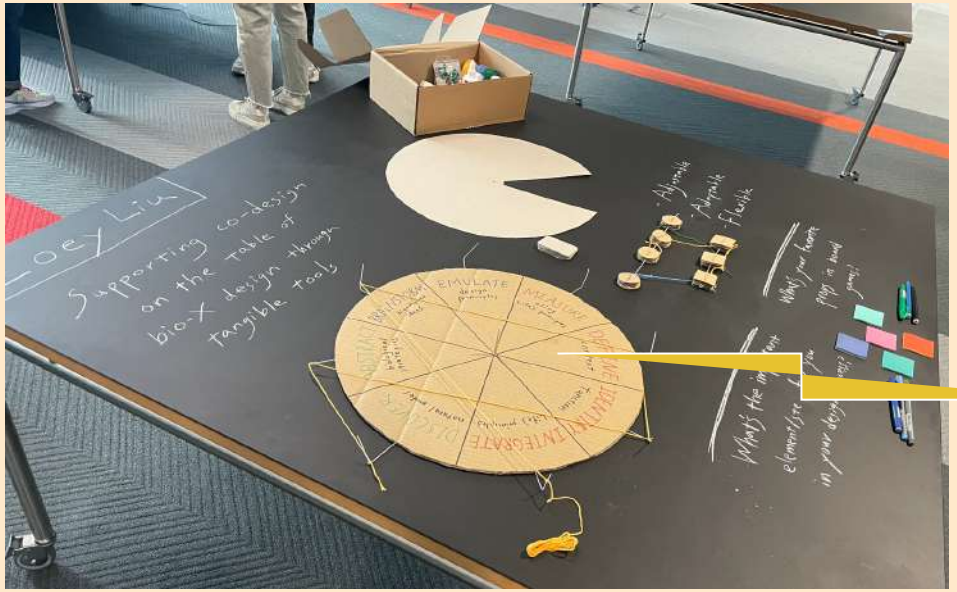


Figure 5: Rough prototype set on Dry-run Demo Day.

1/ A circle base for reminding participants of the structure in the whole project period, aiming at dealing with the issue of neglecting the overview and discussion purpose that happens when the members jump from one topic to another constantly. It is placed on the table, and participants can record the process by twining the string on each stick.

Design object 1: Biomimicry Design Structure Base

Material

- **Cardboard, soft string**

Function

- **Visible reminder**
- **Physical communication**
- **Project development record**

Figure 6: Application Levels Differentiating Tool. Left: 2D version. Right: 3D version.

2/ A tool for assisting the biological application step, aiming at dealing with the issue of neglecting the differentiation of application levels in transforming scientific knowledge. The usage of this item is to twine the string on a specific circle when discussing that aspect. Using this, the participants can concretize the level change and the element they focus on.

Design object 2: Application Levels Differentiating Tool

Material

- **Cardboard, soft string**

Function

- **Visible reminder**
- **Physical communication**
- **Short-term record**

Overall, the functions of this set of the prototype are enhancing the degree of concretization of two subjects that need abstract thinking: process and structure and the levels of knowledge. The design objects can be seen clearly as a reminder and can be moved and pointed to when the user is talking with others. Also, using the soft string as material, which is common but seldom appears in a verbal meeting, can stimulate other person's senses in the discussion.

Phase II

After the analysis of self-reflections, several interviews were set in Phase II to gather viewpoints other than the author's and to preliminarily test part of the findings. The outcomes of the interviews and the preliminary test were analysed. Then, the final prototype would be developed after the search for literature as an ideating approach. Last, a focus group was set for testing.

Interview background

All interviewees have attended design projects that need biological knowledge and collaborated with people from different backgrounds. The interview would start from the experience, background and identity of the interviewee, to the content of the bio-related design project and the background and description of teammates. Then, the questions would go into the multidisciplinary collaboration, personal way of thinking and working, or transforming scientific knowledge according to each one's project experience.

The Ethical Review Form, transcript and commentary are attached in Appendix. The first and second interviews adopted 'Intelligent Verbatim,' a slightly edited transcript. The third interview was in Chinese, so the transcript adopted the 'Edited' approach due to the translation of the content. Below is each interviewee's characteristic and their contributing parts. Following this introduction, the main sections are the results of the preliminary test and the categorised insights from interview findings.

Interviewee A

- Has a design background
- Has experience in collaborations with biology and chemistry background students
- Usually joins a team with a designer identity and contemplates only the design aspects most of the time
- Thinks that there should be an expert on the team to communicate the design parts to him
- Usual workflow
  - Making a significant number of sketches and prototypes (50 sketches/100 prototypes)
  - Talking to people and doing something relaxed when he is stuck (reading, walking, drawing)
  - Emphasise the importance of an unfixed process and iterations

Interviewee B

- Has a design background
- Has many collaboration experiences
- Has learned to switch the language when talking to different people
- Does not insist on her original working mode when joining a new group
- Thinks that people from another background are capable of trying new things in an environment that makes them feel safe
- Has a nice collaboration of bio-related design based on previous experiences
- Has more concerns about practical work, such as equipment, materials and safety, rather than collaboration issues
- Usual workflow
  - Making lots of things and imagining them being in different scenarios
  - Getting sparked by sensing around and talking to people in a physical environment
  - Emphasize that it is important to not be limited by the work frame and to have more iterations as possible

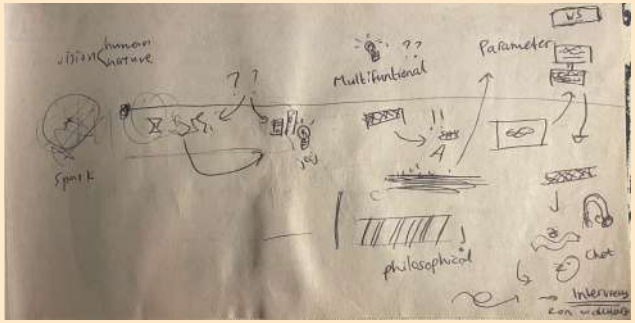


Figure 7: Interviewee B explained her design process.

Interviewee C

- Has a biology background
- Has three collaboration experiences in biomimicry design
- Collaborated with biology students at the BII programme in the second and third project
- Led a team and got awarded in the first project, which was also her first multidisciplinary collaboration
  - There were members with three kinds of backgrounds
  - Each category had two members, which could show the similarity in each background and also the discrepancy in the whole team
  - The collaboration condition became better after they knew each other's characteristics and communicated a lot, which is a useful reference for the 'multidisciplinary collaboration' issue
- All projects involved more biological knowledge than other interviewees, which could hugely contribute to the 'application of scientific knowledge' issue
- Usual workflow
  - Starting from searching for information, then defining the problem, and doing desk research further based on the defined problem
  - Developing the concept according to Biomimicry Thinking Method first, and then deciding whether to make the prototype

Pre-test

/ Biomimicry Design Structure Base

The users all thought that the circle base would be helpful. First, a tangible object supports the project development, especially for a newly forming team. The concretisation of divided processes can remind the group of what they are doing at the moment and what today's goal is, which builds up a shared mental image in the long term. Interviewee C thought this tool would be handy at that time because her teammates were all novices in biomimicry design. Second, it is beneficial to record the project development. All users mentioned the importance of iteration and reviewing several times in the interview before the pre-test. Hence, they strongly agreed that concretisation of the process review and iteration could help the team see the journey backwards and think forwards. Practically, it can facilitate the team to reexamine the steps and repeat a previous step if needed.

Concerning the form, all users have proposed other ways of expression, for example, adding layers to it or using boxes to collect the notes related to a step at different discussions. However, one concern is that the soft string may mess up the scene and does not assist the structure clear. A new idea from the user for the material is magnets.

/ Application Levels Differentiating Tool

The users all thought that the differentiating tool would be helpful. On the one hand, it can visualise the aspects you focus on. Although you have been on the same project and discussed the same biological models for a long time, there are still differences among application levels and project stages. It reminds you of diving into the model. It generates instant help when you communicate with other roles in your team, especially for an uncommon, unfamiliar biological model. On the other hand, the tool can aid in ideating team members' individual work. Besides communication with others, the users have to switch viewpoints when searching for the biological model. Undoubtedly, the existence of this tool facilitates one to think more about the level that is unfamiliar to you. One user also mentioned that forgetting to switch to other levels happens a lot and should be improved.

Concerning the form, all users thought the 3D version did not bring any effect. The 2D version has produced the influence. Moreover, it presents the linear relation of the application levels. Initially, the 3D version was made to give a new sensory experience. Users suggested that developing more on the affordance, such as rotating, taking off, and colours, can bring out the purpose of a 3D version, for instance, make people jump out of the linear perspective.

Interview findings

/ Multidisciplinary Collaboration

Concerning the first issue that this project aims at, the collaboration of people with diverse backgrounds, the interviews implied three points.

First, a fluid structure is more suitable for bio-related designs than a fixed structure. Interviewees mentioned that a fixed process generated many problems in their experience, and they needed principles to follow, not the steps [a4, b5]. In fact, there are many kinds of bio-related designs other than biomimicry design. Although this thinking method can be transformed into other bio-related design projects, it is separate from what this project wants to address: the communication and coordination among different modes of multidisciplinary collaboration. Considering the perspective of people with a design background and the need to make practical designs, it is more fundamental to have reflection and iteration sections in the design process rather than going through a straight set of steps only once [b6].

Although the Biomimicry Design Structure Base gained many positive feedbacks in the pre-test, the main reason was that it concretised the process and structure on the table. Besides, the ideas from interviewees, such as adding layers and boxes, also correspond to their need to want a fluid system in the design process. A fluid-structure has abstract principles to follow and can also remind people of the direction and framework. For example, the Reflective Transformative Design process (RTDp) mentioned by user B is a set of principles generalising the typical design process [b7]. Therefore, in terms of giving a structure, the concretisation of the Biomimicry Thinking Method would be changed into a prompt of RTDp.

Second, acknowledging each other's differences is the key to solving the problems resulting from the discrepancy in team members' function mode. The function mode here combines thinking inclination and behaviour/working habits. In the interviewees' experience, a project with a new working style indeed affects the work condition of the participant [b3]. However, each multidisciplinary team has their particular problems. Instead of implementing new methods to solve a specific issue, assisting the members in recognising the dissimilarity among them in the beginning and understanding the detail of differences in their function modes can facilitate communication naturally [a2, c9]. Besides more effective communication, team members can also know that there are other activities and working ways to try. Two interviewees pointed out that they usually break through the difficulties by receiving random stimulations in the design process [a8, b8].

This point was not tested in the pre-test. Nevertheless, based on the interviews, the design direction would be turned into enhancing members' understanding of each other's distinction and developing the functions they are not used to instead of designing a tool for a specific step or a particular problem. Let the function discrepancy in a team become its unique and beneficial feature rather than a considerable difficulty.

*** Annotations [a1]-[a8]: Appendix- 'Transcript - Interview 01'**
Annotations [b1]-[b8]: Appendix- 'Transcript - Interview 02'
Annotations [c1]-[c13]: Appendix- 'Transcript - Interview 03'
*** Please send a request to zoeyliu.jy@gmail.com for the Appendix**

Third, adding more visual elements fosters communication other than verbal language [b1]. According to the interviews, the participant with more experience in multidisciplinary projects has cultivated the ability to switch languages for different disciplines. In bio-related design projects, there is a gap between biological knowledge and design experience [b4]. All the members should try to learn others' language [c10]. Usually, it takes work to understand the actual language of a new field in a short period. Hence, using a common human basic understanding of visuals is an alternative. Encouraging visual elements also correspond to what the interviewee mentioned: the key to breaking through difficulties in multidisciplinary collaboration is using multiple ways to present and receive information [c12]. Besides opening up the senses, this adjustment can also move the focus of discussion onto neutral facts and eliminate prejudice toward others and the gap generated by language.

This point was not tested in the pre-test. Because the involvement of visual elements is not a noticeable matter in a general meeting, one of the design directions would prompt the team to use more visualised ways to communicate.

Figure 8: Workshop tools for a discussion of societal challenges [10].

/ Application of Scientific Knowledge

The second issue that this project focuses on is the difficulty of applying scientific knowledge. It can be alleviated by adjusting the delivery way to lower others' threshold of understanding knowledge. In the interviewees' experience, there are two kinds of common situations. First, specialised terms are the general obstacle. Although the need for explanation depends on the circumstances, it often influences the team's chemistry [a3]. Second, the concept of application levels is incomplete in novices' thinking, and they usually cannot recognise and use them in a discussion. However, many elements and functions can be applied in a biological model. Recognising and differentiating the levels are essential to transforming knowledge [c8]. Moreover, the transformation of biological knowledge beyond the material level requires methodological assistance and is worth training [a6].

Besides these two aspects, the biological model is the central information to a bio-related design. As a result, collecting lots of information that includes the terminology and application way is needed. Coincidentally, discussing this information over and over is like a card exchange, which can be designed to adjust the delivery way [c13]. Plus, an interviewee mentioned that people from other backgrounds are willing to try new things in an environment where they feel safe [b2].

In the pre-test, the response from users also verifies the findings from interviews. Especially for people learning the biomimicry concept and practising the transformation of biological knowledge initially, this tool seems simple but has a fundamental impact and is helpful on-site. The design direction would focus on intensifying the linear relations by altering the size and expanding the overall degree of application, such as combining it with the accumulated information in the project.

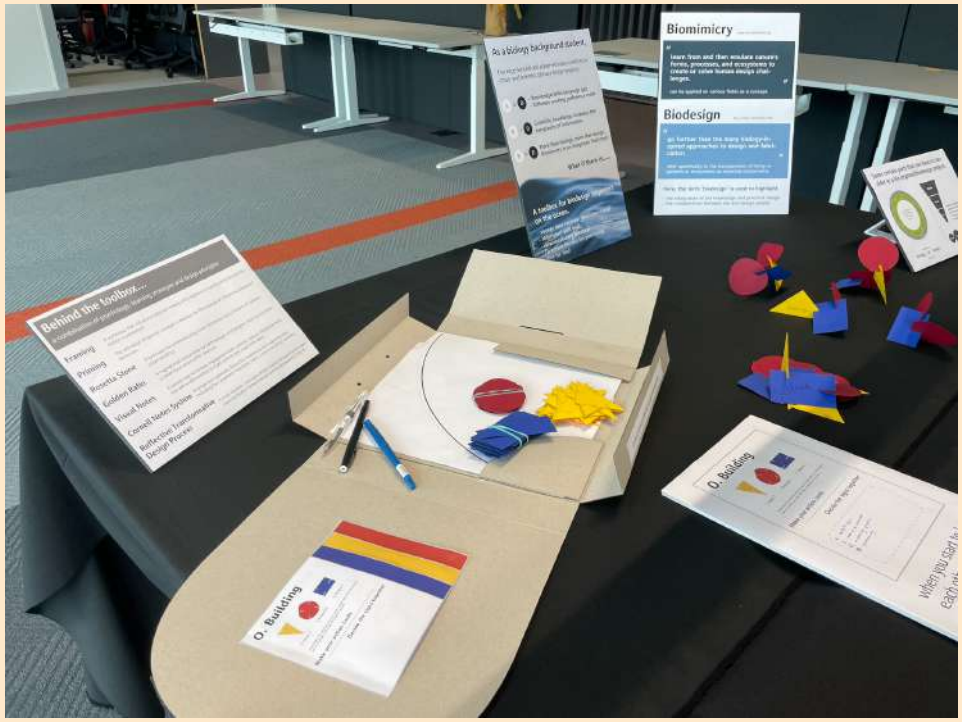


Figure 9: Design objects and concept preesented on Demo Day.

Iteration

At the beginning of Phase I, the original direction was to design tangible tools for specific steps in the Biomimicry Thinking Method. Through the interviews and the preliminary test, the design direction would be turned into a fluid structure, more understanding of each other's dominant functions, visualised communication, and knowledge application with assistance. These four aspects also correspond to four sub-themes suggested by Reflection - 2 in Phase I: a moderate structure, a balanced working mode, a better note-taking way on the table, and a disassembled way of sharing information. As for the final prototype, information from Phase I and II and literature/related work would be compiled to design tools for ambiguous paths in the creative process where intricate knowledge is involved, and perceptual thinking is required.

Literature & related work

/ Language, symbol, and visual effect on learning

'Language' is formed in the development of consensus in a group of people. Before the modern language system was gradually built, symbols were used to communicate between individuals and cultures. This analogical connection is still an effective way that can be comprehended by people using different languages [13].

Graphic organisers are pedagogical tools that can facilitate students' learning with a visual aid, such as charts and maps. The benefits include improving reading comprehension, thinking skills, retention, and cognitive learning [14]. More note-taking ways are adapted to advanced settings. For example, visual note-taking is an effective form of communication for live events, such as meetings and webinars. Combining hand-drawn images and text can boost the viewers' and note-takers' processing, retaining and recalling abilities. Besides the Picture Superiority Effect, it brings out key points and the connection between content, which creates 'bookmarks' in the brain. In addition, Cornell's note-taking system is a well-known learning method based on the graphic organiser effect. It provides a simple and fundamental format which divides the content into three areas: 'notes' for facts, 'cues' for questions or subtitles, and 'summary' for concluding the whole page [15].

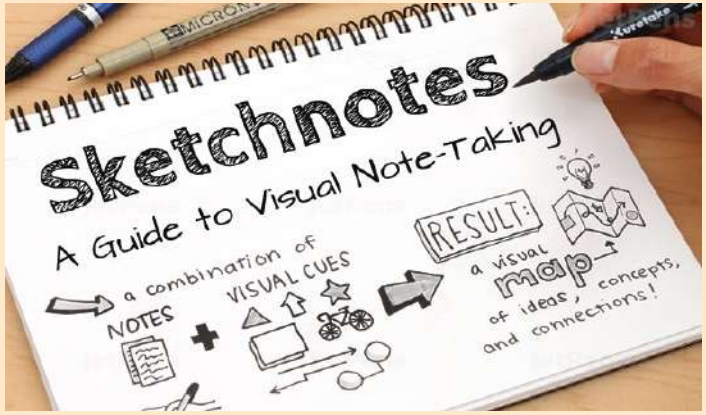


Figure 10: The example and explaination of visual note-taking [22].

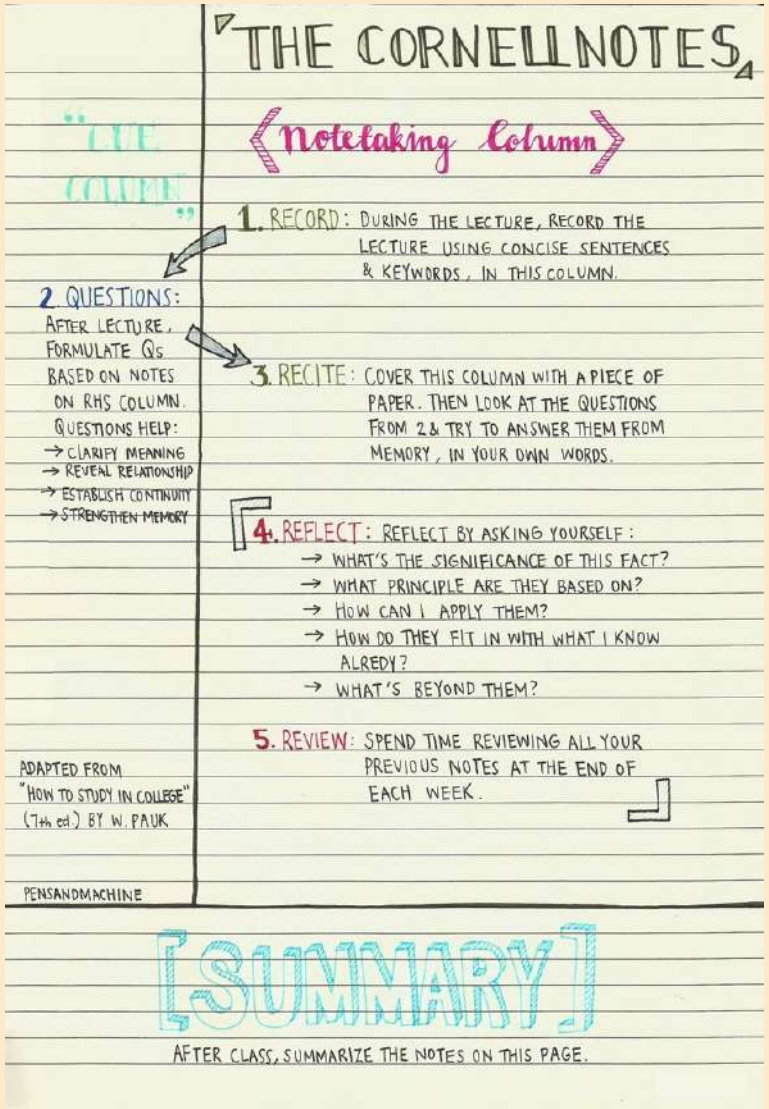


Figure 11: The example and explaination of the Cornell Notes [24].

/ Methodologies of assisting creations by integrating soft and hard aspects

A common hypothesis states that left-brained people are believed to be more analytical and methodical, while right-brained people are more creative, intuitive, and emotional. Although this is a myth, and there are many rapidly evolving theories of brain function, the classification can still be referred to when it comes to skills and abilities. Faste used the terms Right Mode and Left Mode to avoid the misconception and advocated Ambidextrous Thinking to foster creativity [16]. In the course Ambidextrous Thinking in the Design Division at Stanford University, they expect to cultivate engineering design students to use both the right and left sides of the brain, hands, and the whole body in creative thinking. They believe this can solve problems with an individual's talents and resources. This concept is also involved in Design Thinking, which suggests 'Building to Think' and has a theoretical foundation in Visual Thinking [17]. The alternation of kinesthetic, visual, and auditory is recommended to stimulate our leading sensory receivers to learn better and be more creative. Making things tangible is also a way for designers to communicate with themselves by extending thinking between conception and perception simultaneously and iteratively [7].

The Reflective Transformative Design Process developed by the Industrial Design department of the Eindhoven University of Technology gives equal weight to several contrary abilities needed in the design process [18]. The model presents a vertical axis, 'Drives' and a horizontal axis, ' Strategies.' 'Drives' represents a continuous information-gathering process that can direct design decisions through a vision or validate the design decision. 'Strategies' are two ways to generate information and affect each other. One produces experiential data, and one makes formal kind of information with analysis and literature. Every activity impacts others, and the design process is then gradually formed and completed while balancing these two axes reciprocally.

LEFT MODE	RIGHT MODE
Symbolic	Visual and Kinesthetic
Logical	Intuitive
Segmented	Holistic
Sequential	Non-sequential
Detached	Involved
Objective	Emotional
Linear thinking	Pattern Recognition
One-at-a-time	All-at-once, Coordinated
Sequential	Simultaneous
Vertical	Lateral
Specialist	Generalist
Deductive	Inductive
Analytical	Relational
Quantitative	Qualitative
Discrete, Separate	Integrated, Whole
Neat and tidy	Messy
Digital	Analog
Verbal	Non-verbal
Anaesthetic	Aesthetic, Involved with senses
absence of real-time information	Visual, Haptic, Kinesthetic, Olfactory, etc.
Reduction	Synthesis
Categorizing	Wholeness, Seeing similarities
Conscious of time	In-the-moment, No time sense
Black and white	Full color spectrum
Focused thought	Meditative
Thing oriented	Relationship oriented
Masculine traits	Feminine traits
Understanding	Knowing
"Thinking"	"Being"

Figure 12: Attributes of the left and right modes [16].

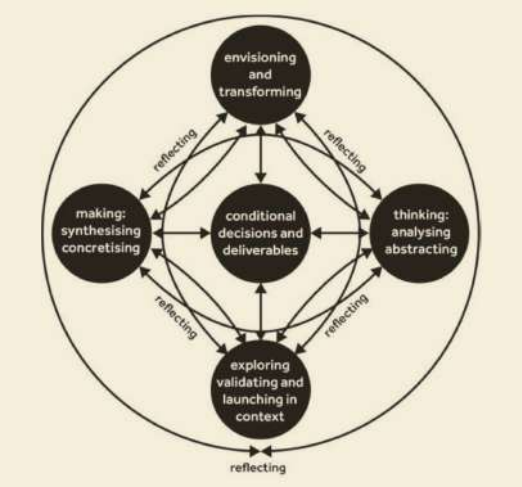


Figure 13: The Reflective Transformative Design Process [18].

Final Prototype

The design purpose of the final prototype was to unite received information in the design process, including the suggestions from Reflection - 2 that had not been involved, new adjustments based on the interviews, results of the pre-test, and the ideas from the literature/related work, and to develop designs that meet the project objectives—a set of tangible tools which can assist bio-related collaborative design projects.

The direction of the final prototype was to design tools for multidisciplinary teams to maximise the value of their collaboration. With a better understanding of each other's differences, they can magnify the importance of logic and creativity by reducing the complexity of knowledge and using multiple forms of language to communicate under the reminder of an appropriate structure and process. The insights from the design process would be broken down into numerous elements and reassembled into four topics.

Figure 14: Sensory Symbolsis toolbox set.

< O. Building >
Assist group members in understanding the differences in each other's thinking and working patterns. Move and assemble the elements on the table while discussing.

< A. Recording >
Record all the discussions within a moderate framework, which can keep clues of the debate in the chaos. Write, draw, and paste notes while discussing.

< B. Clarifying >
Provide physical objects to assist in the conceptual identification of abstract and confusing topics. Take pieces of wood of different sizes while discussing, and write notes or draw on the cards after the discussion or the ideation step.

< C. Stimulating >
Provides randomness to create options different from the current range of ideas. It can be used directly or with other tools.

The four sets of tools can be cross-used, and teams can adjust their use according to their needs. A toolbox containing the devices is used as the core symbol of the team from the beginning to the end of the project.

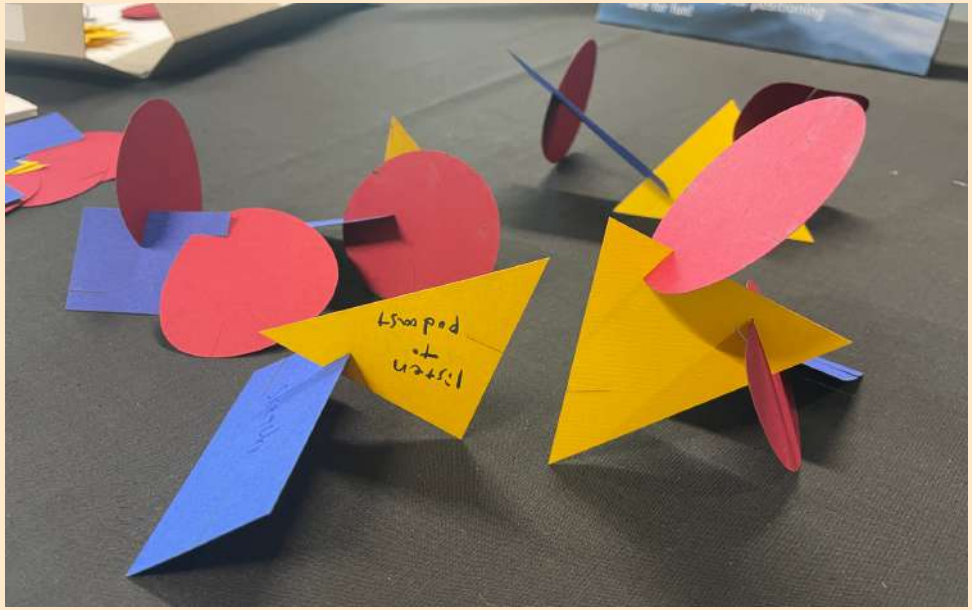


Figure 15: IPO Building Blocks.

Object 1 - < O. Building > IPO Building Blocks

Material

- **Three-colour paper card with cut marks**

Function

- **Write, draw**
- **Assemble, build-up**
- **Collection database**

Feature

- **Stimulating colours**
- **Playfulness**
- **Can be presented in 2D and 3D**

Scenario

- The main purpose is to understand each other's information systems - input, process, and output (IPO). The team can create an activity with these paper blocks according to their needs.

Example

- In a team building session, group members write down what they like to do or what they are good at when inputting, processing, and outputting the information. Plus, they can draw the sensory icon of that activity and number it at the back. Everyone will share the content with others and assemble the set of building blocks on the table with their cards. The blocks can be assembled as individuals, a unit of categories (input, process, and output), or a whole team. New ideas can be induced through the interlocking of cards in the process.
- In a meeting, a member can lead others to do an activity that he/she is used to. For instance, playing with the material to gain inspiration or free writing to get a rough summary in everyone's mind and find the group's consensus.

Figure 16: Senario- explaining how you usually work to others.

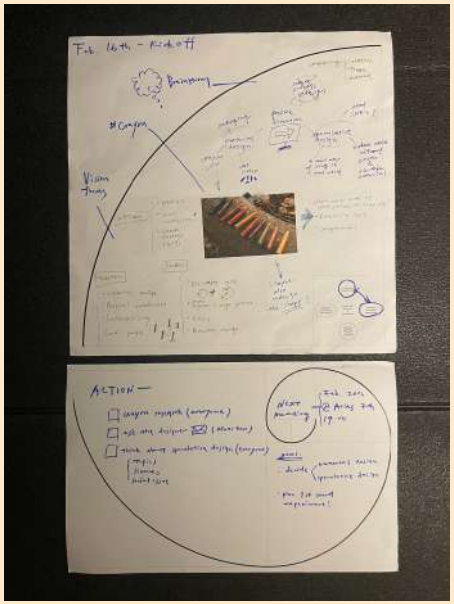


Figure 17: Voyage Data Recorder (VDR)

Object 2 - < A. Recording > Voyage Data Recorder (VDR): Collecting Paper & Condensing Paper

Material

- **White paper with printed format**

Function

- **Documenting in the process**
- **Moderate formatting framework**
- **Fluid way to record the project development**
- **Easy to review**
- **Summary/conclusion/next steps**

Feature

- **Soft structure (blank, arc line)**
- **The Cornell Notes System**
  - clear and simple layout
  - hints for titling recalling and summarizing
  - suitable for the information that is given at a faster rate
- **Encouraging visual notes**
- **Using the golden spiral as the fundamental element to inspire both designers and biologists**
- **Can be presented in 2D and 3D**

Scenario

- At each meeting, write down the common items (number/date/meeting name, etc.) that can be searched for quickly at the top left of the Collecting Paper. Write down discussion points, unorganised ideas, and visual diagrams in the large block. Short titles and symbols are written in the left-hand keyword column. At the bottom right, indicate the category and direction of the discussion in the RTDp diagram. After the meeting, write down the summary/conclusion/next steps on the Condensing Paper (e.g. summarised from 1-3 sheets of transcript paper).

Example

- Write down the date and participants at the top left. As the meeting progresses, draw a mind map for brainstorming in the middle block or paste a printed picture and sticky notes from top to bottom in chronological order.
- When discussing biological ideas, use the BD Ladder to draw the outer frame of the block and the discussion points on the VDR so that you can quickly identify the level of the idea when reviewing.

Figure 18: Senario- taking meeting notes on the VDR.

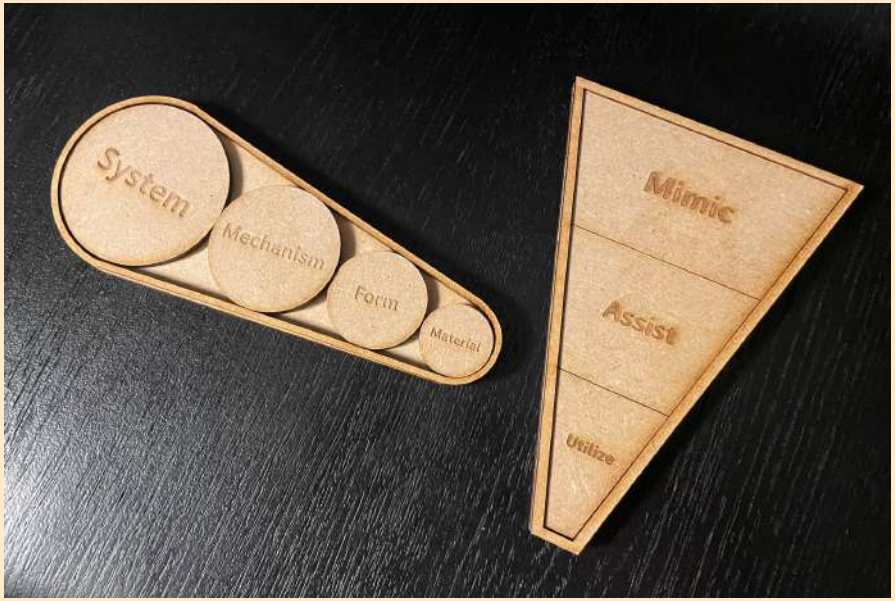


Figure 19: BD Ladder.

Object 3 - < B. Clarifying > BD Ladder

Material

- **Medium Density Fiberboard**

Function

- **Visible reminder**
- **Physical communication**

Feature

- **Size is arranged according to the levels hierarchically**
- **Shape is designed to imply the degree of abstraction and concreteness**

Scenario

- In bio-related design projects, deepen the team's awareness of the level of relationships that need to be considered when transforming biological knowledge during various stages of discussion.

Example

- Before everyone even starts looking for a biological model, the group members get a common base concept of the level of applications.
- When sharing the biological models, other members can check over different pieces of the block and extend the thinking of other combinations.

Figure 20: Scenario- combining the use of BD Ladder and Idea Card when sharing the idea.

Figure 21: Idea Cards and Term Cards.

Object 4 - < B. Clarifying > Idea Card & Term Card

Material

- **White paper**

Function

- **Visible reminder**
- **Record for ideas and terms discussion**
- **Collection database**

Feature

- **Simple and clear**
- **Card style**
- **Compatible with BD Ladder**

Scenario

- Write down and draw the key points of discussions on biological models and collect them as a team database.

Example

- When discussing the design ideas that can be applied to the biological model, draw down your idea and mark the corresponding application level on the Idea Card with the use of BD Ladder.
- Whenever there is a discrepancy in the understanding of terms, write down or draw the terminology in the way you understand it on the Term Card after the discussion, and check whether there is a consensus among each other.

Figure 22: Scenario- sharing the idea details drown on the Idea Card to teammates.

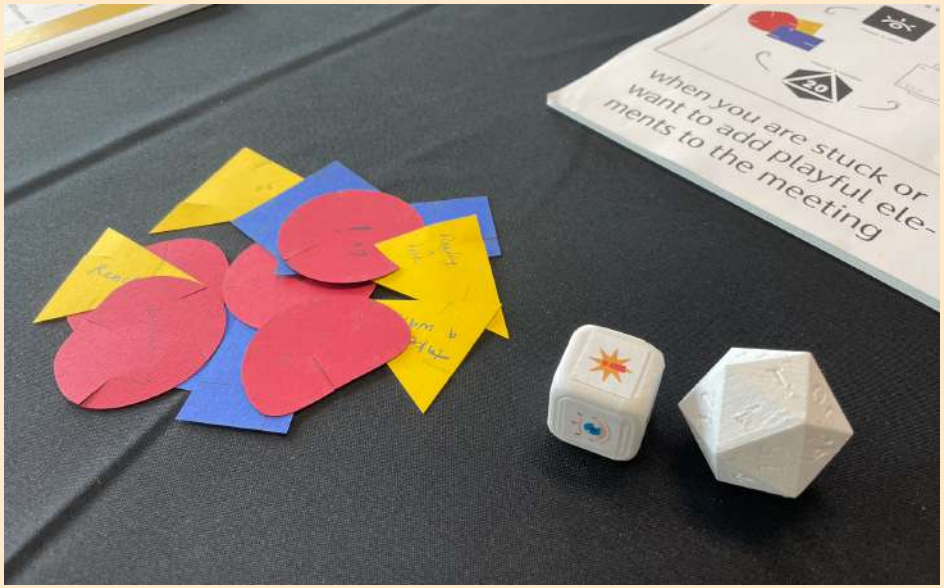


Figure 23: Sensory Dice and Number Dice.

Object 5 - < C. Stimulating > Sensory Dice & Number Dice

Material

- **Hexahedron and dodecahedron by 3D printing**

Function

- **Dice rolling**

Feature

- **Randomness**
- **Playfulness**
- **High compatibility with other tools**
- **Not just have number decision as usual dices**

Scenario

- Develop activities that can use the dice's randomness to help move the project forward with other tools.

Example

- When the team is stuck, use the Sensory Dice and try new activities together or individually based on the database of IPO Building Blocks.
- When the team is stuck, use the Number Dice with the IPO Building Blocks to create a different way of IPO for the team.
- When you want to rethink an idea, use the Number Dice with the Idea Card to choose a few ideas and put them together for comparison and discussion.
- When you want to reconsider an idea, use the Sensory Dice with the Idea Card and the IPO Building Blocks, and perform new sensory activities to gain some thoughts.

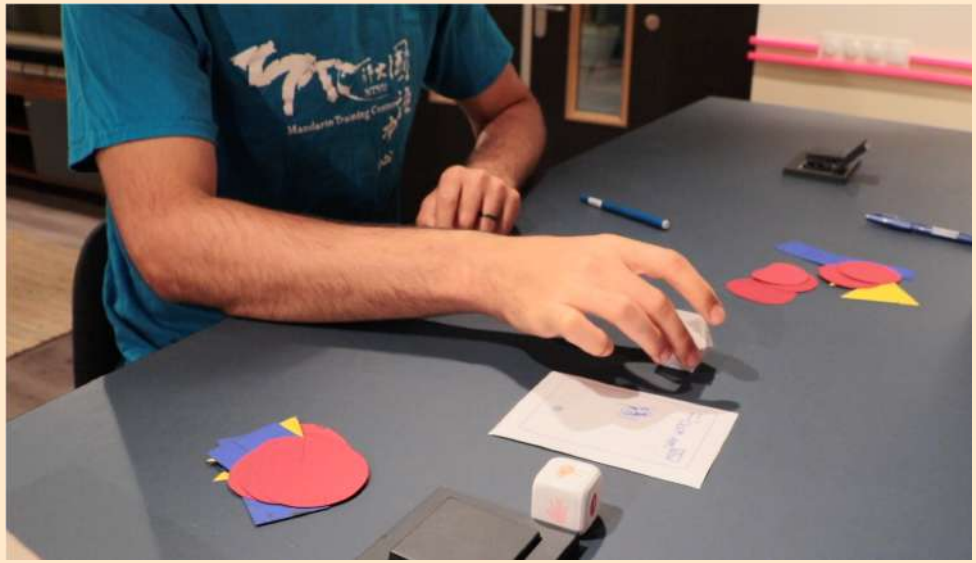


Figure 24: Scenario- rolling the number dice when checking again the Idea Cards.

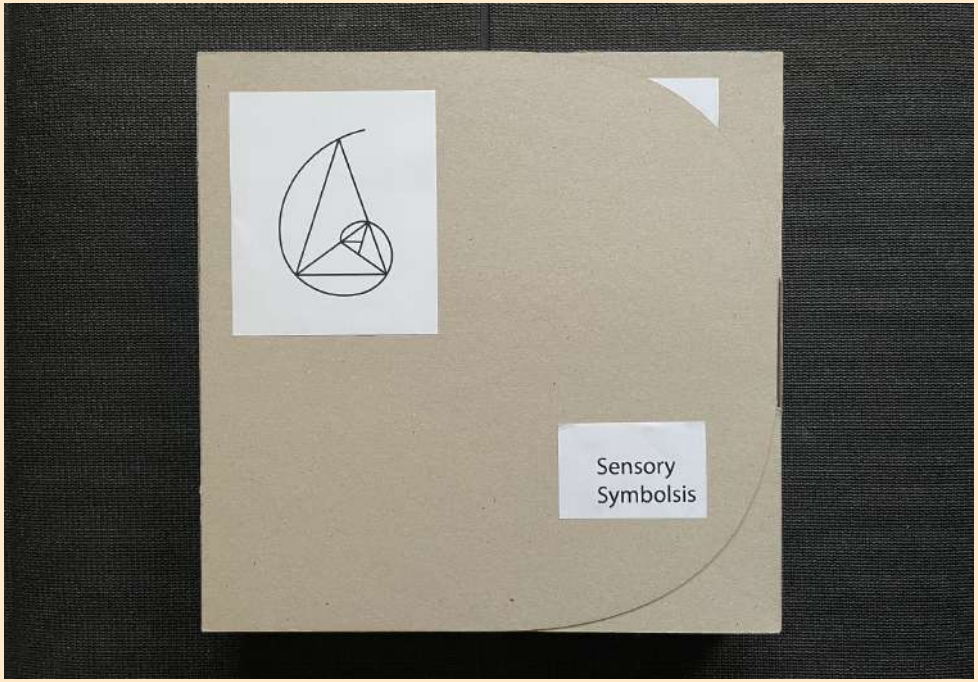


Figure 25: Toolbox.

Object 6 - The Toolbox

Material

- **Cardboard**

Function

- **Collect**
- **Bring everywhere**
- **Instruct**

Feature

- **Pack all tools and other team objects**
- **Simple instruction**

Scenario

- The four sets of tools are stored in the box and carried around. The team can use the entire toolbox as a repository for physical meetings.

Example

- Move around with the toolbox during each physical team meeting. Start and end the meeting by opening the toolbox and packing the tools.
- When tidying up the things after meetings, the team will also regularly go through the meeting record and information cards, which give them a better impression of the past discussions.

Figure 26: Scenario- opening the toolbox when starting the meeting.

Figure 27: Scenario- reading the instructions for use together.

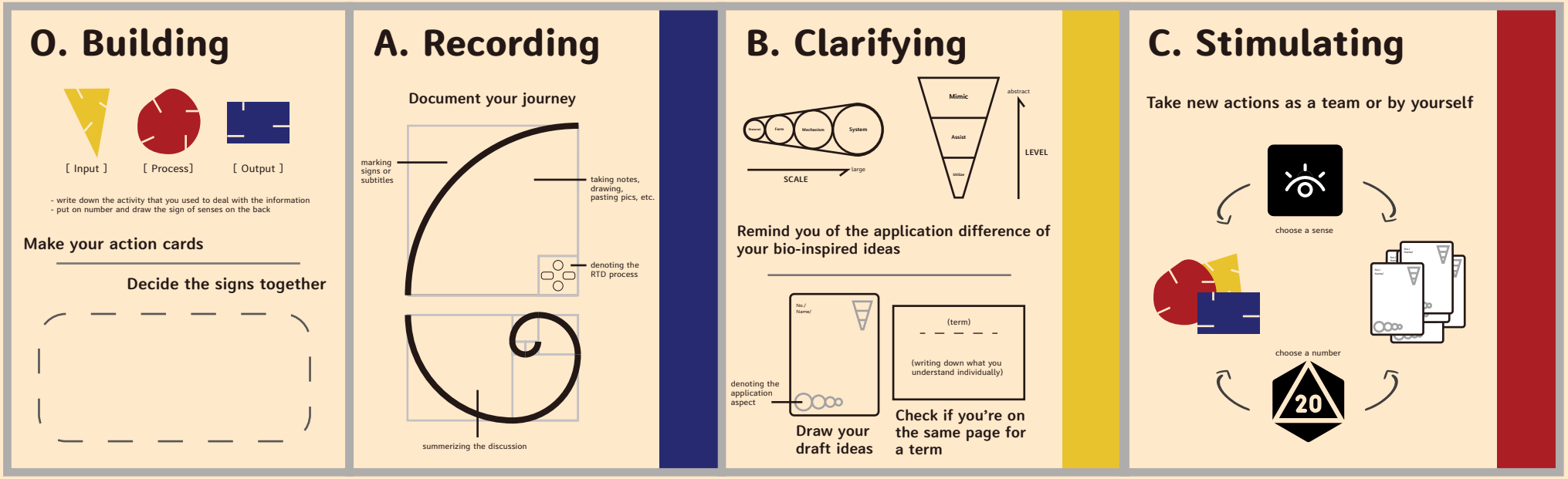


Figure 28: The instructions for use.

RESULTS

[Question 1] - What is the most challenging part when collaborating with people from different backgrounds?

P3: When you say let's start prototyping without just having a concept, I am completely lost.

P2: Only the insides you get out from that have to be very theoretical in my head to get a conclusion from that- 'so this is going to be the proof of concept in this way,' like something is pushing because of this and this forces. That's the only thing I think could be connected within all three of us, but it didn't.

The participants mentioned their definitions of 'prototype' in their respective fields. This discussion covered the three parties' use of words, thinking, and working patterns. It pointed out that before they realised the dissimilarity existed, certain words were translated into different meanings in their minds. Most of the differences in their group were only realised after the project, and now they have a better understanding of the purpose and benefits of different working patterns. Therefore, they now believe that the most important thing to do is to recognise differences between the teammates. Otherwise, people often start the project by focusing on similarities. Besides, they become more conscious of the use of language.

P1: I think the first important thing is that you need to be aware of the difference in backgrounds because I think you weren't that much. We look more at similarities rather than differences.

- P1: It's important that you make sure that you speak the same language. To ensure that you need a lot more explanation and you need to notice that you don't understand each other well. You seem to understand each other.

*** Full content: Appendix - 'Transcript - Focus Group'**

[Question 2] - What are the problems when you are trying to integrate content like scientific knowledge into your design work?

The participants discussed their perceptions of how knowledge content affects communication within the group. One participant thought that if no one were an expert, the communication would be more similar, and the group would be equal. Another participant felt that even if we were all novices with equivalent knowledge, we would still need to explain different parts of the topic to each other because we were interested in different aspects. This knowledge exchange can bring diverse perspectives to a piece of information, and it is beneficial if conflicts can be resolved. Another participant said it is still challenging to find the correct language to communicate knowledge without being an expert. Also, it is only possible to devote a little time to theoretical discussions in a design project, and it is still necessary to move forward with limited knowledge. In any case, a design that covers scientific knowledge does require more attention to the transfer of knowledge. Hence, it is vital to have a space where fragments of information can be recorded together. In addition, for the design background team, which mainly deals with information visually, even if there are data sources and records, only text but no picture illustration still cannot achieve the effect of communication.

P1: If you're all equal, like starting to learn about something you all didn't know about, you find the same level in something, and through that, you might communicate more in a similar language.

P1: When talking about information without the Miro board, it was harder for me to understand what others were saying because I usually think in images and didn't have a picture of it. If the description and setting are still unclear, it didn't reach me.

P2: But it gives you a different perspective on the same thing that you're working on. It's beautiful. But you could also be in conflict. So, look for the balance.

P2: Having it even in a circle or online or just like three sticky notes next to each other already helps with visualising what is actually happening.

/ Tool [O.]

Regarding the function of providing information, the participants agreed that it is true that different people may have different ways of handling information. However, since the data collected by cards may be unclear, such as the details of actions or who said it, the problem of different usage of the same word 'prototype' mentioned earlier may still occur. The detailed information cannot be presented on the card, and the cards are less searchable than the table data. The participants also suggested more ways of using the cards, such as sharing the meaning of their definitions and linking the cards together if they both write the same word, "made".

About the presenting way, the participants liked the idea that the cards could be constructed like building blocks and could go beyond flat. Still, they were also concerned about the difficulty of taking pictures or reading and writing information. In addition, they mentioned that when their thinking changes, they can simultaneously change the three-dimensional presentation of building blocks. During the demo day, many participants liked the card colours and the characteristics, such as the three-dimensional expression and assembling.

/ Tool [A.]

Compared to the previous set of tools, mainly used during the team building period, the participants were not sure about the timing of using this set of tools. However, soon after getting the tools, they could intuitively start assembling the recording paper and giving different partition functions.

They thought that it was an important feature to be able to summarise. Otherwise, it will only feel like there is something written down, but the content is still not organised. They previously used to-do lists as a summary function and wrote on blank paper, personal notebooks, WhatsApp or Miro, depending on the meeting location. On reflection, the participants felt that it would be good to have a shared space and that the to-do list is different from the summary function, as it is more important to have a summary because people with varying patterns of work in the collaboration have different understandings of what to do. Both functions are essential and can be indicated in different sections of the recording paper.

The participants felt that it was necessary to recap the project overview in chronological order and that it would be easier to review the project with an initial structure for documentation. They used to use blank paper or a simple notepad application on the laptop, and Miro was only used in online meetings. The participants felt that paper was best for physical meetings. Still, that online documentation would be helpful, or even necessary, to allow different group members to refer to it simultaneously. Because the format on the paper is designed with golden spirals, which are self-similar, and the shape can be repeated when magnified, they thought this feature was worth using more in the online version. Moreover, if it can be displayed on a digital board on the table in the future, it can combine physical meetings and online records.

This test did not discuss the importance of encouraging visualisation, which is one of the functions of this tool, but the importance of visual information presentation was mentioned in Question 2. In addition, during the demo day, a design student with a biology background said that the use of the golden spiral excited her and she felt inspired by it.

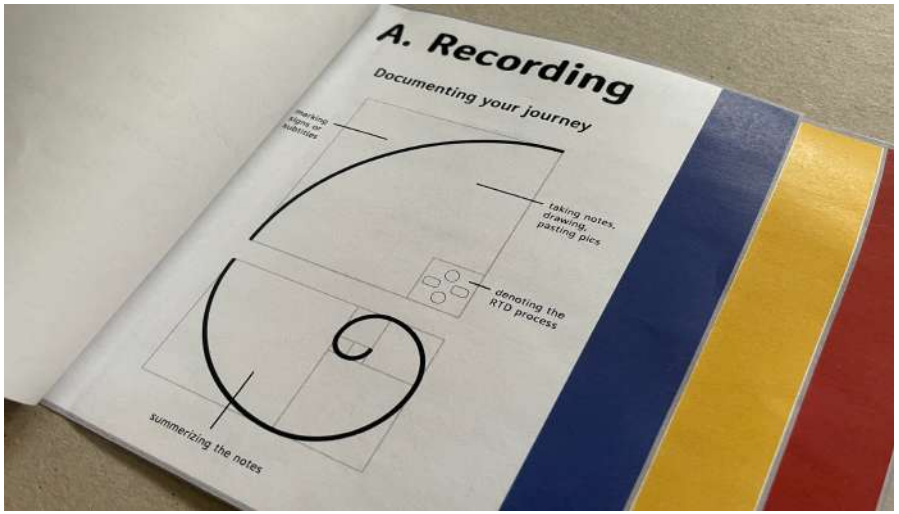


Figure 29: The instruction of Tool [A.] Voyage Data Recorder.

Figure 30: Participants tried out a new way to use the VDR in the focus group.

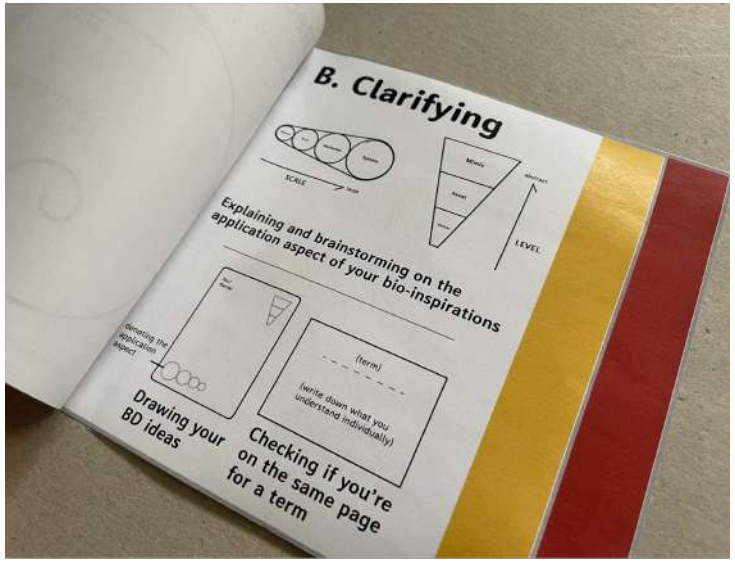


Figure 31: The instruction of Tool [B.].

Figure 32: Participants wrote down their usual design workflow on the IPO Building Blocks.

/ Tool [B.]

Compared to the pre-test, the participants this time could not imagine the timing of using this set of tools. They thought that BD Ladder, in its current form, is only physically touchable and that the same effect could be achieved with cards. After knowing that it can be used with other paper tools such as the recording paper VDR and Idea Card, participants suggested that if two ladders can be used in combination, they can be designed in a corresponding shape to be combined.

As for the Idea Card and Term Card, the participants thought it was good to see the descriptions but did not know how to use them. In their experience of having conflicts, they felt a cognitive gap in using words, as in the case of 'prototype.' And then, three participants discussed their previous experience of one member using a particular technique in the project and felt that they did not need to know the knowledge behind it in that context, nor did they need to use this tool to communicate.

In general, they could not imagine discussing terminology specific to biology knowledge. They felt there was no need for detailed explanations in some collaborations, or it just required more visual communication. The scientific knowledge issue can be further addressed when the process issue is first handled. Regarding the tool's existence, some participants felt that the tool could change the atmosphere and overall team understanding when some people did not understand, which creates room for empathy. However, it is essential to design a tool that provides basic and understandable use. Otherwise, the team will need to be guided by a person, and then the facilitating function will be shifted from a neutral tool to people. During the demo day, few design students had experience translating biological knowledge, but those who had worked with biologists pointed out that the discussion on terminology was constructive.

/ Tool [C.]

Regarding the function of stimulating the group to take different activities, some participants felt that it was very random and preferred to think about what they could do on their own, especially when the information was already more tangible on the table with the assistance of the first three tools. However, two others agreed it was helpful to have a random stimulus when stuck. The participants suggested that a more game-like approach could be introduced, such as challenge cards that provoke people to act and provide more guidance, as people might not write down unusual activities in the IPO Building Blocks.

In terms of form, some liked the three-dimensional feature of the dice as opposed to other flat tools. In contrast, others felt inconsistent with different tools and thought that if they wanted to make randomness, they could pick out cards from a container directly, which would also not limit the number as the dice. Some of the participants also suggested that the dice did not achieve playfulness compared to the building feature of the IPO Building Blocks. During the demo day, some students said they found it very interesting and were curious about how the whole set of tools could be played in the project.

Figure 32: Participants used the BD Ladder in the focus group test.

Overall, the participants felt that the context of the use of each tool needed to be made more explicit, with full descriptions and even pictures in the booklet. Instead of only knowing instructions simply on using individual tools, users could invent their ways if they knew what might happen if using which tool in what situation. In conclusion, a more detailed description of the instruction booklet is needed.

DISCUSSION

The results of the focus group indicated that the overall purpose of the toolset was well received by the participants, with all agreeing that collaboration of multiple backgrounds and knowledge translation are essential issues needed to be assisted in biology-related design projects. However, the unsatisfactory design performance and delivery way of the tools did not allow the purpose to be achieved well. Three aspects of the design performance can be reviewed; in terms of **function**, the design process was rushed and not precisely defined. Because the issues and target group from Reflection I & II differed, it would need more time and a more comprehensive approach to address the integrative scenario. In terms of **form**, there needed to be more related work benchmarks. The prototype could be played with different materials as suggested by the designer interviewees to develop other possibilities of texture, colour and shape to add value through its tangibility [19]. In terms of **fit**, the tools' degree of priming has to be improved to bring out engagement and interaction [19]. Since all three participants had new ideas for the circle base in the pre-test, providing basic functions can inspire users to add new functions to the tools. Lastly, more detailed **explanations** are needed to deliver to the users. Due to the limited time, making the manual like a board game was not allowed, and the original simple guide could not show the subtle design features, such as the effect of visual notes and symbols.

In addition to the prototype, problems with the test itself also had an impact. Mostly, the mixed characteristics of the project and the limited time made it difficult to find the right participants. The development of this project started with the author's project experiences in Reflection - 1, which had a more similar member background and mainly brought up the issue of translating biological knowledge, and Reflection - 2, which used less biological knowledge and mainly brought up cross-domain collaboration problems. This project attempts to integrate two situations and envision a biology-related design project scenario that requires the integration of members from design backgrounds. Therefore, both pre-test and test subjects did not have all the pain points as the authors do and expressed different preferences. For example, focus group subjects, who were only involved in the project in Reflection - 2, could not directly imagine the usage scenario of tool [B.] compared to the pre-test. Interviewee C was the only person with a biological background in the test and pre-test. Her projects involved deeper discussions on the biological model, so she has more pain points on the application level problem. In addition, because some design features are aimed at underlying long-term cognitive effects, it is difficult for participants to appreciate or imagine the far-reaching consequences during a single test. For example, the balance of different activities on the left and right brain and the help of random inspiration. However, these relevant aids are often shown in a general long-term design process [19], as the participants mentioned in the interviews [a8, b8].

The pre-test and the test show that tool interventions can be meaningful and valuable. Adjusting the level of abstraction by physical tools to help bring the discussion to the table is how the design support users [19]. For example, design objects 1, 2, and 4 visually store information that would dissipate quickly in verbal communication, especially since the content of object 1 is not often remembered, used, and thought about differences. Still, it has a significant impact on the entire project. In addition, this design is distinctive from other tools in that it is designed to aid abstract thinking in a form that is accessible and influential to participants from both science and design backgrounds, such as the golden spiral as a frame of record and the 3D building blocks that incorporate the IPO system concept to show the changes in the team's collaborative perceptions. More of these elements can be added to other tools in the future. Overall, four tools can be used in various themes and phases in a bio-related design project.

One primary path to transfer knowledge to design creation is to maintain members' roles, allowing designers to be creative and biologists to be theoretical examiners without needing to be involved in each other's content. Another is to open up the role function so people from different fields can try more in a safe environment [a7]. The former may seem like a clean division of labour, but it is still expected that one side needs help knowing the other side or feels limited in learning more about the other side. The vision of this project is to open up more possibilities for multidisciplinary creation, so the second type of collaboration is the leading target group. In addition to the mindset that members bring to the project from their backgrounds, the project also emphasises the knowledge extraction and application skills required for cross-disciplinary collaboration. Therefore, the next step after dealing with the collaboration language can be to further develop tools for knowledge application, such as integrating information architecture, biology databases, open source science, etc. [20]. In the future, the author hopes to make up for the gap in design experience and develop more physical objects that integrate the general properties of biology and design so that bio-related design can be more popularly learned.

The difficulties caused by the difference in thinking patterns, work order and language are long-term and require a more comprehensive understanding of each other and a greater willingness to make explanations a habit [c1; 21]. Furthermore, no matter the gap's dimension, it is a conflict. However, when there is a conflict, it also means that there was a connection before. Suppose there are better recording ways and matching tools. In that case, we can utilise the conflict as a positive force [7], enhance the communication awareness within the team, catch the disconnect point and then create the reconnection.

Based on this internship, which includes the author's participation experience with design students and this personal project, the following three suggestions are given for the course design of biology-related design projects that incorporate members from design backgrounds. Here, the BII programme is the main target of advice since it is where the author and interviewees gained their experience from.

1. Method

MIBID course is more of a consultative design, which is different from what design students at TU/e are used to. The design students feel that the current curriculum gives unclear guidelines to help make a design and a specific process framework, but they expect the opposite. They prefer a free and fluid design process but more specific design content, meaning not to lead to an all-inclusive outcome, which is called 'Everything project' by interviewee A.

On the other hand, if we want to deal with systemic design, we need to have a more specific methodological and analytical approach to integrate the content of each group rather than letting each group come up with several integrating ideas in a short period. Systematic linking requires time and comprehensively corresponding points. All three pre-test participants mentioned that there is potential for the final system design to be more in-depth, which is also what they expect.

2. Mindset

Students from different backgrounds may have different underlying intentions for learning biology-related design and using biological knowledge, but they may not be able to articulate them clearly in the beginning. In most cases, students from biology backgrounds take problem-solving as their starting point, so the 'finding inspiration from Nature' route is appropriate; students from design backgrounds expect this learning to bring them a new perspective of creating a new thing, so perhaps the 'starting from biological knowledge' route is more suitable. However, this is just a very rough separation. The most important thing is to pay attention to their intentions to design the team and course accordingly. Moreover, it is also necessary to focus on building the mindset so that participants are more aware of each other's differences at the beginning of the collaboration.

3. Role positioning

The BII students are characterised by their biology backgrounds, propensity for innovative design, and tendency to have non-traditional, sustainable, and life-oriented mindsets. However, they are not always able to use the specific expertise as typical biology students, and they often self-question their roles [citation needed]. Interviewee C mentioned that people with a biological background and innovative mindset can read the meaning that may not be present in the text and translate it [c3], including the translation between natural and human meanings and the translation to people from different backgrounds [c4]. Thus, this role is helpful for collaboration in bio-related design. Still, better tools will be the focus of future development to foster them as a bridge between the traditional biology community and the innovative design community.

CONCLUSION

This project used auto-ethnographic combined with semi-structured interviews to summarise four significant dimensions of the problem using thematic analysis. The analysis revealed that each multidisciplinary team has many problems and is unique in its diversity. Regardless of the issue, it comes back to whether the teams are aware of the gaps in the spectrum within each other. In addition, discussion and creation are fluid. Modular tools can be assembled in response to different situations in the flow to resolve the disconnection points based on the recording document. As for the intricate knowledge part, when the transmitter changes language, the receiver has the mentality to gradually try to understand, and a more suitable transmission method is used, the fundamental knowledge gap can be solved [c2].

The toolset was designed tangibly since it is vital to develop and balance team members' inspiration sources from both theoretical thinking and physical object sides. Moreover, the subtle playfulness brought by the game-like tools on the table can create another kind of dialogue experience humans can feel innately, even though the languages are different. By translating the words back to the signs, new vocabularies are coined and learned together. By moving the objects on the table, the order of actions in the team is adjusted visibly. By connecting the information relationship, the roadmap of knowledge concretisation is observable.

Because this is an integrated problem, a comprehensive and indirectly influential toolkit, 'Sensory Symbolsis', is designed. By valuing balance and finding ways to better integrate the two modes of thinking and acting, teams can solve problems and create innovations further. In the future, a more complete toolbox can be developed for 'bio-design collaborative language' and 'knowledge translating and transforming' to do more bio-design projects at different scales and contents.

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