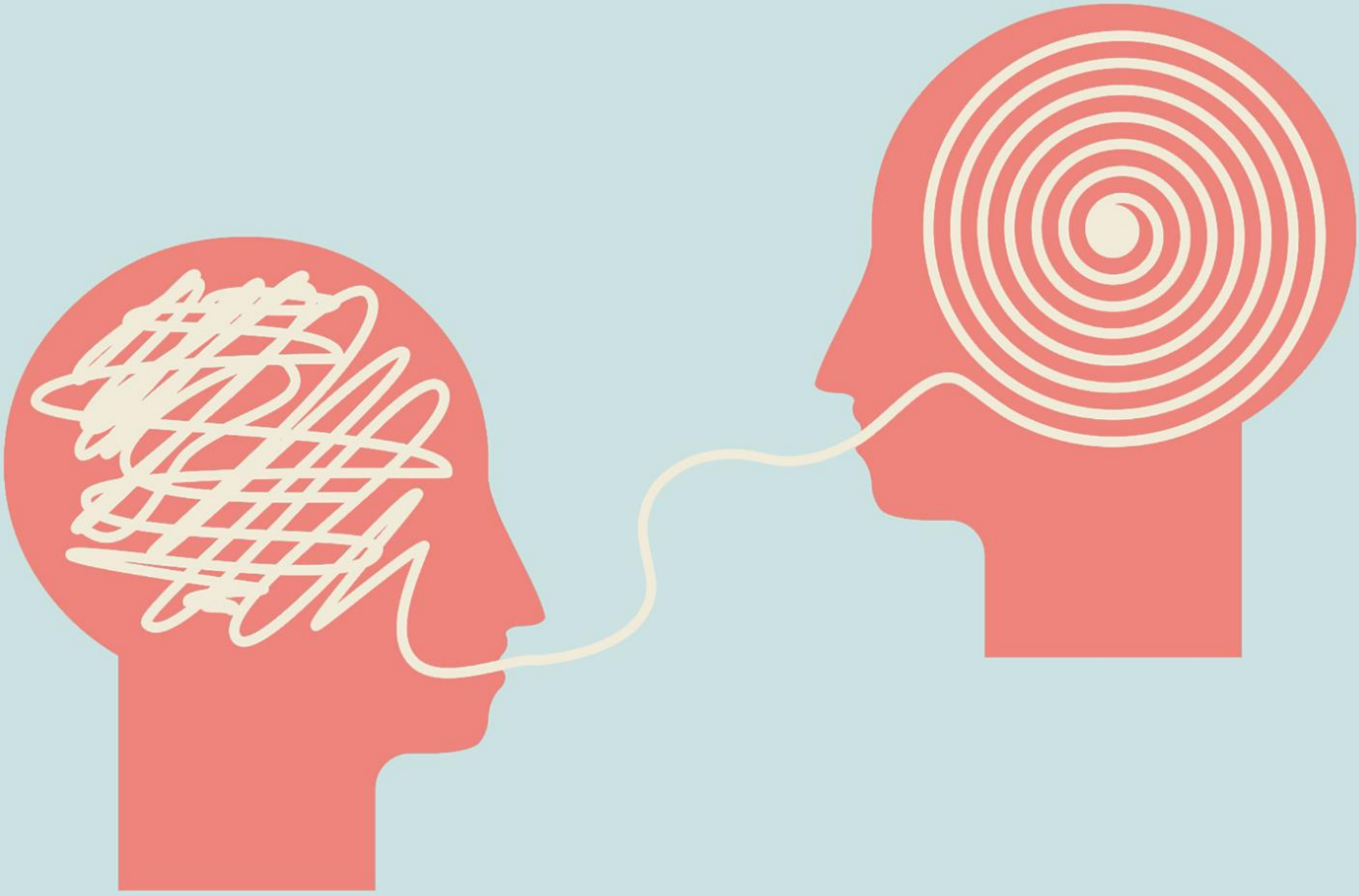
Enhancing Team Effectiveness in Biodesign

The Role of a Dual Feedback System in Enhancing Team Effectiveness in Academic Teams



Master Thesis CDI

Josine Beets

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[Background Image: Adapted from the original image sourced from https://presentheart.nl/wat-is-geweldloze-communicatie/]

Enhancing Team Effectiveness in Biodesign

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The Role of a Dual Feedback System in Enhancing Team Effectiveness in Academic Teams

By

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Contents

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1. Introduction

Team effectiveness in the field of Biodesign will be examined in this thesis report, which is part of a double degree together with the Master in Nanobiology. The aim here is to better understand how transdisciplinary collaboration affects team effectiveness in the Biodesign field and explore ways to enhance team effectiveness in the future.

1.1. Biodesign: A Collaborative Research Field

In recent years, collaborative research across scientific disciplines has gained popularity. Trans- and interdisciplinarity approaches are increasingly applied in teams to address pressing and complex problems of scientific, societal, and environmental significance (Wuchty, Jones, & Uzzi, 2007; Stokols, Hall, Taylor, & Moser, 2008; Jones, Wuchty, & Uzzi, 2008). A team's output is dependent on overall effectiveness, which is influenced by a variety of factors, e.g., the expertise of individual team members, the disciplinary makeup of the team, and contextual factors such as antecedent conditions, collaborative processes, and technological support. Social factors, such as team size and organisational complexity, also play a significant role in determining the outcomes of team-based research (Stokols, 2006; Olson & Olson, 2000; National Research Council, 2015). Kozlowski and Ilgen (2006), in their comprehensive overview of over 50 years of psychological research on team effectiveness, highlight that "*failures of team leadership, coordination, and communication are well-documented causes of the majority of air crashes, medical errors, and industrial disasters*," emphasizing the ongoing challenge of aligning these factors in many mature industries (p. 78).

In his book "Why Hospitals Should Fly", Nance (2008) provides a tragic example of the negative effects of traditional hierarchical cultures within teams. In 1977, an aviation accident that occurred in Tenerife resulted in the death of 583 people. The cause: a lack of communication. Multiple misunderstandings, unchallenged assumptions and hierarchical boundaries that clouded vital information played a significant role in mistakes made during take-off and the crash that followed. The captain of one of the Boeings involved, who was also the chief pilot of KLM Royal Dutch Airlines and a corporate vice-president, had a near-perfect performance record for over 30 years as a pilot. In the hierarchical culture that was prevalent in aviation at the time, this senior pilot was presumed to be infallible by his peers, which in turn increased the pressure to maintain this image of an accomplished expert in the field and fuelled the fear of making mistakes from his end. Additionally, this assumption negatively influenced the psychological safety felt by the co-pilot and flight engineer in the cockpit, who tried to warn the captain but did not feel safe enough to push through due to the hierarchical gap and the belief that their opinions were incorrect. This "*halo*" effect was key in the accident and marked the start of changing the traditional aviation hierarchy structures. Interpersonal social networks and work culture have become more equal, resulting in a greater sense of psychological safety, wherein all team members are encouraged to intervene during take-off (Nance, 2008).

Next to aviation, Biodesign is an industry where team effectiveness is of paramount importance. Collaborative and transdisciplinary research in this field involves individuals from different areas of expertise, such as researchers, designers, and other collaborators, working together to research and design biology-inspired innovations. For example, some innovative biodesigns use living organisms (e.g. algae) to enhance "normal" properties or replace non-biodegradable components with biodegradable materials (Balasubramanian, Yu, Meyer, Karana, & Aubin-Tam, 2021).

Currently, Biodesign is mostly used to raise awareness of sustainability and environmental preservation (Parakul, 2021). However, as seen in Figure 1, research into Biodesign applications is getting increasingly more traction worldwide as the importance of bringing climate change to a halt is becoming a priority across the globe. The trend in Figure 1 is driven by an increase in grants for circular procurement and sustainability projects within Europe and The Netherlands, indicating that Biodesign can play an important role towards reaching international sustainability goals (Hanemaaijer, et al., 2021; European Council, 2022).

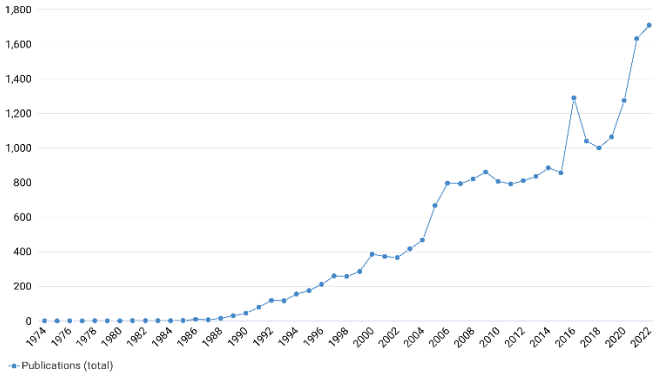


Figure 1 All publications between 1974-2023 with the criteria "Biodesign", adapted from source: https://app.dimensions.ai

1.2. Aim of the Study

As identified above, the dual trend of increasing transdisciplinarity in scientific research fields and the rising prominence of Biodesign research presents a unique opportunity to study the impact of transdisciplinarity within the Biodesign field. Therefore, this report will focus on how the convergence of different scientific backgrounds and individual researchers' perspectives affects team effectiveness and collaboration in transdisciplinary Biodesign teams. The objective of this thesis is to utilize the findings from this study to develop a tool that enhances overall team effectiveness in Biodesign in the future.

1.3. Research Questions

Based on the topics mentioned previously, the following main research question is proposed:

"How can a transdisciplinary design tool contribute to team effectiveness in the process of Biodesign?"

In order to answer this question, it is categorised into three sub-questions. The first sub-question will deepen the understanding of the Biodesign process and what themes could play a significant role during the whole process:

"What themes, connected to team processes, social networks, hierarchy, disciplinarity, and participatory design, have an impact on or are significant for team effectiveness in science teams?"

The answer to the second sub-question will shed more light on how these themes link to the team effectiveness within teams in the Biodesign field:

"How do these themes affect the overall team effectiveness in the Biodesign field?"

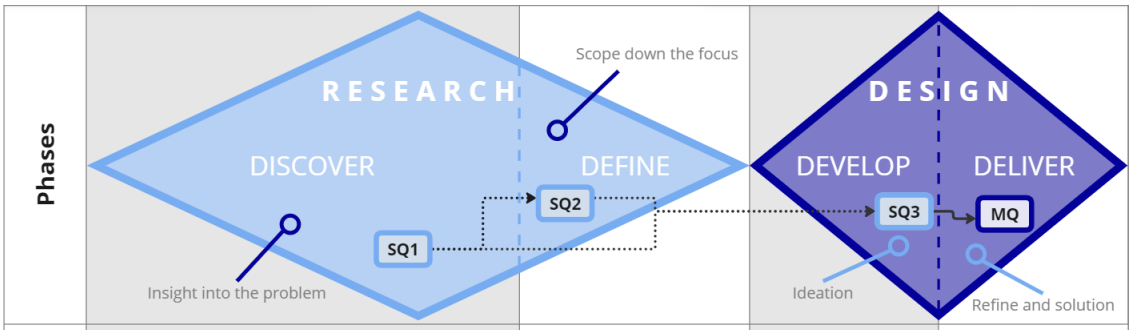
The last sub-question will then look into the possibility of using an intervention as a tool to enhance team effectiveness in a Biodesign research team:

"How can these themes be leveraged to enhance the team effectiveness of a Biodesign research group?"

Answering all three sub-questions will pave the way to the conclusion of this research by providing a foundation to answer the main research question. How these questions relate to one another and in what chapter of this report they are answered can be seen in Figure 2.

1.4. Approach and Research Design

The overall research method of this thesis report was done according to the "Double-Diamond" approach (Design Council, 2007). In Figure 2, this approach is depicted and has been adapted to represent the phases that have been followed to complete this thesis. In the following sections, an analysis of the different phases present in the overview as well as a concise elaboration on each phase will be given.



Methods	Literature review & Semi-Structured Expert Interviews	Data Analysis & Problem Statement	Brainstorming & Design Intervention	Validation & Feedback Iteration
Expected Outputs	Theoretical Framework: Frame of Reference and Frame of Relevance	Problem Statement & Linking Results to Framework	Ideas & Iteration	Intervention & Future Views
Report Chapter	Chapter 1 & 2	Chapter 3	Chapter 4	Chapter 5

Figure 2 Overview of the four phases of the double diamond, the methods used in each phase, the expected outcomes after completion of each phase and the respective report chapters per phase

1.4.1. Phase 1: The "Discover" Phase

Upon starting Part II of this thesis, various research possibilities were considered before selecting a specific goal and forming research questions. With a clear objective in place, Phase 1 can commence, which involves a thorough investigation of the topics identified during the literature study. Due to the novelty of the Biodesign field (as shown in Figure 1), an exploratory case study will be conducted through six expert interviews. This study is considered crucial to gain a topical and accurate understanding of Biodesign. The interviews will provide detailed insights into the impact of team effectiveness in current projects and explore Biodesign's potential as a form of participatory design. A total of five biodesigners from Delft University of Technology and one external biodesigner will be interviewed.

The literature study and interviews will serve as the foundation for answering sub-questions 1 and 2. By diverging the research at the end of Phase 1, the groundwork will be laid to converge to the problem statement at the end of Phase 2. Chapter 2 outlines all the steps involved in the "Discover" phase.

1.4.2. Phase 2: The "Define" Phase

During Phase 2, topic-specific information from the literature study will be analysed. Moreover, the interviews' data analysis will aim to provide a comprehensive understanding of the Biodesign process, particularly its advantages and challenges in this transdisciplinary field. The combination of information from both analyses, i.e. the literature review and interview data analysis, will aid in defining a problem statement that aligns with the research objectives. The "Define" phase is fully elaborated upon in Chapter 3.

1.4.3. Phase 3: The "Develop" Phase

Once the fitting problem statement has been defined in Phase 2, the ideation or "Develop" phase will commence. This phase begins with a brainstorming session aimed at generating possible solutions to the previously stated problem statement. The session will leverage information obtained from the literature study and conducted interviews. At the conclusion of Phase 3, the initial blueprint of the chosen solution will be tested on 14 Master End Project (MEP) students, consisting of those still working on or those who have completed their final project, all of whom are studying or have studied at TU Delft. Chapter 4 provides a summary of the brainstorming session(s), its outcomes, and the experiment's setup process.

1.4.4. Phase 4: The "Deliver" Phase

After results from the Develop Phase have been collected, the "Deliver Phase" will be initiated. During this stage, feedback provided by the 14 MEP students will be utilised to iterate the tool one last time, resulting in a finalised design. Subsequently, this final design will be validated by testing it with a Postdoc and their supervisor at TU Delft. Next to an in-the-field validation, a student counsellor will also carefully review it. Validation and review results, in combination with the first iteration tests, will be examined for convergence, ultimately concluding the research project. Following the conclusion and discussion of the results, future recommendations for enhancing team effectiveness in the world of Biodesign will be presented. Additionally, a personal reflection on the experience throughout this project will be provided. All steps defining the "Deliver Phase" are discussed in Chapter 5.

2. Phase 1: Discover

The objective of Phase 1 is to enhance the understanding of Biodesign and the factors that influence team effectiveness. Initially, the topics relevant to this thesis are investigated through a literature study, which is detailed in Section 2.1. This step provides insights into the definitions and key findings of each topic and their relevance to the research. Subsequently, the expert interviews are prepared using this knowledge as the foundation. In Section 2.2, the setup for the expert interviews is given and the interview questions are linked to the topics discussed in the literature study.

2.1. Literature

2.1.1. Team Effectiveness: Team Processes and Key Challenges

First, more information was needed on team effectiveness and how this translates into the Biodesign field. To get a better understanding of this topic, chapters 1 to 3 in the book "Enhancing the Effectiveness of Team Science" were used (National Research Council, 2015).

In this book, the definition of team effectiveness that will be used in this thesis report is introduced. According to the definition, team effectiveness, or team performance, refers to the ability of a team to reach the objectives or goals set by that team. The personal outcomes corresponding to the team members (i.e. satisfaction and willingness of team members to stay in a team) are directly correlated with the effectiveness of the team. In the same way, the output, influenced or produced by the team, is also dependent on team effectiveness. In scientific or academic teams, the output may include new research methodologies or findings, as well as real-world applications. As previously noted in the introduction of Part II, Biodesign and its research teams belong to the scientific or academic field.

To enhance team effectiveness in the Biodesign field, it is necessary to understand what influences the effectiveness of a scientific team. The adapted Input-Process-Output (IPO) model, originally by McGarth (1964), presented in Figure 3, provides a valuable framework to study team effectiveness as it focuses on the process of transforming a collective input into a desired output, which in turn influences the input again (Kalmár & Stenfert, 2020). In Chapter 3 of "Enhancing the Effectiveness of Team Science", the IPO model is introduced as the origin of the term "team processes".

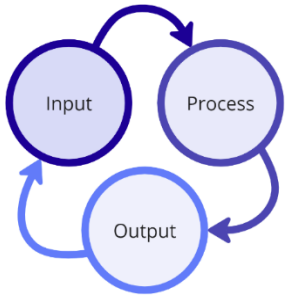


Figure 3 The Input-Process-Output model designed by McGrath (1964)

Within this context, team processes represent the "process" step in this IPO model and are described as the way a team collects and manages the individual, team and organisational inputs to reach a common goal or output. In other words, team processes are the actions that team members use to combine their resources, such as time, money, team members and their skills and expertise, equipment, information, data, communication tools, etc., to meet the team's task demands and common goals. For a team to be effective, the cognitive, behavioural and motivational inputs have to be properly aligned with these demands.

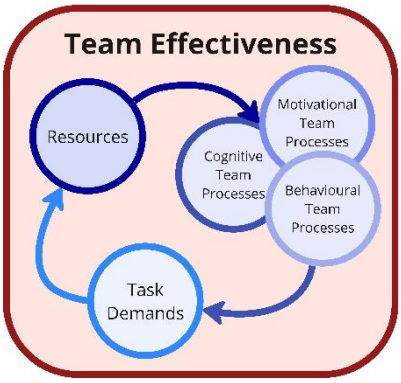


Figure 4 The further Adapted IPO Model, based on Chapter 3 of "Enhancing the Effectiveness of Team Science"

Therefore, enhancing team effectiveness can be achieved by targeting and improving team processes (Kozlowski & Ilgen, 2006; National Research Council, 2015). In Figure 4, a further distinction is made based on how the team processes, which influence team effectiveness, can be categorised. These processes depend on the type of resources employed by the team to address task demands, specifically Cognitive, Affective, and Behavioural resources (Kozlowski & Ilgen, 2006; National Research Council, 2015). This integration results in a further adapted version of McGrath's IPO model. The three different team processes will be elaborated upon in the following sections.

Cognitive Team processes

The cognitive subgroup, shown in Figure 5, is based on the notion that teams can be characterised as "information processing systems" that use the collective cognition of the team to drive task-relevant interactions (Hinsz, Tindale, & Vollrath, 1997). This subgroup consists of five cognitive team processes*: Transactive Memory, Team Mental Models, Team Climate, Psychological Safety* and *Cognitive Team Interactions* (National Research Council, 2015).

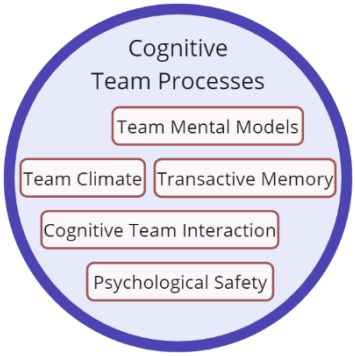


Figure 5 The five Cognitive Team Processes

Transactive Memory of a team is the team member's shared understanding of "who knows what". By understanding how unique expertise is distributed in the team, team members can access and coordinate this knowledge.

Team Mental Models represent a more common understanding. They are the shared understanding of what the goals, responsibilities and tasks are for each team member.

Cognitive Team Interactions are the cognitive processes team members actively engage in. They facilitate knowledge and information-sharing processes, such as decision-making, situation assessment, planning, knowledge sharing and problem-solving (Brannick, Prince, Prince, & Salas, 1995; Letsky, Warner, Fiore, & Smith, 2008). The fundamental building block of team cognition is explicit communication (Cooke, Gorman, Myers, & Duran, 2013).

Team Climate is the shared perspective a team has on team goals, it shapes the overall behaviour and culture of the team. Team leaders have an impact on team climate through their communication of messages from management and what they emphasise to their team. This influences how team members perceive and prioritise goals, as well as the attitudes and behaviours towards these goals (Kozlowski & Doherty, 1989; Zohar, 2000; 2002; Zohar & Luria, 2004; Schaubroeck, et al., 2012).

Psychological Safety is the shared understanding in a team that the environment is safe for learning and taking risks. In a psychologically safe setting, team members feel comfortable enough to share their ideas and opinions without the fear of negative consequences (Edmondson, 1999). Learning from errors is especially crucial in science teams, as it forms the basis for a team to identify and reflect on mistakes. This will help diagnose the cause and develop an appropriate solution for the made error (Edmondson & Nembhard, 2009). Reducing power differences and fostering inclusion positively influences psychological safety.

Motivational Team Processes

In Figure 6 the motivational subgroup is depicted which encompasses *Team Cohesion*, *Team Efficacy* and *Team Conflict*, all of which have recognised links to team effectiveness (National Research Council, 2015).

Team Cohesion refers to the degree to which team members feel a sense of unity and connection to their team and its members (Festinger, 1950). The cohesiveness of a team is affected by several motivational factors connected to task commitment, group pride and social relations (Beal, Cohen, Burke, & McLendon, 2003). Likely, team leader developmental efforts and diversity in teams (e.g. personality) play important roles in the formation of team cohesion and its maintenance (Kozlowski, Gully, McHugh, Salas, & Cannon-Bowers, 1996; Kozlowski, Watola, Jensen, Kim, & Botero, 2009).

Figure 6 The three Motivational Team Processes, with the three Factors of Team Conflict

Where self-efficacy refers to the perception of one's ability to reach an individually set goal by performing the given tasks (Stajkovic & Luthans, 1998), *Team Efficacy* refers to shared perception across the team (Bandura, 1977). Team efficacy influences the level of difficulty of the common goals, the team's determination to achieve those goals and the team's persistence in overcoming challenges while working towards the shared goals (National Research Council, 2015).

The last motivational team process is *Team Conflict* which has three different factors of conflicts: process, task and relationship conflict. Process conflicts are disagreements among team members about the delegation of responsibilities and tasks. Relationship conflicts are about interpersonal relations, such as differences in personality or norms and values. Task conflicts involve disagreements about the content and outcomes of the performed tasks (deWit, Greer, & Jehn, 2012). These three conflict types have, on one hand, a negative influence on team process factors, such as satisfaction, commitment and trust. On the other hand, team effectiveness and cohesion were not affected by task conflict, however, they were negatively affected by process and relationship conflicts (deWit, Greer, & Jehn, 2012). Team conflict can be anticipated through pre-emptive strategies (e.g. guiding conflict in advance via cooperative structures shaping conflict processes) or through responsive strategies (e.g. working through disagreements via compromising, problem-solving and being flexible) (Kozlowski & Bell, 2013).

Behavioural Team Processes

The behavioural team processes consist of two different team processes – *Team Process Competencies* and *Team Self-Regulation* – and focus on how team members act to combine their unique expertise and skill to translate resources into the team's task demands (National Research Council, 2015). The three behavioural processes are depicted in Figure 7.

Team Process Competencies can be divided into three sequential phases. The first phase is "transition" and involves the transition of preparation and strategizing of goals to task engagement and then to reflection (e.g. feedback loop). The second phase is "action" and involves active task engagement, such as coordinating and monitoring progress. The final phase consists of "interpersonal processes", which include motivation and conflict resolution (Marks, Mathieu,

& Zaccaro, 2001). Research by LePine et al. (2008), confirmed that these three process phases were positively related to team effectiveness (LePine, Piccolo, Jackson, Mathieu, & Saul, 2008).

The final team process is *team Self-Regulation*. This team process influences how team members select their resources to perform and adapt tasks to reach common goals effectively (DeShon, Kozlowski, Schmidt, Milner, & Wiechmann, 2004). Team self-regulation is linked to the team process of "team efficacy". As mentioned, team efficacy is the perception of team members that the team is able to successfully complete tasks and achieve their task demands. As such, this motivational perception is part of the behavioural process of team self-regulation (Gully, Incalcaterra, K.A., & Beaubien, 2002).

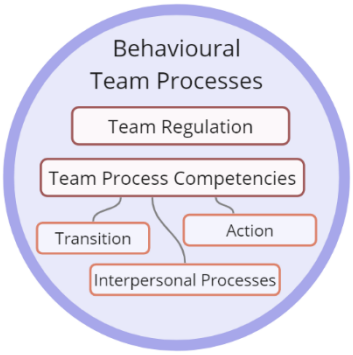


Figure 7 The three Behavioural Team Processes, with the Three Types of Team Process Competencies

Key Features Posing Challenges to Team Effectiveness

In addition to the cognitive, motivational, and behavioural processes discussed in the previous sections, several key features can present challenges to team effectiveness. These seven team features, along with their corresponding dimensions (National Research Council, 2015), are as follows:

1. *Team Size*: Small (2) – Large (+10),
2. *Permeability of Team and Organisational Boundaries*: Stable – Fluid,
3. *Knowledge Integration*: Undisciplinary – Transdisciplinary,
4. *Diversity of Membership*: Homogeneous – Heterogeneous,
5. *Geographic Dispersion*: Co-located – Globally distributed,
6. *Task Interdependence*: Low – High,
7. *Goal Alignment with Other Teams*: Aligned – Divergent.

The given dimensions reflect how the features impact the team's effectiveness. For example, the transdisciplinary dimension for the "Knowledge Integration" feature implies that a team comprising members from diverse disciplines might encounter more challenges when attempting to effectively combine and integrate their knowledge and expertise to generate new insights and understanding among all team members. Similarly, moving toward the right side of the given dimension scale, the other features become increasingly challenging, ultimately playing a pivotal role in shaping team effectiveness and significantly influencing team outcomes.

In Figure 8, the key features with the dimensions that result in challenges to team effectiveness (blue boxes) are explored in more detail. Knowledge integration challenges (orange boxes), features that can create conflict (purple boxes) and coordination challenges (yellow boxes) are linked to their specific key feature and how they present a challenge to team effectiveness. The green boxes show the positive side of the key features.

Even though these aspects pose challenges to scientific teams, they often are necessary for a team to reach their task demands. The features defined here, together with the team processes mentioned in the previous sections, will be used as an integral part of the expert interviews to get a better understanding of which of these features are most frequently integrated into Biodesign teams.

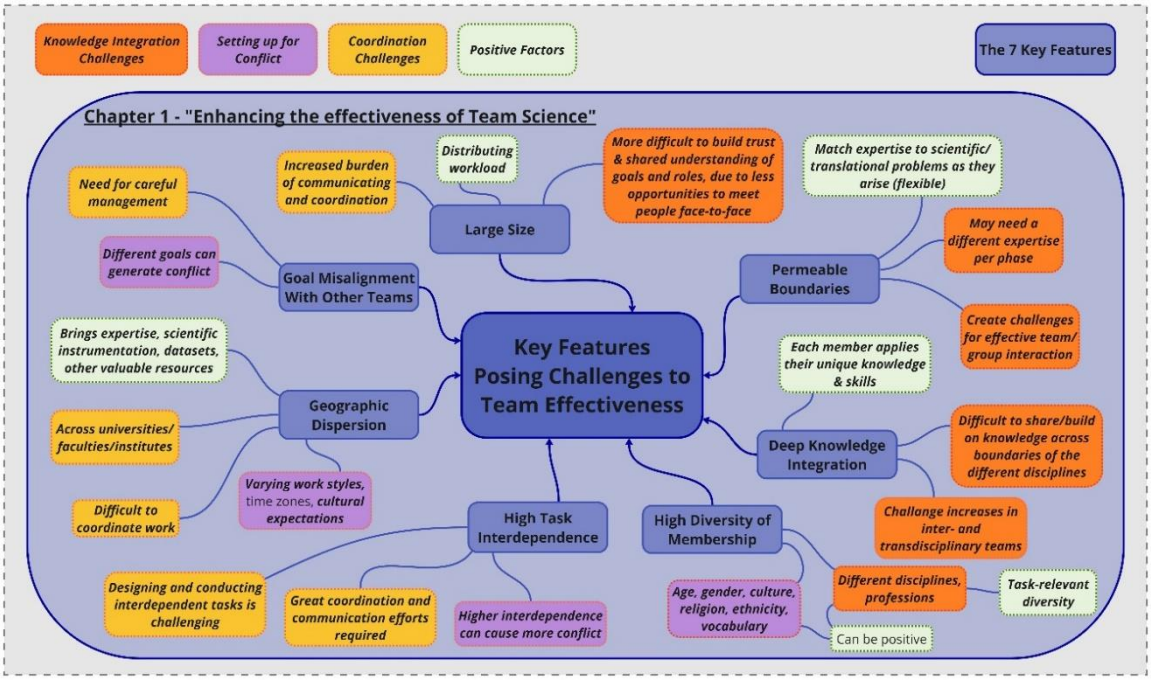


Figure 8 The Seven Key Features and The Challenges They Pose on Team Effectiveness, an overview of Chapter 1 of "Enhancing the Effectiveness of Team Science"

2.1.2. Enhancing Team Effectiveness

Interventions Targeting Team Processes

In Chapter 3 of "Enhancing the Effectiveness of Team Science", several interventions or "levers" are given for each of the ten team processes listed in Table 1. These actions and interventions have been researched to positively influence the team processes.

Table 1 Team processes and the corresponding levers or interventions that can influence, shape and align the respective team processes

Team Process	Interventions or "levers"
Transactive Memory	Face-to-face interaction; Shared experience
Team Mental Models	Training; Leadership; Shared experience
Cognitive Team Interactions	Training; Team composition
Team Climate	Strategic imperatives - team goals - policies, practices and procedures; Leadership; Team member interaction
Psychological Safety	Leader coaching, inclusion; Positive interpersonal climate
Team Cohesion	Team composition (theory); Leadership (theory); Antecedants (ambiguous)
Team Efficacy	Mastery experiences; Vicarious observation; Verbal persuasion; Leader behaviour (theory)
Team Conflict	Team composition, faultlines; Conflict management skills
Team Process Competencies	Training; Leadership (theory)
Team Self-Regulation	System design; Leadership (theory)

In Chapter 3 of this report, a case study will be performed based on the team processes and study the link of the processes to the field of Biodesign. Furthermore, the seven key features that pose challenges to team effectiveness will be kept in mind when formulating the interview questions. In "Enhancing the Effectiveness of Team Science", the importance of further research is mentioned: "At the same time, however, we have noted the need for further "basic" research on team processes within science teams and larger groups and how these processes are related to

scientific discovery […] Such an approach includes […] surveys and interviews of team science participants" (National Research Council, 2015, p. 217-218). This need for further research strengthens the basis to conduct interviews with Biodesign experts and the case study resulting from this. This research will be the foundation for a novel intervention or lever that improves team effectiveness in Biodesign teams.

In the "Define" phase, the results of the case study will be linked to team effectiveness, transdisciplinarity, hierarchy and social networks. At the end of this phase, the problem statement will be used as a stepping stone to introduce a newly designed intervention.

2.1.3. Topics Linked to Team Effectiveness

The topics that will be introduced in this subsection will form the common thread throughout this whole research project. First, the layers of social networks in the field of Biodesign and the academic world, in general, will be discussed. Next, hierarchy and leadership will be reviewed. The third topic that will be elaborated on is the disciplinarity of Biodesign. Finally, more light will be shed on how the Biodesign field could benefit from participatory design or co-design. These four topics form a direct link to team processes and thus, team effectiveness. How they might affect the effectiveness of teams in the Biodesign field will be discussed further in Section 2.2.

Layers of social networks

The first topic that will be linked to team effectiveness is a three-level analytical approach. In this thesis, it will be referred to as the "Layers of Social Networks" (Zheng, Ke, Zeng, Ram, & Lu, 2011). This analytical approach will serve as a framework for organising the themes found in the case study interviews. To be specific, in Subsection 3.1.2, each identified theme from the case study will be linked to the layer of social network it pertains to. Additionally, these themes can then be linked to the corresponding team processes they impact.

This three-level analytical approach, depicted in Figure 9, consists of the micro-, meso-, and macro-level (Zheng, Ke, Zeng, Ram, & Lu, 2011).

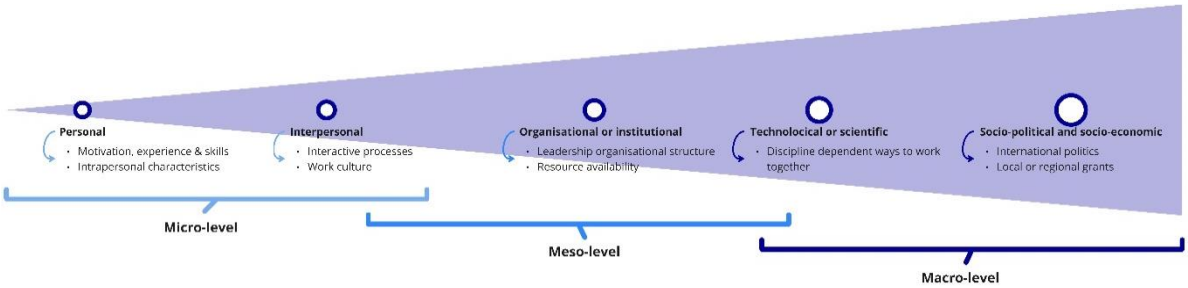


Figure 9 The micro-, meso- and macro-level of social networks, adapted from Zheng et al. (2011)

At the micro-level, the focus lies on the personal and interpersonal aspects of social networks. The personal aspects include individual, internal motivations, experience and skills, and intrapersonal characteristics. These aspects focus on the personal inputs that individuals have within a team. The interpersonal aspects of social networks cover interactive collaboration, communication processes, and the work culture of a team. The main focus lies on how individual inputs relate to certain outputs of the team. This input-output relation, on the micro-level of social networks, is directly related to the adapted IPO Model proposed in Subsection 2.1.1 (Kalmár & Stenfert, 2020). The meso-level shifts focus to organisational or institutional structures where resource availability and leadership play a more important role. Finally, the meso-level transforms

into the macro-level, which is concerned with technological/scientific and socio-political/-economic collaborations and their impact on, e.g., society.

In the case study, these theories will serve as background structures for better understanding the link with team effectiveness. By using this analytical approach, this thesis will organise the themes found in the case study interviews and link them to the corresponding layers of social networks and team processes they influence.

Hierarchical Structures and Leadership

The aircraft accident mentioned in the introduction is a tragic example of how hierarchical structures can be detrimental to team processes such as team climate, team mental models, cognitive team interaction and psychological safety. As mentioned in "Enhancing Team Effectiveness of Team Science, one of the most unconventional practices is that leaders of scientific teams are often selected solely based on their scientific expertise and not on leadership qualities.

> *"Currently, most leaders of science teams and larger groups are appointed to their positions based solely on scientific expertise and lack formal leadership training" (Enhancing Team Effectiveness of Team Science, 2015, p. 9).*

This practice can be disadvantageous to the same team processes as mentioned in the example of the accident in Tenerife. However, research in the field of organisational and team leadership has provided insights into leadership styles and behaviours that promote positive interpersonal processes. Implementing these strategies in scientific teams has been shown to be promising in enhancing team effectiveness (National Research Council, 2015).

The results of research conducted by Hackett (2005), showed that prosperous microbiology laboratories at elite research universities have team leaders that value and implement both directive, hierarchical leadership (i.e. traditional leadership) and shared, participative leadership styles (i.e. democratic leadership). The choice between these two styles can be paradoxical. Sharing and participating in the team's research as a leader can positively influence several team processes (e.g. team climate). However, it can take its toll on other tasks team leaders have, for example writing proposals and papers, or applying for grants that fund the laboratory (Hackett, 2005; National Research Council, 2015).

Concluding, hierarchical structures are a key feature in teams and can influence team effectiveness both negatively and positively. Team leaders need to find a balance between, on one hand, decreasing the power differences and hierarchical gap to establish psychological safety and a positive team climate. On the other hand, a certain hierarchy must be kept that promotes a shared understanding of task requirements, role responsibilities and team procedures. To find this balance team leaders have to be flexible to adapt to the needs of the team if needed. Leadership training and team coaching are found to aid in achieving this goal (National Research Council, 2015).

Disciplinarity

Biodesign is a field of industry where many different external fields fuse. Therefore, it makes an interesting candidate for exploring interdisciplinary connections. To do so, several levels of disciplinarity and their respective boundary conditions need to be defined.

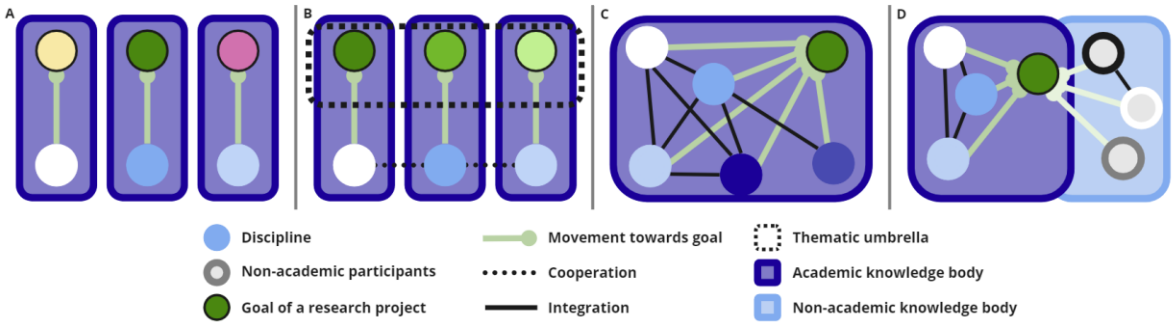


Figure 10 Schematic overview of A) Disciplinarity, B) Multi-Disciplinarity, C) Interdisciplinarity and D) Transdisciplinarity, image adapted from Tress et al. (2005)

In Figure 10, an overview is given of research concepts explaining the four levels of disciplinarity. Below, they are described following the definition of Tress et al. (2005):

A. Disciplinarity: "*Within one academic discipline, disciplinary goal setting, no cooperation with other disciplines, and development of new disciplinary knowledge and theory*",
B. Multi-Disciplinarity: "*multiple disciplines, multiple disciplinary goal setting under one thematic umbrella, loose cooperation disciplines for exchange of knowledge, and disciplinary theory development*",
C. Interdisciplinarity: "*Crosses disciplinary boundaries, common goal setting, integration of disciplines, and development of integrated knowledge and theory*".
D. Transdisciplinarity: *"Crosses disciplinary and scientific/academic boundaries, common goal setting, integration of disciplines and non-academic participants, and development of integrated knowledge and theory among science and society".*

This last definition, i.e., Transdisciplinarity, can be connected to Biodesign through a study conducted by Bandoni et al. (2022). In this research, a definition for Biodesigners is given: *"[Biodesigners] are exemplary in developing mechanisms to absorb scientific approaches and integrate their disciplinary methods to that field, and as a consequence, they are impacting society by creating new products, materials, courses, companies"* (Bandoni, Almendra, & Forman, 2022).

In "Enhancing the Effectiveness of Team Science", disciplinarity is used as a means to explain the level of knowledge integration from different disciplines in scientific teams. Here, a transdisciplinary approach is seen as an approach where researchers not only integrate but also transcend disciplinary methods to generate fundamentally new conceptual theories, frameworks, models and applications (National Research Council, 2015).

The need for multi-, inter-, and transdisciplinarity in research teams comes from a form of "information asymmetry". This asymmetry yields a knowledge gap that can only be fulfilled by reaching out or exchanging ideas with professionals from different backgrounds and in turn often result in teams that have members from different expertise and professional backgrounds (e.g. Biodesign artists vs. academic Biodesigners). This diversity can give rise to challenges like knowledge integration (Rekonen, 2017). Adding to this, the knowledge asymmetry has a direct link to the key feature #3, "Deep Knowledge Integration", given in Subsection 2.1.1.

Moreover, Stokels et al. (2006) describe a transdisciplinary research cycle as working toward a community goal, such as environmental pollution (Stokols, 2006). Thus, Biodesign is transdisciplinary as it draws its necessity from the need to develop applications or new technologies for science and society with integrated knowledge. In this field, there is a common goal setting, namely developing materials or designs that are sustainable and biodegradable.

Additionally, Biodesign crosses disciplinary and sectorial boundaries because stakeholders such as artists, scientists, designers, institutions and museums come together to reach this common goal. The University of Utrecht introduces Transdisciplinarity as a possible buffer zone that, on one hand, protects the scientific core values of curiosity-based and application-based research, and on the other hand, addresses societal demands (Robinson, 2019). Since Biodesign consists of participants from a biology background (curiosity-based) and a design background (application-based), this difference in research approaches can negatively influence team processes in the Biodesign field. For example, processes such as team climate, team cohesion and team conflict in the form of task conflict.

The Biodesign field draws from 'multiple disciplines' and contributes back to them. This research will see Biodesign as a transdisciplinary field.

To summarise, Biodesign is a transdisciplinary field that draws from multiple disciplines and contributes back to them. To explore interdisciplinary connections and their link to team effectiveness, the concepts of Disciplinarity, Multi-Disciplinarity, Interdisciplinarity, and Transdisciplinarity have been explained. Biodesign can be seen as a transdisciplinary field that involves a common goal setting, integration of disciplines and non-academic participants, and development of integrated knowledge and theory among science and society. The need to fuse multiple disciplines in research teams arises from the information asymmetry that yields a knowledge gap, which can only be filled by exchanging ideas with professionals from different backgrounds. The diversity of expertise and professional backgrounds can give rise to challenges such as "knowledge integration". To address such challenges, transdisciplinarity can serve as a buffer zone that protects scientific core values and addresses societal demands. Figure 11 shows the combination of the abovementioned statements.

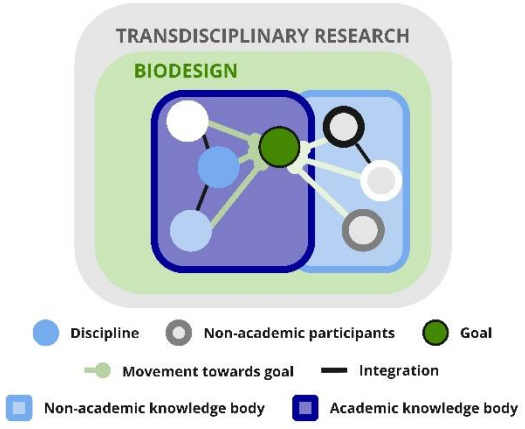


Figure 11 Biodesign as a Transdisciplinary Research Field

Participatory Design or Co-Design

As mentioned before, Biodesign is a blend of design and biology. In this field, the biology experts are used for their technical expertise whereas the designers think about specific design. However, this research project wants to investigate another interesting design method. This approach is Participatory Design (PD), otherwise known as Co-design or Co-creation, where next to designers, developers, scientists and other stakeholders, users take part in the design process (Sanders & Stappers, 2008; Bergvall-Kåreborn & Ståhlbrost, 2008; Bannon & Ehn, 2012; Pedersen, 2020).

In 1993, Joan Greenbaum wrote a personal statement on PD in the field of system development (Greenbaum, 1993). In this article, three different perspectives are introduced on why PD is

needed in this field and how being informed about the other perspectives can help people communicate about them and find common ground. The perspectives proposed are: pragmatic, political and theoretical. The pragmatic reasoning for using PD is that the majority of problems in a design process come from “inadequate requirement specifications” or in other words a lack of knowledge of what the specifications of a product or application should be for the user to benefit from it or use it properly. In this case, mitigating such issues can offer pragmatic solutions for management by increasing service and product quality, as well as mitigating problems for system developers while building systems. The second perspective is the political perspective. Here, the sense of obligation is the key factor for using PD techniques in the design process. Involving the people that will use the systems is a sound reason from a political perspective. The theoretical perspective can be explained with a quote from Wittgenstein: “*If a lion could speak we wouldn't be able to understand it*”. In this sense, PD provides designers with a hands-on experience of what is needed in a real-life setting. All perspectives form sound reasoning for using PD in other fields.

Furthermore, Bergvall- Kåreborn and Ståhlbrost (2006), reviewed fifteen research papers to study the status of PD in information systems (Bergvall-Kåreborn & Ståhlbrost, 2008). The review proposes that there are three classification methods for PD based on (1) motives, (2) types of participants, and (3) level of participation. The classification based on the motives of PD is described in the personal statement of Greenbaum (1993) and classifies three motivational perspectives for the need for PD (Greenbaum, 1993). The method where the types of participants classify PD is a bit more complicated. However, Bergvall- Kåreborn and Ståhlbrost (2006) conclude that in all cases the end-user (potential or actual) plays a central role in PD. The last classification can be categorised through six levels of user involvement or participation (Ives & Olson, 1984). The six categories, given in increasing involvement, are: no involvement, symbolic involvement, involvement by advice, involvement by weak control, involvement by doing and involvement by strong control.

The specifications of transdisciplinarity mentioned above can be linked to the three given perspectives and the specifications of PD. Therefore, it can be argued that PD can be considered a specific transdisciplinary design method because it combines various disciplines and stakeholders, however, it also emphasises user involvement, which is not a necessity in transdisciplinary research. There is not much information on the link between Biodesign and PD. User involvement in this field is not yet fully developed. However, there are some projects under development to enhance the awareness of Biodesign and get more user involvement. One such project is the “Doing It Together Science” project (DITOs Consortium, 2019). In this grant agreement report, user participation in Biodesign is called participatory Biodesign and the main goal was to research the potential of citizen involvement in Biodesign.

In this research project, participatory Biodesign will be investigated as well, however, the main focus lies on team effectiveness in the Biodesign field and the influence of disciplinarity, hierarchy and social networks on team performance.

2.1.4. Applying Focus: Expert Interviews

In the previous subsections, the basis for team effectiveness and its links to transdisciplinarity, social networks, hierarchy, and participatory design have been established. To answer the first sub-questions, "*What themes, connected to team processes, social networks, hierarchy, disciplinarity, and participatory design have an impact on or are significant for team effectiveness in science teams?*" and "*How do these themes affect the overall team effectiveness in the Biodesign field?*", the focus needs to be applied and a case study will be conducted to get a good grip on who plays a role in the Biodesign field and what the effect of transdisciplinarity, hierarchy, social networks and PD in the Biodesign field is on team effectiveness.

Also, the focus will lie on the interaction between the different stakeholders of the Biodesign field. As this field is relatively new, not much is known about how scientists with a biology background and designers who transitioned to biodesign collaborate and how this collaboration translates to other stakeholders, such as policymakers and the public.

Secondly, the goal of the case study will be to find patterns in Biodesign interactions that can be connected to team processes and how, positively or negatively, these team interactions influence team effectiveness.

Lastly, these patterns will be the foundation of the problem statement. They will be connected to the proposed levers in Table 1 and in turn, this will result in the solution proposed in the "Deliver" phase in the form of a communication tool at the end of this thesis.

2.2. The Expert Interviews

For this research, a case study was performed by conducting a total of six expert interviews. This was done to get a better understanding of what factors play a significant role in interpersonal relations, transdisciplinarity and participation in the field of Biodesign and how they affect team effectiveness.

The interview format and the description of the participants are elaborated on in Subsection 2.2.1. The interview protocol is described in Subsection 2.2.2. This protocol includes the participant consent collection, interview questions, interview setting and interview completion. In Subsection 2.2.3, the method and themes for the interview analysis will be discussed and Subsection 2.2.4 explores the Biodesign expert's opinions on the selected themes.

In Section 3.1, the results will be linked to the previously discussed literature topics. These will ultimately converge into the problem statement at the end of Chapter 3.

2.2.1. Setting up the interviews

Interview format

To gather as much relevant information as possible a semi-structured interview protocol was chosen to interview the participants. Not only are semi-structured interviews suited to get detailed and topical information, but they are also more open than a structured interview, where the questions are set in stone before the interview. This will make the interview resemble an open conversation with a wider range of pathways whenever the participant gets sidetracked on topics relevant to the research questions. Meaning that even though most questions were predetermined during the interview, other questions were asked as well to get a profound insight into the interviewee's situation and opinion. This setup forms an ideal basis to address the main

objective of these interviews: to better understand how different stakeholders from different teams in the Biodesign field view their interpersonal relations and the disciplinarity, co-design and effectiveness in their teams.

Participants

As the quality of the data collected from the interviews could be heavily influenced by the selection of participants, the selection process was carefully planned to answer the first sub-question as completely as possible. Firstly, participants were required to be stakeholders in the Biodesign field to ensure the research could investigate team effectiveness, co-design, and disciplinarity in this area. Secondly, a diverse range of perspectives was sought, so participants were selected from different teams and backgrounds within the Biodesign field. Finally, to gain a comprehensive understanding of all ranks in Biodesign teams, participants were chosen from different hierarchical levels.

Therefore, five interviewees were either principal investigators (PIs), postdoctoral fellows (Postdocs), PhD or MEP students at various faculties of TU Delft, such as Industrial Design Engineering (IDE), Applied Sciences (AS) and Aerospace Engineering (AE). The sixth interviewee is an external Biodesigner, who works independently. However, this participant is connected to universities through programs that connect external designers or researchers to universities, such as TU Delft.

2.2.2. Interview protocol

After the research design was established, the next step was to gather data through semi-structured interviews. In this subsection, the process of preparing for the interviews will be outlined, including the development of a consent form, the creation of interview questions, and the procedures for conducting and completing the interviews. This subsection aims to provide a comprehensive overview of the interview process, ensuring that the research is conducted in an ethical and structured manner.

Consent form for the interview

Before the interviews were conducted, each participant had to sign a consent form. In this consent form, the participants got familiar with the subject and objective of the interview. Furthermore, the consent form stated that the interview will be recorded and used as a basis for the case study. Next to this, the interviewee's identity will be kept anonymous and only the faculty and function can be published. In some cases, the cultural background of participants might be elaborated on, as differences in cultural background can influence certain team challenges. Lastly, the consent form indicated that the data collected during the interview were stored on a TU Delft-based server. The participants all signed the form, the complete consent form can be found in Appendix C, specifically in Annex C1.

Interview Questions

First, the interviewees were warmed up with some general questions. This was done to make them at ease and familiar with the subject of the interview. Giving answers to questions, such as "What is your role in the team? What does your position entail?" and "What do you like most about your work?", will direct the attention of the interviewee to teamwork and interpersonal relationships. This will help the interviewee to answer the more serious questions.

To conduct a comprehensive case study on team effectiveness in the Biodesign field, suitable interview questions had to be constructed. For this, a combination of Kalmár's IPO model (Kalmár & Stenfert, 2020), designed to study and conceptualise how individuals interpret and process information, and information from Chapter 3 of the book "Enhancing the Effectiveness of Team Science" (National Research Council, 2015) was used. The definitive interview questions focused, amongst other things, on researching team dynamics, differences in motivation and interpersonal relationships that might affect team effectiveness in the Biodesign field.

As seen in Figure 4, the first part of the model focuses on the input individuals put into the team to ascertain reaching their task demands. This can be in the form of communication or individual work but can also be in the form of resources and tools facilitated by different team members. The input questions, therefore, were formulated in this way: "What resources does the team have?" or "What type of people are part of your team?".

The second part of this adapted IPO model focuses on the process phase in teams. Here, the input is transformed into outputs. This involves problem-solving, communication and coordination activities. Due to the semi-structured nature of the interview, this part only counted four questions. However, during the interviews, more in-depth information was gathered through questions, such as "Do you think you could have been more open about the problems you encountered? Stating your feelings or saying that you felt something was missing in the group dynamic?".

Then questions were asked about the output of the team. These questions were asked to get a better understanding of how the team came to a successful end of the project and how they dealt with failures in the outcomes. Also, questions were asked about how the interviewee would change group dynamics to enhance team effectiveness in the future. The pre-determined interview questions can be found in Table 2.

Interview Setting

The interviews for this study were conducted between May 2022 and November 2022, which coincided with the COVID-19 pandemic that lasted from February 2020 to March 2022. It is important to consider the impact of this pandemic when interpreting the interview results. Due to the restrictions and challenges posed by the pandemic, in-person meetings were difficult to arrange. However, the laboratories at TU Delft remained operational during this period, adhering to the necessary COVID regulations, such as maintaining a physical distance of 1.5 meters.

Table 2 The pre-planned interview questions for the case study, designed to research Team Effectiveness in the Biodesign field, linked to the adapted IPO Model

Theme	Question	Comments
Questions for Input	What lab are you part of? What project do you work on?	Questions to get detailed information about the team setup and input into the team processes **Empowering leadership** = enhance use of team's individual resources (Kumpfer et al., 1993)
	What do you do? What does this position entail?	
	What do you like most about your work?	
	How many colleagues do you have?	
	What does the team hierarchy look like?	
	How do you as a leader/team member empower team effectiveness?	
	What type of people are part of the team? (Age, gender, cultural background)	
	What are individual differences across team members?	
	What resources does the team have?	
	Are there any problems you encounter when looking at the input of the team?	
Questions for Process	What do you like most about helping the people that you manage/work with?	Questions about how team members reach common goals and communicate about these goals
	What type of communication do you use to communicate with the different stakeholders involved in a project?	
	How do team members combine their resources to meet task demands?	
	What tools for communication does your team use to enhance team effectiveness?	
Questions for Output	What type of output does your team try to achieve most? (Papers, learning, patents)	Questions about the desired output of the group and how change can benefit the future team effectiveness
	Do you think this output could change in the future?	
	How would you like to change the overall dynamics to get a better team effectiveness?	
	What is the focus of the team's work activity?	

Due to time constraints, some participants had shorter interviews than others. Nonetheless, all interviews provided new perspectives and were included in the case study.

Interview Completion

After obtaining the desired information, the interviewee was asked if they had additional insights to share about the team dynamics or other topics discussed during the interview. This often led to further discussions, where both the interviewer as well as the interviewee were able to ask questions and engage in a deeper dialogue. Due to the semi-structured format, the interviews had an open conversational style and the interviewees were often eager to contribute to this case study by sharing additional concerns and situations that described teamwork in the Biodesign field.

At the end of each interview, the next steps of the thesis project were explained to the interviewee. The first step involved transcribing and analysing the interview data. After that, a problem statement would be formulated, and an intervention would be designed to address these challenges and issues.

2.2.3. Thematic Analysis: Methodology

For the case study, the interviews were prepared with the adapted IPO model and Chapters 1-3 of “Enhancing the Effectiveness of Team Science” (National Research Council, 2015). They were designed to give first-hand information from experts in the Biodesign field. After the recordings were transcribed and interpreted, the results were analysed by categorising the data into themes connected to the IPO Model, the team processes and the features described in Subsection 2.1.2.

Exploring Thematic Categories

The data, obtained from the six expert interviews, were analysed using protocol coding (Saldana, 2016). This method was selected to promote further exploration beyond the links to the topics mentioned in the literature study. Quenching the need for more in-depth knowledge on how research teams in the Biodesign field relate to team effectiveness will be the foundation for a suitable tool that enhances team effectiveness in Biodesign teams.

The semi-structured interview questions were designed to gather detailed information on the three team processes (cognitive, motivational, and behavioural), hierarchy, social networks, transdisciplinarity, and key features that influence team effectiveness. The complexity of these interrelated factors made the thematic analysis challenging. For instance, questions such as "How many colleagues do you have?" were linked to several key features (e.g., "Large Size") and multiple team processes (e.g., "Team Mental Models" and "Team Cohesion"). Additionally, the question had connections to transdisciplinarity and micro-level social networks.

The Themes for Analysis

The highly complicated connections and interlinkages between team processes, key features, hierarchy, transdisciplinarity and team effectiveness, made it difficult to find the perfect thematic categorisation. In total, ten code families were selected, resulting in ten analysis themes to categorise the interview data. They are presented in Figure 12.

Figure 12 The Ten Code Families Used to Create Ten Themes in the Interview Analysis

The first three themes provide information on team size and the interviewee's role within their team, the diversity of team members and the resources and tools that can be used to reach the team's desired output. The data from these themes can be linked to the input phase and team processes of the adapted IPO Model, as well as the seven key features, transdisciplinarity, and the layers of social networks mentioned in the previous subsections.

The "Leadership" and "Hierarchy" themes encompass data on leadership styles and their impact on team effectiveness. These themes are connected to the resource and process phase of the IPO Model and give data on the hierarchical structures in Biodesign. They are also indirectly linked to the seven key features as these challenges need proper management and alignment through good leadership. They are situated at the micro-level of social networks.

The data, relevant to task demands, reaching a common goal, societal purpose and goal misalignment are presented in the themes "Task Demand and Goal" and "Goal Misalignment".

Both themes are relevant to the output phase of the adapted IPO Model and include data related to the key features and transdisciplinarity.

The last three themes are related to the relationship with either other research teams or the organisational structure, TU Delft, making them part of the meso- and macro-level of social networks. The data obtained also sheds light on the difficulties and uncertainties of working with living materials. Furthermore, the data from "Relationship to Other Teams" can be linked to Transdisciplinarity, the team processes and key features, such as "Goal misalignment with other teams", "Geographic Dispersion" and "Permeable boundaries". The theme "Organisational Structure" gives more information on what resources the teams receive from the TU Delft and what hierarchical structures are known in this institution. It also provides some insight into how different faculties manage their geographic dispersion and how external designers feel about working together with teams at this university. The last theme gives crucial information on bridging the knowledge gap in the field of Biodesign to reach the common goal.

These themes are thus highly intertwined with the four literature topics and the team processes that affect team effectiveness in science teams. Therefore, the first sub-question, "*What themes, connected to team processes, social networks, hierarchy, disciplinarity, and participatory design have an impact on or are significant for team effectiveness in science teams?*", is answered. Overall, the selected analysis themes provide a comprehensive framework for understanding the interconnectedness between team processes, social networks, hierarchy, disciplinarity, participatory design, and their impact on team effectiveness in science teams.

Building upon the established analysis themes, the next subsection delves into the valuable insights gained from exploring the perspectives of Biodesign experts, further exploring the themes and their implications for team effectiveness in the Biodesign field.

2.2.4. Biodesign Expert Perspectives: Analysis Themes Explored

In this subsection, the results of the thematic analysis of the expert interview data are presented for each theme. Elaborations on all six interviews are provided, where the interviewees and their quotes are kept anonymous and only their faculty and the details such as background and position of the interviewees are detailed. In Appendix A, Figure A1 presents the blurred thematic analysis overview, created in MIRO, to demonstrate the extent of the analysis.

To provide context for the upcoming results, this subsection briefly summarises the backgrounds of the interviewees. The first interviewee referred to as P1, was the Principal Investigator (PI) of one of the teams of the case study. Three other interviewees (P2, P3, and P4) were part of the other team, with P2 serving as the team's PI, P3 as a Postdoc, and P4 as a former MEP student and employee. Additionally, one member of Team C was interviewed. The final interviewee, P6, was an external designer and artist in the field of Biodesign.

The relationships between the teams, the external biodesigner, and TU Delft (large blue circle) are depicted in Figure 13.

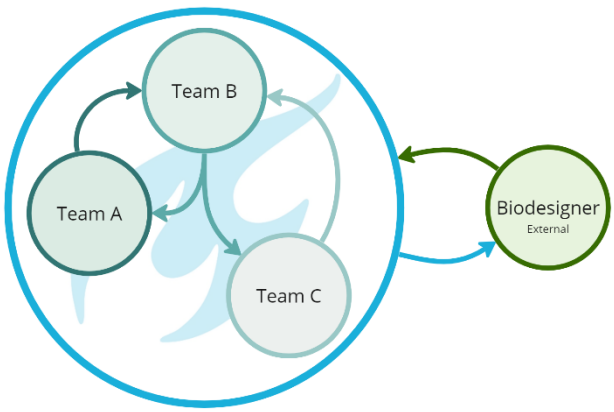


Figure 13 The relationships between the three Teams at TU Delft and the relationship of the Biodesigner to TU Delft

Team Size and Setting

In line with the discussion in Subsection 2.2.3, this theme explores the team size of the interviewees' teams and their respective roles within their teams. It also highlights the way they are connected to one another. The roles of the team leaders (PIs) are discussed under the theme "Leadership".

The first team consists of around 20 team members, one postdoctoral researcher, four PhD students, and the remaining members are either master students or interns. Participant 1, the PI, noted that [P1] has not yet had the opportunity to establish a solid network, as [P1] only assumed the position of PI around 2.5 years ago.

The second participant, P2, is the PI at one of the Biodesign laboratories at TU Delft. In total, their team consists of nine to ten team members.

> *P2: "I have two PhD students, […] three or four master students and one bachelor student and two lab technicians."*

Participant 3 was a Postdoctoral researcher and has a microbiology background.

> *P3: "I mainly worked with the supervisors, [P2] and the PI of Team C […] I also worked together with the research scientists of the [Biodesign] lab and also with graduate students. There were many students I worked with and also post-docs and PhD students."*

Participant 4 started with a design background as a graduate student in Team C, worked in the lab of and with Team B, and maintained close contact with Team A. After graduating, Participant 4 kept working in Team B as a part-time researcher to finish part of the project for a research paper.

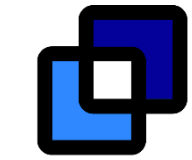
> *P4: "Then after connecting with [P1], there were a few students from [P1's] lab, with whom I worked together and asked a lot of questions. So, that was to get information and get more knowledge about their work and if I could use it for my project."*

Participant 5 works in a Biodesign lab with around seven to eight colleagues, one group leader, three assistant professors, postdocs and PhD students. Mostly, P5 works alone and takes full responsibility for the PhD project.

> *P5: "I'm doing a PhD, I'm studying, learning or searching about Biodesign, especially how the microorganisms we design with could be augmented to express their well-being to the users."*

The sixth participant has a biology background and combined their bachelor studies with creative activities, such as theatre and scenographics. The first contact with biodesign was through P6's former professor, who worked with algae (making biofuels). After that, P6 switched to a design academy, where biology could be incorporated into designs. Currently, P6 works alone and has a design studio in Amsterdam. However, P6 often has to work together with museums and with academic teams.

> *P6: "I collaborate with people who can help me with the making process. […] On the other hand, a lot of the collaborations are with scientists. […] At the moment I am working with TU Delft. I've worked several times with people from TU Delft, but at the moment I'm working with [a researcher], he's a professor and he [had a big breakthrough in the Biodesign field]."*



Diversity of Team Members

The diversity between team members is an important feature of research teams. This can be a difference in personality, work ethic, cultural background, age, etc., but it can also indicate a difference in professional background.

Personal Diversity

The first participant indicates that the difference in personality is the most notable difference present in the team. The PI of Team A tries to be very active in the lab to increase the bond they have with the team members, see what the members are struggling with and how their project is progressing over time.

> *P1: "How they are feeling about progress or lack of progress? How do they communicate their work? What kind of help do they need? Emotional or technical or scientific."*

The PI, the Postdoc and the former MEP student of Team B (consisting of young and international people), also express that diversity of team members is common in the academic world and can be something positive. As an international person, the PI relates to being an international in The Netherlands.

> *P2: "I like this diversity and during my studies, PhD and postdoc this was the case. Most academic teams have a diverse group of people, people from all over the world are part of my team."*

However, participant 4 notes that differences in cultural background can cause a disbalance in work ethics and having fewer obligations outside of work (e.g. visiting family) causes this imbalance.

> *P4: "I think the work ethic is a bit different for [international people]. I also have the feeling that because they don't have a social life here in the Netherlands they can focus more on just work. Whereas people that already lived here for a longer time have more obligations outside of work too. Some people in the group did want to have more social things. But, in the lab it was "work" and then in the evening, you can socialise, but not during your work."*

Participant 5, the PhD candidate of Team C, highlighted that Team C is mostly made up of people from foreign countries, ranging from Italy to Turkey and that this feature of the team makes the bond stronger as they all have fewer friends that live in The Netherlands.

> *P5: "All being internationals, we are trying to get closer anyway, because we are all from different places and we don't know The Netherlands that well and don't have many Dutch friends compared to Dutch people. So I think the bond is quite strong between us because we share being a foreigner in The Netherlands."*

Professional Diversity

The PI of Team A (P1) expresses the importance of diversity in the lab. The variation in expertise helps with creativity, which is especially important in Biodesign. The members of Team A have to work with different types of tools, such as digital and simulation tools, 3D printing technologies, material science and experimental work. In their opinion, in a team, it is necessary to interact and exchange knowledge with each other about these topics. The team leader indicates that this is a fluid process, with permeable boundaries, that changes once team members have acquired the desired knowledge and the problem shifts.

> *P1: "I rarely have any student which has more than one of these [diverse skills], so they have to be comfortable to be stepping into projects where they are completely clueless about the other tools […] That is the one thing I say: "If you are starting here and going to be overwhelmed by the fact that*

you don't know what you are doing, then probably this isn't the lab for you". […] It is a process, […] when you acquire that knowledge the problem for you changes to a different subject, so then you need to match up with someone else. So, it's a constant moving problem. […] When a really good material scientist connects with a computational expert, the computational expert has a good opportunity to get better at doing experiments […] The other one has a good chance to learn more about simulation tools."

Participant 5 also mentions the need for professional diversity, as [P5] combines the expertise of the team members in their research. However, [P5] also expresses that this leads to a diverse focus between team members and that every person has "*a different research method and research field interest*". In their opinion, this difference causes a large knowledge gap as the team members do not work together much and [P5] does not really feel team cohesion.

P5: "[…] our projects are quite separate from each other. […] I think it's not really efficient, because we don't and can't share knowledge on our projects […] Everybody has their own agenda and we only share what's probably going to be overlapping, which is very little. […] we mostly share the [research] process, for example, we all come to a point where we get stuck and we could just give each other some encouragement, and say it's going to be fine […] mental reassurance and support"

The fifth participant expresses the desire to have an extra team member added to Team C, with a more similar professional background. In that way, they could "*share more knowledge and information".*

The external Biodesigner (P6) also expresses the need for diversity in expertise.

P6: "The collaborations are super important and I like that you can inspire each other and see that you have a different approach while having the same goal in the end. Even if you're coming from a different angle. You start to understand each other and also what I see is that within science and design and art there's a lot of overlap of creativity and problem-solving."

However, the second participant notes that this diversity can create a disbalance of knowledge. In their opinion, it is best to get to know the other's background and close this gap.

P2: "When I am working with someone with a rigorous mathematics background, it is good to know that they have this background because they will put more emphasis on that part when we have a conversation."

The fourth participant expressed putting two completely different backgrounds together can be interesting as they can share and learn from each other, creating a positive atmosphere. However, the created knowledge disbalance was quite large in P4's opinion. The two completely different teams with non-related goals worked together in one office and P4 even suggested separating the working space and connecting on Friday evenings to enhance team bonding.

P4: "The different backgrounds did make it more difficult for the discussions […] for the feeling of team bonding, it is not nice to have two completely closed-off research groups together as one group. It would make more sense to put the [subject] research in a separate office. […] You can have drinks on Friday together to connect with the whole group."

Participant 3 mentioned that [P3] was not involved in their research but did know what was going on in their research due to the common lab meetings. The interaction was mostly based on communication about sharing lab facilities, there was no common goal (see Goal Misalignment).

P3: "Initially, the 3D printer was located in one of the [other sub-teams] rooms. We had to make sure that we worked in alignment with each other so that each other's experiments were not disturbed or bothered."

Resources & Tools
What are the resources and tools?
How are they regulated?

Resources and Tools

The "Resources and Tools" theme explores the methods and tools used by team members to work collaboratively towards a common goal. This theme provides an in-depth analysis of the planning, communication, and meeting strategies that contribute to the success of each team.

Participant 1 notes that due to the large team size, Team A has a weekly group meeting, where one team member updates the rest of the group on the progress of their project. By doing this the PI of Team A keeps track of how the team members are doing and if the amount of meetings needs to be updated.

> *P1: "[…] one person presents a detailed presentation for 15 minutes, with a 15-minute long discussion and everybody else does a 2 or 3-minute long presentation to update everyone on the progress. […] very fast way and this facilitates discussions I have with separate people throughout the week."*

The PI of Team B describes that they also have weekly meetings to discuss progress and give updates.

> *P2: "[The weekly meeting] is when we update one another on the progress but it also depends on everybody, some people have a different arrangement. For these meetings, I try to adapt to the needs of the project. So, for some people, I alternate individual meetings and then meetings with collaborators. […] For example, one team member prefers to meet with everybody because that is more helpful for that member."*

The fourth participant elaborated more on the monetary capacity of the different faculties. But even though there was a disbalance, Participant 4 recalls that Team A was very happy to share their resources and tools with people from outside their team. Team B helped Team A in exchange.

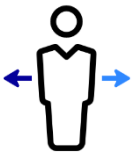
> *P4: "There were a lot more resources, especially money, there was a lot more money in the [other] Faculty. That was quite obvious. [Team B] shared their resources with everyone. Which can hurt your work. They didn't have to share their printers with us. That was more like a nuisance to them […] you have to trust that if you help someone and you share your resources, you also get something out of it. In the end, they did get some new information from [Team B] from that collaboration and a published paper with their names written on it."*

The fifth participant also mentions that most progress is discussed in a meeting that is scheduled every other week and that resources and knowledge are not shared between team members as Team C has too diverse research topics.

> *P5: "We do not really share resources or knowledge because we all have quite different research topics […] we share the process, we all come to a point where we get stuck […] give each other encouragement […] The biweekly meeting is more for sharing the research progress in a more formal atmosphere."*

The sixth interviewee spoke about how, as a biodesign artist, they do not have the facilities a laboratory has, a place where you can easily work with living organisms. However, with P6's Biology background, it was easier to be allowed back into the lab and use the facilities there.

> *P6: "I'm an artist now, but I'm still welcome here in the lab and that was cool."*



Leadership

This theme elaborates on how the leader of each team is situated in their respective team and what their role is in the Biodesign team. This includes the views and beliefs of the team leaders (PIs of Teams A and B), as well as the thoughts and opinions of the team members (Participants 3 and 4 on the PIs of Team A, B and C, Participant 5 on Team C and Participant 6 on working with PIs). Below, the roles and responsibilities of the PI in Team B are described by P2.

> *P2: "Part of my time is for education, I teach two courses […] I also develop courses next to teaching […] part of the management team of the department […] I collaborate and meet with other (co-)teachers and researchers […] I have a lot of meetings […] I do research […] in part for applying to get funds for my research […] help plan and arrange projects […] I offer supervision to bachelor, master, PhD and post-doc students, who publish our results and present at conferences […] problem-solving in the science and engineering part, but also sometimes in the relationships between team members […] training, mentoring, help them get to know what research is, help writing their report […] promoting that there is room for people to talk to each other about their projects and give ideas or help."*

Participant 1 sheds further light on the professional responsibilities of a PI in the Biodesign field.

> *P1: "I try to facilitate that my group meets people whom they can interact with and that there are mutual learning possibilities."*

The PI of Team A also reflects on the importance of social responsibilities and keeping track of each member of the team, adapting to their needs when situational changes arise. Participant 1 mentions that this is a time-consuming feat next to having to apply for grants.

> *P1: "I try not to be cocooned in my office […] I interact with them daily and this is how I can see if they are struggling. I can see how they react to certain situations when they are developing, and that's a mechanism for setting up discussions. By interacting with them in the lab I can see up close how they are doing, and next to using digital means of communication, [personal interaction] really makes the process complete. […] If there are some issues I can come back to them during the week, or if they have material for a paper we can have a meeting. And if there are people stressed because they are finalising their project we can have more regular meetings. With the new grant coming along, 3 more people will be added to the group, so that will also be time-consuming."*

Being a leader also means balancing between delegating (i.e. low supportive and low directive behaviour), supporting (i.e. high supportive and low directive behaviour), coaching (i.e. high directive and high supportive behaviour) and directing (i.e. high directive and low supportive behaviour). This situational leadership style, developed by Hersey and Blanchard (1988), is exemplified by Participants 1 and 2.

> *P2: "[The team members] organise the experiments they do themselves. So, I think they can also try new things that may or may not work for them. I can see sometimes if the way they organise themselves is working or not and then maybe I will be a bit more hands-on and ask how they organise their time and discuss together how they can find a better strategy to reach their goal, but as a first, I prefer to give them freedom. […] I am open to discussing another strategy."*

> *P1: "Finding this balance [being too overbearing or asking independent thinking] is a constant feedback loop."*

Participants 3 and 4, the Postdoc and the former MEP student of Team B, mention that being a leader does not only mean helping people but also learning from them.

P3: "In the process of helping, you will also learn […] if they didn't know something I was open to teaching them. And if I didn't know something, I would also be open to learning from them."

P4: "I think if you teach something to someone, you also learn something yourself."

Furthermore, P3 added that as a Postdoc, the workload was often too much and the resulting delays were very common in the academic world.

P3: "We have so many things on our plate that we need to manage, it's not just researching, we also have administrative things to manage […] we are always occupied from a student's point of view. They probably ask themselves why is that person not replying, but there are so many things to do. […] I think it's a very normal thing in academia to respond later to emails. […] I think it is due to the workload. This is a part of our work, but you also have so many other dimensions. And with social lives next to work, we have to balance that too. So that's something that you learn eventually and I am still learning."

The fourth participant explained that introducing someone into the team as a mentor also includes making the new member feel at ease. In the case of P4, this lacked when they were introduced into the lab. Coming from a design background, they did not know what rules applied in a laboratory. When they introduced someone into the lab themselves, they tried to keep that in mind.

P4: "My introduction was not that good. Which made me quite scared to work in the lab. […] if I could take that away for [the other team member], that would make life easier."

Next to this, P4 also emphasises the exemplary role the PI of Team A took on and the effect it had on the team effectiveness of Team A. By focusing on helping people and being present in the lab P1 set an example for the team members of Team A. P4 observed that this approach led to stronger collaborations and more favourable results in terms of the team's output. On the other hand, P4 expresses the feeling that the PI of Team B was less open to feedback, often resulting in miscommunication between them. The PI of Team A related that the goal is to have a self-supporting network in Team A, where a positive group environment stands central.

P4: "[P1] had a really big influence on this[1] group dynamic because [they] were the leader and [they] set the example. One of the things I found the most interesting was that somehow everyone [of Team A] you spoke to was really helpful. And not helping to get something in return […] [Team B] lab there could have been room for this too, but this did not happen. I think the difference was that [the PI of Team A] set the example because [they] were always helping without getting something in return and I think all the students saw that and just sort of mimicked that. Maybe without even knowing it and if someone does set the example the others see it and then everyone will do it. And that was really, really fruitful for the research. So, then you have fewer separate islands and everyone is helping each other and collaborating better."

P1: "[I try to] facilitate a positive group environment where they can already solve many problems before they come to me […] develop and grow through one generation or two so that it becomes a self-supporting network."

[1] *Doing sports together during the lunch breaks, like bouldering and running, having lunch together and celebrating if someone graduated – P4 about the group dynamic of Team A.*

P4: "The PI [of Team B] expected very different things than I did […] people say things and then they do things differently and that happened in this project […] I should have evaluated that better […] there also has to be some sort of environment to do so and there was not an environment for that, I don't think the PI was open to that. And then you just make the best of it."

The PhD candidate of Team C indicated that the PI of their team mostly communicates the direction of interest and after discussing that direction with P5, a decision is made together.

P5: "The professor shares their opinions or direction to indicate what they are interested in. We can always discuss these topics and form decisions together."

Furthermore, Participant 5 feels that there is a lack of support due to the busyness of their PI. This results in P5 having to rely on their skills and find expertise in people outside of Team C.

P5: "At times I don't feel supported by someone who knows more than me and I am relying on my learning to reach some goals. […] The supervisors try to give some direction or guidance, but they have so many PhD students to supervise that they are not able to be really on top of your project. […] you should not rely on your supervisor to tell you everything."

The external Biodesigner further underlined that PIs in general are very busy.

P6: "I think the most difficult part […] is the period where you are only working with the professor. They have such a busy schedule and you are not their priority, you are never their priority, but no one is a priority on a professor's schedule. And they find it difficult that you have a fixed period of time you can work on a project. And you notice that professors are used to having much more time for their research. So, it's difficult to really get it […] Then once you get assigned to a student of them it starts to roll."

Hierarchy

The theme of "Hierarchy" focuses on getting more insight into the hierarchical structures of the teams in the Biodesign field.

On this topic, Participant 1 said there is indeed a formal, hierarchical structure. However, the PI hopes to close this hierarchical gap by being as involved as possible with the work the team members of Team A do.

> *P1: "In the formal sense, yes [there is a strict hierarchical structure]. But I try to be as involved as I can and work with everybody. I hope this opens up communication throughout the group, by leaving out this hierarchical separation."*

The PI of Team B mentioned that the departments of their faculty work with a PI system.

> *P2: "The department works with a PI system, so every group has a leader, an assistant or a full professor, each independent from the other labs. […] 18-20 groups in this department. And there are different groups in each department. So, the other group leaders or PIs are my colleagues and each of their groups has bachelor, master, PhD and postdoc students."*

Participant 3, the Postdoc, notes that the PIs mostly "*supervised and led the project*", whereas the researchers "*were actually doing the experiments in the lab*". Nonetheless, P3 mentioned that in their opinion there was not much of a hierarchy in place in Team B.

> *P3: "I actually did not think there was that much hierarchy. It was more that people were open to exchanging information and also open to learning from each other because everybody was from a different background."*

Participant 4 stated that while a certain degree of hierarchy is necessary, it is not always enjoyable. According to P4, having some fun and not taking everything too seriously can improve team dynamics. Additionally, feeling equal to other team members is crucial for team bonding and low-key interactions can prove to be the perfect setting for coming up with innovative ideas.

> *P4: "I think for the lab work it was necessary [to have a hierarchy]. Because it's quite a responsible task and you are responsible for a lot of different experiments. So, I think it's important to have a clear distinction between leading figures, teachers and pupils and know what that relationship entails. I think it's necessary, but it wasn't always fun. […] I think you have to sometimes joke also with each other and not take it so seriously. Research is serious, but you can't take it too seriously. That is not helpful, I think. […] Having your responsibilities and feeling equal in the project is important. […] The office arrangement of Team B was based on hierarchy instead of team bonding. I saw the difference between Team B and Team A, Team A works."*

> *P4: "The best ideas happen in the hallway when you pass each other on the way to the toilet. Or just when someone is looking over your shoulder and sees what you're doing, "Like, oh, did you try this with that?". These low-key interactions are quite useful."*

Participant 1 agrees with P4 that low-key interactions can be very fruitful and that bridging the hierarchical gap can help with team bonding.

> *P1: "I am the one that goes around at 16.30h in the afternoon to get everybody to join me in the bar at [the faculty]. To get to know each other better and talk about something else than work. And also, half of the good ideas I come up with arise in the bar and the other half on my bike."*

While Participant 6 did not discuss any hierarchical structures they encountered, they shared a story stressing the importance of low-key interactions in fostering spontaneous discoveries.

P6: "Spontaneous discoveries are very important. [The researcher P6 works with] told me that [the researcher] went to a congress and at some point, […] got a bit bored or tired and went to get a beer […] there was another enzymologist […] they had a beer together. They started to talk about their research and then one of them showed the other an enzyme and they said, well, this really looks a lot like the enzyme that I'm looking for in my research […] it was a match, an enormous development in the [field]."

In Team C, Participant 5 noted that there is not a strict hierarchy between the postdocs, PhD students and assistant professors. There is one group leader who gives direction to the project.

P5: "One group leader […] [the PI] has three assistant professors, then we have postdocs and then PhD students. But I wouldn't say that there is a very clear hierarchy. Just that the supervisor or the professor shares their opinions or direction to indicate what they are interested in. […] I don't think there's a clear hierarchy between the postdocs, PhD students or assistant professors."

Lastly, Participant 4 discussed how the hierarchical gap between themselves and their PI (P2) was partly created due to the grading scheme. During their MEP, they focused on gaining approval and achieving good grades. However, after graduating and working in the same team (Team B), they realised that delivering good results was stimulated by the pay they received and being able to speak up to the PI was easier due to a more evened-out playing field. Additionally, they noted that grades are quite subjective, making it difficult to express feelings as a student. Lastly, they mentioned that influencing the PI's behaviour is hard for a newcomer.

P4: "I was trying to gain the approval of the professors and hoping I would get good grades and I continued to stay in that vibe after graduating because it was the continuation of that same project. During the graduation project, you are looking up to the person who is going to give you grades and who judges you in some sense […] When you start working you receive payment and it is much more important that you get good results for the company. Also, you are in a better position to say things to a manager […] as a student, you want to have good grades, so why would you make things more difficult by explaining your feelings to someone and hoping that they understand and do something with them? It is a bad position to be in, you are powerless and that is a strange dynamic. So, there is no even playing field because grades are also quite subjective as they also grade you on your behaviour […] I don't think I could have influenced the PI to behave differently in the research group. As a newcomer, it is quite hard to change that and for the group, it worked I think or at least they seemed happy. They found it normal and it worked, but it was just different for me."

Task Demands and Goal

In this theme the *Task Demands and Goal* of the Biodesigners are detailed. The common goal of a team is important to foster a positive influence on team processes. For example, a common goal helps to create, amongst other things, a feeling of unity and a positive climate in the team.

Participants 1 and 2, the PIs of both teams, mentioned this about the goal of their respective teams:

P1: "Trying to do science […] Create all kinds of bio-inspired materials which are shaped using 3D printing technologies. That's the core focus of our group. […] "Get good results and deliver nice work" "By supporting your team."

P2: "Develop new materials […] take advantage of the properties of microorganisms […] understand how these microorganisms behave within the material […] push both the science and engineering parts and our goal is to […] publish the results and report it to the world."

Participant 3 related that the goal of Team B was to deliver qualitative science and research.

P3: "The goal was to deliver quality science and research. [...] not focused on publishing papers in a quantitative way, but in a qualitative way. [...] always wanted to deliver good research and once we had very good results or an overall story […] only then we went for publication."

The fourth participant gave more insight into how a common goal helped the members of Team A ask and answer questions related to their projects. The common goal of Team B was less clear to P4. In addition, P4 mentioned how team composition might influence team dynamics and task demands.

P4: "There were a lot of differences [between Teams A and B]. First of all, I think they [Team A] had a clearer common goal. They were all working on different materials, but they were all working in that same lab. They shared a lot of expertise in that field and they also shared common interests. So, they were also very enthusiastic about each other's projects. And that helps because if you're enthusiastic about someone else's work it is easier to ask questions. And if you ask questions, you get new answers and new ideas. They all worked with 3D printing and that was their common goal. […] The focus was really on publishing high-quality papers. While having a fun workplace they did not lose that. […] In Team A, people were selected on how curious they were and how much they liked working with other people. In Team B, the selection was more focused on work ethic and expertise […] the general vibe was to work very hard."

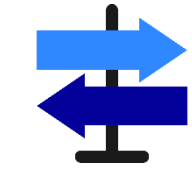
Participant 4 also spoke about the personal bond created by working on the same subject as the people from Team A.

P4: "We shared each other's feelings because sometimes it's quite a difficult field to work in and you both have your struggles and then we confided in each other."

As mentioned in the theme "Diversity of Team Members", the team of Participant 5 does not share a common goal and this sometimes resulted in feeling less united and having a large knowledge gap.

The external Biodesigner explained that the goal of Biodesign for them is to create an intuitive design that has a visual story and can be incorporated into the daily life of users.

P6: "Biodesign should focus on creating something that is recognisable and aesthetic and has a visual story or a personality and incorporates science in an intuitive way. When this is accomplished, people realise that this design […] can have a place in their daily life."



Goal Misalignment

The theme of "Goal Misalignment" refers to situations in which team members have different understandings or priorities when it comes to the goals of the team. As discussed before, this can affect the team processes, such as *Team Cohesion*, *Team Climate*, *Team Conflict* and *Team Efficacy*. In this theme, examples will be given of goal misalignment and its consequences.

The first participant mentioned a case where the misalignment of motivational differences between a team member and the PI resulted in conflict. This conflict was solved after discussing the problem and reshaping the project to their needs.

P1: "It felt one-sided […] this [team member] was just not excited about that project and so were struggling to communicate with enthusiasm, and excitement and trying to get feedback on their project because they were not excited about it. So therefore they were a bit lost because they were

not spending time on it […] we discussed if we could reshape it into something that fits more with their motivation."

The PI also mentioned that there is a different goal for the two subteams that are part of Team B.

P2: "There is an engineering part where we want to develop [subject one] but there's also a scientific part where we want to understand how [subject two] works."

The Postdoc (P3) explained that communication between the two subteams mostly happened during group meetings and most interpersonal interactions were about coordinating the shared facilities.

P3: "I was not involved in their research, but I did know what was going on in their research due to the common lab meetings. So, we did interact whenever we had to share facilities in the lab."

Participant 4 elaborated on the goal misalignment between the two subteams of Team B.

P4: "There was not a common goal […] except for the common goal of doing "research" […] if you have some results it's quite important to celebrate with each other. For that common goal interest, the feeling that you're all researching this same project […] which is quite important I think if you're doing research work because you have to be very patient. I think that might have been the problem."

Furthermore, P4 expressed that there was a goal misalignment between P4 and their PI (P2). This misalignment resulted in more time needed to manage this misalignment as well as the project itself, lowering the team's effectiveness.

P4: "There was a difference in interests, […] I wanted to finish the project fast because [I] wanted to be done with it. And for the project leader, it is not necessary to finish it. So, there is a goal difference and that made it frustrating most of the time […] the PI said nice results were [their] goal and that is not the same as quick or fast. And the goal from the point of view of [Team B] was to publish the paper as fast as possible to be the first, making their goal more aligned with my and […] goal. At [the other faculty] that was less important. This caused a misalignment between the stakeholders of the project and then you have to manage that as well."

Adding to this, Participant 4 shared that a goal needs to be flexible and when needed it should be adapted to the needs of the team members.

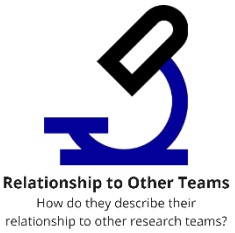
P4: "[Goal misalignment] is something which we encountered a lot at [my original faculty] [understanding] the problem behind the problem or the goal behind the goal. It always seems very easy to set a goal, but the goal also changes a lot. Over time people change, and subjects change. You have to evaluate it throughout the project. Asking questions like are we still having this goal? And how do we set mechanisms in place to be able to get this feedback loop? Because as I said people change and situations change. So, you can't just say something at the beginning of the project and then expect it to last for years."

The fifth participant explained that the mentioned diversity and knowledge gap made it impossible to advise team members on their research topic.

P5: "[Helping a colleague] would be impossible, our topics are really too diverse. I don't know anything about [their topic], so that would be difficult for me to give advice."

Participant 6 mentioned that the scientific students they collaborated with are educated with a "research" mindset. This made that one of P6's goals now is to help Biodesign to translate research into application, this sometimes creates a misalignment between them and the research-focused collaborators.

P6: "It's so freaking hard for these topics and these discoveries to set foot and set ground in our society and get their place in daily life. And I just thought it's not weird at all that this is happening if students are educated to research and they're not educated to translate this research into a valuable company or a product or an application. […] When I saw this, I knew where I wanted to help out. Because when a lot of this research is done, it can take about 10 years or longer before any of it gets to the trial phase or gets implemented in daily life and I just thought, okay we can speed this up, even if it's in the research phase."



Relationship to Other Teams

This next theme gives more insight into how the interviewed Biodesign experts feel about the relationship they have with other research teams. As illustrated in Figure 13, Team B worked closely together with Team A and Team C. During the interviews, more information was gathered about how all parties felt about collaborating with other research teams.

Participants 1, 3 and 4 elaborated on the relationship Team A has with Team B.

P1: "The relationship is really good, the PI of Team B and I are pretty busy but well aligned. We know what the other is trying to achieve and what our separate backgrounds and weaknesses are and we try to facilitate to support each other in that as well. So, what they lack in knowhow we fill up with our expertise and knowledge and vice versa. Bright future and the communication is really good. We're both learning along the way, so it's not without mistakes, but we never blame each other, it's a mutual effort."

P3: "I would say it was super collaborative and the co-operator's spirit was there because even though we were from completely different backgrounds, we had the opportunity to use their lab and 3D print in their lab. [P1] was always super open about learning new concepts and delivering cutting-edge science to the world. They were really excited and enthusiastic about this collaboration and so was [P2], so it was quite nice to have this relationship between the two labs. And the students of our lab could use their lab and so they did research in different labs during their theses which also helped the students to build relationships across different environments with people from different educational backgrounds. So I think that was a very good collaborative spirit and that's what I really liked about that collaboration."

P4: "[P1] got interested and it was [P1's] idea to become more involved because we felt that we could learn from each other. And [P1] saw that I was enthusiastic about the project and because [P1] was doing the same thing, we could combine our expertise."

Sometimes it was difficult to coordinate the projects between both teams and mistakes were made. An example was the contamination with Fungi during the project of one of the MEP students from Team B, now called "Fungigate". Participants 1 and 2 mentioned this on Fungigate.

P1: "I worked successfully with multiple organisms for a year and a half before, I wasn't scared about getting contaminations […] new people integrated into the group who maybe didn't have the same working practices. I think that is why [Team B] had these contaminations [at Team A's lab], we identified these contaminations and instantaneously stopped and took action […] I was a bit relaxed before, not enforcing [cleaning] a lot, people also got a bit relaxed, now I'm extra careful and so people are also getting this message that they have to pay attention and take care when working with living biological materials."

P2: "There was really good communication because we solved it quickly. […] It would have been good to know that they were printing with other organisms, but maybe they did tell us but we didn't take it as seriously as we should have. But, now we know that we need to be more careful […] and take

certain measures when we bring a sample from one place to another and think about how we should do this in the future."

On collaboration with Team C, Participant 2 mentioned that they helped Team B bring their material to a possible product.

P2: "Team C helps by bringing our material to a possible product […] they are more looking into how can this be applied and what improvements can be made and how we can use the qualities of the material. They can tell us what properties are nice and when the quality of an aspect of the material can be improved for a certain goal."

Participant 5 mentioned that the collaboration with Team B was not very close but P5 learned a lot from working with P3.

P5: "The collaboration is not really tight or close […] close collaboration with postdoc [...] my knowledge of my project got enhanced. [P3] shared [...] knowledge and sent me papers that might be interesting for my project."

Next to these positive interactions, there are also some negative aspects of collaborating with other research groups. P1, the PI of Team A, explained that other teams might feel threatened by their team.

P1: "There are groups that we have worked with at TU Delft where I can feel that people are threatened or feel competition from me and my group rather than that they have a collaborative feeling towards our group and knowhow."

Another example was given by Participant 5. The PhD candidate of Team C expressed that integrating into the Dutch culture can be difficult at times. Especially, when trying to make new collaborations with teams at another faculty.

P5: "I couldn't find anyone who could help me. But for the next project, I think I should open up and I should be more persistent and maybe even a bit pushy […] Otherwise they just say "I don't have time". […] In China, we are a bit more cautious."

Participant 4 discussed that receiving new knowledge from teams with different backgrounds can be difficult due to the knowledge gap. P4 also asked the question of how you can be certain the other person or yourself understood what the message was.

P4: "I think it's really important to be able to explain your subject in such a way that you can receive proper feedback and that you are understood at the same time. It is important to try to train yourself to talk simply about the problems of your research. Because you can lose quite a lot of information using difficult language and with a lot of terms and abbreviations. In the end, people might feel like they understood each other's terms and words, but, how can you check for yourself that you understood what the other person was saying?"

The external Biodesigner expressed that most collaborations are surprising and important. In their opinion, the goal stays the same even though the approach might be different.

P6: "I like the collaborations [with museums (e.g. Centre Pompidou), scientists, students], and I like the surprise that lies in the science behind my designs. The collaborations are super important and I like that you can inspire each other and see that you have a different approach, while having the same goal in the end. Even if you're coming from a different angle. You start to understand each other and also what I see is that within science and design and art there's a lot of overlap of creativity and problem-solving."

Organisational Structure

This theme will shed more light on how the interviewees felt about their relationship with TU Delft and other organisational structures.

Participant 4 observed that the academic setting diminished their confidence, particularly due to joining the same team immediately after graduating. Additionally, P4 pointed out that within the academic world, they perceived a higher tolerance for the lack of communication and team bonding.

> *P4: "Now I can also see how things can be done differently and back then I was part of a more academic setting […] if I went into that group now, through the normal process of doing a job interview, I would have more of a working relationship […] there are people who feel fine with having less communication, team building and group bonding or a common goal. Maybe [people being fine with that] is more prone in the academic world."*

The Postdoc from Team B raised the concern that the university should enhance inclusivity for students working in the laboratory. Participant 3 emphasised the significance of MEP/BEP (Master/Bachelor End Project) students as the backbone of TU Delft and advocated for treating them as equals to employees of TU Delft.

> *P3: "I actually think that TU Delft should be more inclusive in terms of including students in activities, they should not make a distinction between employees and students […] when an activity day is planned only employees can participate in the complete programme and students can only participate in the lecture part and not in the fun part […] they should always include students, they are the backbone of TU Delft […] we learn from each other […] I think they should make sure that they include students so that they are part of all the activities that happen. And if money plays a role, TU Delft should look at this organisational problem and find a feasible solution."*

The PhD candidate of Team C shed light on the PhD system at TU Delft and expressed it is more a rule than an exception that PhD students take longer than 4 years to finish their PhD.

> *P5: "It takes people five or six years to complete their PhD […] that's two years more than what is planned by the university […] It's a problem of the system, because if the system is perfect then people won't take two more years than what's planned for just four years."*

P5 also mentioned how they would solve this problem.

> *P5: "PhD students should have more time for their real studies and for writing their thesis […] the first year is a too long and too open […] not clear what my scope was, in the first year I diverged too much and at the end of the first year it was hard to converge into a more fixed direction […] the first year could be more clear for PhD students […] know what their scope is instead of going crazy on the literature research."*

Additionally, Participant 5 expressed how the policy on publishing papers should be more flexible at their faculty to match the needs of Biodesign PhD students better.

> *P5: "[People with a] design background […] have a different way of thinking than publishing on paper. Writing is a linear process […] have to be good in English […] Design process is totally different, you don't have to rely on words, you need to be creative and you don't have to fit yourself in what is already there […] I think the paper requirements in this faculty could be a bit more relaxed instead of obligating students to write 3-4 papers […] My PI asks [Team C] to publish 3-4 papers but if you did some good work the papers are less important. This is not really written down, but I feel that it is possible to ask for a more relaxed policy. And I think that the whole faculty should consider this."*

About their work, Participant 1 expressed their least favourite aspect to be the bureaucracy at TU Delft, which they attributed to the organisational structure within the Netherlands.

> *P1: "The thing I hate the most about my job is the bureaucracy. Dealing with administration, paperwork and forms. Working with the materials we work with and also having many people in our lab makes it a bit trickier, but just in general paperwork can become tedious. The Dutch system is quite bureaucratic in my opinion […] applying for grants takes a lot of time […] for the grant writing it's not the forms and paperwork that's annoying so much. It's the low probability of success of them. You write a lot, but only a fraction of the applied grants are successful."*

The external Biodesigner found that the implementation of discoveries of TU Delft is too low.

> *P6: "There's a really small percentage of the patented discoveries of TU Delft that are actually implemented. That's problematic, there's not enough structure around the implementation of discoveries."*

In addition to that, P6 mentioned that there are many policies to take into account when working together with a university. When working alone, these policies are less strict but all the responsibility lies with P6.

> *P6: "When you work through a university you have a lot of policies to take into account […] working together with TU Delft, I was more limited when I said they were supplied by TU Delft than when I would have ordered them myself and grown them in my atelier […] For example, I could not send it somewhere and I had to bring it personally or I needed someone from the university to bring it […] I feel a responsibility [when working with living materials][…] I would not want to do that […] on my own responsibility alone."*

However, working together with a university also means that P6 can use the network of that university.

> *P6: "But it also had advantages, because officially you're not supposed to send organic living material intercontinental for example to the United States. But for instance, you could send it from Gent University to Harvard because they can send organic material to other universities and then Harvard could send it to the Cooper Hewitt Museum. So, sometimes it also creates opportunity, and sometimes it limits."*

Working with Living Material

The final analysis theme explores the perspectives of the interviewed Biodesign experts regarding their experiences and opinions on working with materials that incorporate living organisms.

As mentioned in the previous theme, Participant 1 expressed that dealing with the paperwork is harder due to the materials Team A works with.

> *P1: "Working with the materials we work with […] in our lab makes [dealing with administration, paperwork and forms] a bit trickier."*

Next, P1 mentioned that developing durable and green materials will have a positive impact on society and science worldwide.

> *P1: "A flavour of my work is to develop materials in a way that is scalable and useful for the world, this helps science because then the science we are developing has a nice impact on the world. This also means that afterwards, if people want to take it on, there is a commercialisation potential."*

Participants 2, 4 and 6 related that working with living material can increase the uncertainties scientists already face when doing research.

P2: "[Uncertainty] is not inherent to this project alone. This applies to all research fields […] it is part of this job because we are doing something that no one has done before […] there's always some uncertainty. When you are doing research at the edge of what's possible the more it might never work […] many times you wonder what to do and ask yourself will it ever work? And if it does then you are extra happy […] I learned to deal with failure because it is quite normal. The first time you encounter failure, you might get discouraged […] after a few times, you get more used to it […] if things work the first time I am surprised and did not expect that to happen and I even get suspicious."

P4: "If you're doing practical work, always something goes wrong. I think it's part of that type of research. So, everybody could share that with each other. It is a bit like the first pancake, when building something, it's sort of a rule in the book, everything has to go wrong a few times before it goes right. Especially if you're working on a new subject. Living materials is a subject where knowledge is lacking, so you have to share knowledge with each other, but you can also share a lot of emotions with group members when something goes wrong."

P6: "My designs contain living things and living things can get sick and die. It's just a fact and some institutes really accept it and […] they just put a note up saying "it died" and they understand that it is one of the things that can happen with these designs."

The third and sixth participants elaborated on the positive side of working with and creating new living materials.

P3: "I liked that it's innovative, being a part of making living materials. The whole idea of having living materials is fascinating […] it's cutting-edge technology, to make a material that is alive but still has material-like properties."

P6: "The most circular idea that I had heard, that used nature [about using living cells to make biofuels]."

The PhD candidate of Team C and the external Biodesigner expressed that collaborating with people was difficult due to the novelty of living materials.

P5: "It's difficult to establish the link [with people from outside my lab]. When my question is too specific, then usually the answer is "Sorry I'm not an expert in what you ask and I cannot give you any answer". For example, I tried to e-mail some PhD students from another faculty because I had some questions. But they didn't want to talk with me, because my questions were a bit far from what they were working on."

P6: "If you are a little bit like me, working on your own, it becomes very difficult. Especially when working with scientific or living materials, producers and galleries cannot produce that easily."

Lastly, P6 expressed that it is difficult to make people accept designs that incorporate living organisms into our daily lives. P6 thinks that Biodesigners can form the bridge between science and application.

P6: "When we drink beer we are drinking an organism, yeast. We completely accepted that, but in a lot of cases something which is alive, we find very difficult and weird to introduce into our daily lives. So, I think biodesigners should try to make this more approachable."

The results of the expert interviews presented in this phase will serve as a foundation for the discussions in the next chapter, the "Define" phase. In Chapter 3, the analysis of these interviews will be conducted, exploring the key insights that will form the subsequent stages of this research. Building upon this knowledge from the expert interviews, the next phase will provide a comprehensive understanding of the factors influencing team effectiveness in the Biodesign field.

3. Phase 2: Define

The goal of the “Define” phase was to form a problem statement in the Biodesign field. For this, six expert interviews were conducted. The interview questions, described in the interview protocol, were linked with the literature on team effectiveness, hierarchy, disciplinarity, participation and social networks. The data obtained from the interviews were used to fill the gaps in the literature study and link the themes to situations or problems indicated by the experts in the Biodesign field, ultimately defining the problem statement.

3.1. Integration of Literature and Expert Perspectives

This chapter combines expert opinions from the six interviewed Biodesigners with the relevant literature themes discussed in Section 2.1 to establish a comprehensive problem statement. By intertwining insights from experts with existing literature, a deeper understanding of the research topic emerges.

Subsection 3.1.1 highlights the key findings from the interview analysis, providing valuable insights. In Subsection 3.1.2, a meaningful discussion establishes the link between these findings and the literature. Subsection 3.1.3 addresses the explored challenges in the Biodesign field and their impact on team effectiveness.

Through this analysis, the chapter aims to provide a holistic perspective by integrating expert insights and existing research. It serves as a foundation for formulating the final problem statement proposed in Section 3.2 and contributes to a deeper understanding of the complexities within the field of Biodesign.

3.1.1. Key Findings on Interview Analysis Themes

The purpose of this subsection is to filter and distil the interview findings, focusing on the key insights and conclusions derived from the analysis. Each analysis theme is carefully examined, and concise summaries are provided to encapsulate the significant findings.

Conclusion on Team Size and Setting

The findings from the interviews shed light on the varying sizes of Biodesign research groups. Teams A and B were identified as large teams, comprising approximately 10-20 members, while Team C was categorized as a medium-sized team with around 8 members. It is worth noting that teams and groups in academia can range from as small as two individuals to well over 1000 members, as mentioned in the book “Enhancing Team Effectiveness of Team Science”. Therefore, the key feature “Large Size” can be included as a feature challenging team effectiveness in most Biodesign teams. This feature directly links to the next theme “Diversity of Team Members”.

Conclusion on Diversity of Team Members

As the first, second and fourth participants note, the personal differences between team members can be overcome by shared experiences and group communication. Both P4 and P5 mentioned that international team members might have fewer obligations as they are not originally from The Netherlands. This results in the opportunity to focus more on work and relationships between team members, instead of having to balance this attention between work and personal relationships.

The professional diversity, mentioned by Participants 4 and 3 and that large science teams consisting of subteams with a goal misalignment can result in problems in feeling team cohesion. As related by some of the interviewees, for a team to be effective a common goal is necessary to bridge these different professional backgrounds.

The diversity of team members also brings another challenge to the table. As mentioned by Participant 1, the process in Team A is fluid and reflects the changes in the project's direction over time. This permeability, where a team is flexible and adapts to these changes, is beneficial to the process but can create challenges for effective interactions between team members.

Overall, as expected Biodesign is indeed a diverse field with multiple backgrounds working together in research teams. On one hand, this diversity is needed to reach a common goal but on the other hand, when the common goal is missing, this diversity can have a negative influence on Team Cohesion and Team Climate and might even generate Team Conflict.

Conclusion on Resources and Tools

As described in the previous theme, the unique skill sets members of Biodesign teams bring, can greatly benefit their research projects. However, effective management when facing high team disciplinarity is crucial for a team to reach its common goals. All three teams have implemented a weekly or biweekly meeting set up to keep track of the progress and activities of each individual. These meetings increase the shared understanding of the roles and goals of the separate team members as well as a shared understanding of who knows what. Enhancing this shared understanding positively influences the Transactive Memory and Team Mental Models of these teams. Adding to this, P4 and P6, both emphasised the importance of establishing a network, especially when facilities or tools are lacking, to facilitate efficient collaboration and knowledge sharing.

Conclusion on Leadership

There are several different leadership styles and leading a medium-sized or large team makes it even more difficult to manage all tasks. The PIs elaborated on all the responsibilities they have. All these tasks increase the burden of communication and coordination and result in a busy schedule that needs careful management.

One of the PIs mentioned that they try to be active in the lab to keep track of all that is happening in the lab and with the team members. This leadership style indicates supportive behaviour. Next to this, the PI tries to shift between low (i.e. supporting) or high (i.e. coaching) directive behaviour. One of the interviewees confirmed that the environment in one team felt more motivating and stimulating due to the exemplary role of the PI and that this resulted in a high output of the team. The PI emphasised that a self-supporting network in their team is the ultimate goal and that finding the balance between being too overbearing and giving too much freedom is a constant feedback loop.

The other PI explained how the team members are free to come up with their own interpretations of how to tackle a problem and only when needed the PI will interfere, by doing so opting for a loose delegating (i.e. low directive) or loose directive (i.e. high directive) leadership approach.

One of the interviewees discussed how the feeling of cohesiveness was affected. Even though their PI noted that there is room for open communication, the interviewee mentioned that they

found it difficult to give feedback to their PI and felt that the environment was lacking room to talk about expectations.

Another participant stated that their PI had a more directive approach, where the direction was guided by the beliefs and views of the PI. Even though the decision was made together, the participant often felt there was not enough support from their PI. They noted that this could be due to the busyness of the PI and that as a student you should not rely on the PI too much.

The Postdoc and the external Biodesigner both mentioned that PIs are very busy. The external Biodesigner explained that the priority of a PI lies elsewhere and shifting to a student works best, as they are more flexible.

Lastly, two participants indicated that leadership on the one hand means teaching something new to someone and on the other hand also means learning something from them in return. In their eyes, leadership should be a two-way street.

Conclusion on Hierarchy

The results of the interviews regarding “Hierarchy” in the Biodesign field revealed that there is a formal hierarchical structure in place in most academic, Biodesign teams. There is a clear distinction between leading figures (PIs) and team members (BEP, MEP and PhD students and Postdocs), but as mentioned by one of the interviewees a certain degree of hierarchy is necessary for coordinating the lab work and managing the team.

Three out of the six interviewees emphasized the significance of informal interactions, such as bonding over a beer or having spontaneous hallway conversations, among team members across all hierarchies. These low-key interactions were seen as ideal for generating new ideas or finding solutions to problems.

Moreover, it was noted that grades can create a hierarchical gap between students and PIs, making it difficult for students to express their feelings or influence their PIs' behaviour. Nevertheless, fostering a culture of open communication and low-key interactions can bridge this hierarchical gap and improve team dynamics.

Conclusion on Task Demands and Goal

Having a common goal is important to create a positive team environment, and participants discussed the goals of their respective teams. The fourth participant mentioned how a clear common goal helped Team A to collaborate effectively, while the common goal of Team B was less clear to them. Team composition was also noted to influence team dynamics and task demands. The external Biodesigner highlighted the goal of Biodesign is to keep in mind the user as well as to create an intuitive design that has a visual story. Overall, having a clear and shared goal is important for effective teamwork and team composition can affect the team’s task demands.

Conclusion on Goal Misalignment

Goal misalignment can be caused by personal and professional motivational differences among team members. This personal and professional diversity of "who-finds-what important and why" can result in a lack of team cohesion, cognitive team interaction and team climate, and can increase team conflict.

As mentioned, "Goal Misalignment" refers to situations in which team members have different understandings or priorities regarding the goals of their team. Such misalignments can significantly impact team effectiveness.

For instance, P1 described a case where motivational differences between them and a team member resulted in conflict. This issue was eventually resolved through discussion and restructuring of the project. The three participants of Team B noted that there was no common goal between the two subteams within their overarching team. This lack of a common goal can be detrimental, P4 expressed that the professional knowledge gap between the different subteams made it difficult to see a common goal other than the general goal of doing "research". This goal misalignment resulted in a disparity between the two subteams and affected the feeling of unity in Team B. In "Enhancing the Team Effectiveness of Team Science" the authors note that "*Large science groups composed of subteams that may be misaligned with other subteams […] may also be less cohesive than other teams or groups*." (National Research Council, 2015, p.78). In another case, goal misalignment resulted in frustration, lower team effectiveness, and additional time and effort needed to manage the misalignment.

Overall, interviewees emphasised that goals should be flexible and continuously evaluated throughout the project. Additionally, team members with diverse backgrounds and knowledge gaps may face challenges in offering helpful advice or guidance on research topics.

Lastly, one participant discussed that the goal misalignment changed their own goal to fill the gap between goals.

Conclusion on Relationship to Other Teams

The interviewed Biodesign experts had positive experiences with collaborating with other research teams, as illustrated by the collaboration Team B has with both Team A and C.

Participants noted that working with people from different educational backgrounds and expertise improved their projects and strengthened relationships between teams. However, there were also some negative aspects, such as difficulties in coordinating projects and motivational differences. These challenges sometimes led to mistakes, such as contaminations, but participants emphasised the importance of quick communication and problem-solving to resolve these issues.

Overall, the participants recognised the value of collaboration between teams with different backgrounds but also acknowledged the need for caution and communication in the process.

Conclusion on Organisational Structure

The theme of "Organisational Structure" highlighted various perspectives of the Biodesign experts on the relationship to TU Delft and other organisational structures.

Participant 4 expressed feeling less confident in the academic setting (concerning where they work now) and mentioned that the academic setting had more tolerance for less communication.

The Postdoc of Team B advocated for greater inclusivity of students in university activities, emphasising their significant contribution as the backbone of TU Delft.

Participant 5 noted that it is common for PhD students to exceed the planned duration of their studies, suggesting a need for clearer direction and scope in the early stages of research. Additionally, Participant 5 emphasised the need for a more flexible publishing policy within their faculty to accommodate the unique needs of design-oriented PhD students.

Participant 1 identified bureaucracy as their least favourite aspect of their work at TU Delft, attributing it to the organisational structure in the Netherlands. The external Biodesigner highlighted the low implementation rate of discoveries from TU Delft and discussed the challenges and advantages of working with a university, including adherence to policies and access to networks.

These insights underline the importance of addressing organisational aspects to enhance collaboration and efficiency within research and academic environments.

Conclusion on Working with Living Material

To conclude the findings of this theme, working with living materials can give rise to extra policies and Biodesign experts have to take these into account. Biodesign is also a novel research field, which can result in an increase in uncertainties and difficulties when looking for the right people to collaborate with. Furthermore, the Biodesign experts highlighted the positive aspects and the potential impact on science and society, linking this theme to Transdisciplinarity. Lastly, they emphasised the difficulty of making people accept designs that have living organisms added to the material. The external Biodesigner said that the role of Biodesigners lies in bridging this gap.

3.1.2. Discussion: Linking the Interview Results to the Literature

This subsection will draw connections between the results of the interviews and the literature themes explored in the "Discover" phase: Transdisciplinarity, Hierarchy, the Layers of Social Networks, Team Effectiveness, and Participatory Design. Although the first four themes were extensively explored in the interviews, the topic of PD was not raised during the interviews. As a result, PD will only be considered as a potential solution to one of the problems discussed in the interviews.

The View of Biodesign Experts on Transdisciplinarity

As mentioned in the literature study, Biodesign can be seen as a Transdisciplinary research field, where scientific approaches are absorbed, multiple disciplinary methods are integrated and society is impacted by the created products, courses, materials and companies (Bandoni, Almendra, & Forman, 2022). The results of the interviews indicate that this statement is true, but there are several challenges linked to this Transdisciplinarity as well. Figure 14 depicts the six most prominent analysis themes that are related to Transdisciplinarity.

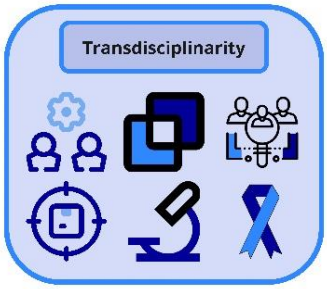


Figure 14 The Six Analysis Themes that are Connected to Transdisciplinarity in Biodesign

The theme of *Diversity of Team Members* showed that Biodesign teams are indeed diverse in personal and professional backgrounds, as expected. In all researched teams, collaborations between people with different expertise were needed to reach the goal of the respective teams. Diversity was also seen as something positive by most interviewees.

However, when this diversity becomes too high and there is no common goal and/or work ethics lie too far apart, conflicts between team members can arise and the team's cohesion and climate can suffer from that as well. The personal differences between team members can be overcome by shared experiences and group communication. This is an example of implementing the "Symbolic Convergence Theory" (Bormann, Cragan, & Shields, 2001) and the levers that increase *Team Cohesion* and *Team Climate* that improve team member interactions and leadership skills (National Research Council, 2015). The problem of professional diversity is described in "Enhancing the Team Effectiveness of Team Science". Here it is asserted that large science teams consisting of subteams with a goal misalignment can experience problems in team cohesion (National Research Council, 2015). However, differences in professional background are important in transdisciplinarity where the common goal can be tackled by using different expertise and "way-of-thinking".

Adding to this, *Team Size and Role/Setting* were researched and the teams were all large or medium-sized. "Large Size" is a key feature of teams that can pose challenges to Team Effectiveness but also adds to the diversity between team members (National Research Council, 2015). The PI of Team A also discussed that due to the transdisciplinarity in the team, there is plenty of opportunity for linking team members to each other and changing these links if the goal changes. This permeability can be challenging as it can foster a burden for group interactions (National Research Council, 2015).

Furthermore, the results from the theme *Resources and Tools* indicated that the diverse skill sets mentioned in the previous sections need to be effectively managed. The researched Biodesign teams hold weekly or biweekly meetings to coordinate and manage the team's tools and resources. This benefits the *Transactive Memory* and *Team Mental Models* of the Biodesign teams.

All of these factors (diversity, team size, and resources and tools) need to be taken into account when defining the *Task Demands and Goal* of the team. The goal of the teams varied between "research-driven" and "application-driven" (i.e. "curiosity-based" and "application-based" research (Robinson, 2019)). One of the participants explicitly highlighted a significant gap in the Biodesign field, emphasising that while research efforts are substantial, the practical application of Biodesign lags behind. Participants 1, 4, 5, and 6 specifically focused on application-based research, contrasting with traditional biologists who tend to prioritise curiosity-based research. From their perspective, the designers appeared to possess a more realistic outlook due to their diverse experiences.

Relationship to Other Teams is important in Biodesign and especially to foster its transdisciplinarity. The external Biodesigner stressed that working with people, who are experienced in manufacturing and application or have the facilities P6 is missing, is necessary to create these living designs. Collaborations between different teams in Biodesign bring together scientists and designers, fostering creativity and problem-solving. However, this collaboration also brings challenges when looking at the geographic dispersion of the teams. As mentioned, "Fungi Gate" is a good example of how miscommunication and different protocols in separate teams can result in mistakes.

As mentioned, *Working with Living Material* catalyses a field where transdisciplinarity plays a central role. Only by combining various disciplines (e.g. biology, design, material science) can

researchers achieve the threefold goal of Biodesign: creating materials that are sustainable and circular, creating awareness of the field and forming a bridge between science and society.

All in all, the participants mentioned that diversity amongst team members is necessary to work in a field that incorporates living organisms in materials and that this challenge can be overcome by sharing experiences with and open communication between team members. Having a common goal is necessary for a transdisciplinary team to work, as mentioned in Subsection 2.1.3 (Tress, Tress, & Fry, 2005). Large teams that miss this common goal often have a lack of *Team Cohesion* and *Team Climate* and this can generate conflict between team members (National Research Council, 2015). Furthermore, advocating for a common goal is highly recommended, as the knowledge gap between stakeholders can be closed by combining problem-solving skills with creative thinking and managing the geographic dispersion between the separate teams.

The View of Biodesign Experts on Social Networks

In Figure 15 below, the analysis themes are associated with the corresponding "Layers of Social Networks" level to which they pertain

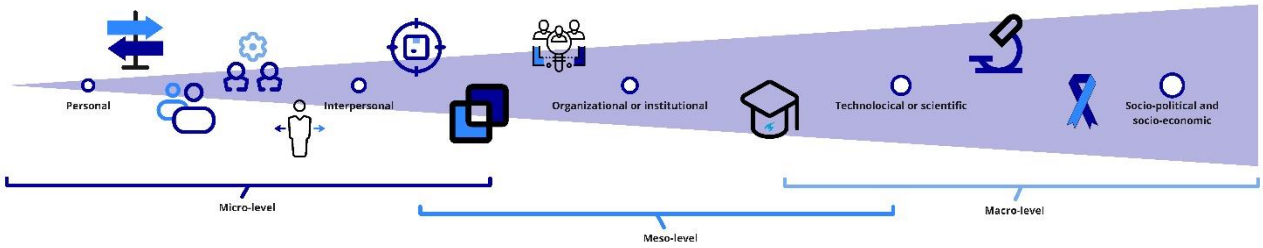


Figure 15 The Analysis Themes and the Level of Social Network they pertain to

Goal Misalignment, Team Size and Setting, Hierarchy, and Leadership are classified under the micro-level. The following bullet points provide a brief overview explaining this classification:

- The *Team Size & Setting* of Biodesign teams can be directly linked to the micro-level as this theme influences the team dynamics on a personal and interpersonal level,
- *Goal Misalignment* was mostly seen by the Biodesign experts as a difference in personal or professional motivation, leading to interpersonal conflicts within their research teams,
- *Leadership* in the Biodesign teams is closely linked to team dynamics and interpersonal social interactions between team members and their PI, thus positioned on the left side of the interpersonal social networks,
- Similarly, *Hierarchy* can be associated with the group dynamics of teams in the Biodesign field. It is a paradoxical feature as excessive rigidity creates a significant hierarchical gap and hinders the emergence of low-key interactions, while insufficient hierarchy results in a lack of clarity in roles and responsibilities.

The themes of Task Demands and Goal, Diversity of Team Members, and Resources and Tools can be linked to the transition phase between the micro and meso-levels or between the interpersonal and organisational levels. The reasoning behind their placement between these layers is elaborated below:

- The personal *Diversity of Team Members* is associated with the interpersonal dynamics of team members in the Biodesign field. However, it is positioned on the right side of the

interpersonal social networks because Biodesign teams draw diversity from various disciplines and organisations,

- The *Task Demands and Goal* of Biodesign teams revolve around applying their scientific knowledge in a societal context. However, due to the relatively new nature of the Biodesign field, broad application remains challenging. Currently, awareness serves as the bridge between science and society, justifying its placement between the interpersonal and organisational/institutional levels,
- Likewise, *Resources and Tools* can be linked to personal skills and motivations. However, considering the transdisciplinarity of Biodesign, it is more appropriate to position this theme on the right side of interpersonal social networks.

The theme of *Organisational Structure* is positioned on the right side of the organisational social network. This placement is justified by the insights provided by the Biodesign experts, underlining the significance of addressing organisational aspects to enhance collaboration and efficiency within research and academic environments.

Relationship to Other Teams is associated with the macro-level and can be linked to the technological/scientific social network, whereas Working with Living Materials connects to both the technical/scientific as the socio-political/socio-economic social network layer:

- The Biodesigner's *Relationship to Other Teams* holds great importance in this transdisciplinary field, involving collaboration with scientific/technological teams from different backgrounds,
- *Working with Living Materials*, i.e. Biodesign, serves both scientific/technical and socio-political/economic purposes.

Overall, the themes impact the formation, structure, and dynamics of social networks within Biodesign teams and organisations.

The View of Biodesign Experts on Hierarchical Structures and Leadership

The themes that gave more insight into the hierarchical structures and leadership styles in the Biodesign field are Leadership, Hierarchy and Organisational Structure, which are depicted in Figure 16.

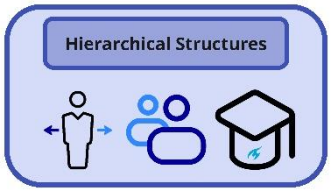


Figure 16 The Three Themes Linked to Hierarchical Structures in Research

The analysis theme of *Leadership* shed more light on how leaders in the Biodesign field empowered their team's effectiveness. The PIs described their responsibilities and the challenges of managing a medium-sized or large team and mentioned that leadership needs to be fluid and adaptable to the needs of their team members. Various leadership styles were used, with some PIs adopting a supportive and directive approach while others allowed more freedom for team members to tackle problems. The importance of finding a balance between being too overbearing and giving too much freedom was emphasised. Feedback from team members indicated that the leadership style influenced team cohesion and output. The busy schedules of PIs were mentioned as a factor impacting support and communication. Participants also highlighted the importance of leadership as a two-way street, involving teaching and learning from team members.

In terms of *Hierarchy*, the interviews revealed the existence of a formal hierarchical structure in most Biodesign teams, with clear distinctions between PIs and team members. A certain degree

of hierarchy was considered necessary for coordination and management, linking to the literature discussed in Subsection 2.1.3. Low-key interactions among team members, including bonding moments, were seen as conducive to generating new ideas and solutions. The hierarchical gap created by grading systems was acknowledged, affecting students' ability to express themselves or influence their PIs' behaviour, drawing parallels to the historical event in 1977 elaborated on in Section 2.1 (Nance, 2008). However, fostering open communication and low-key interactions was seen as a way to bridge this gap and improve team dynamics.

Regarding *Organisational Structures*, the perspectives of Biodesign experts highlighted various aspects related to their relationship with TU Delft and other organisational entities. Challenges such as bureaucracy, the need for clearer direction in the early stages of research, and flexible publishing policies for design-oriented PhD students were discussed. The importance of inclusivity, collaboration, and efficient organisational practices within research and academic environments was emphasised. These insights suggest the need to address organisational aspects to enhance collaboration and effectiveness in these settings.

Side Note: Participatory Design

Participatory design approaches have not yet been fully integrated into the Biodesign field, as revealed by the interviewees. Notably, none of the participants mentioned actively involving users in their design processes. However, an external biodesigner shared an interesting observation, mentioning that during their project, a user and private client expressed interest in purchasing one of their designs without the living material component. Moreover, PD could be an interesting way to tackle the question of what is a realistic application for users when implementing Biodesign in everyday life.

3.1.3. Team Effectiveness and the Challenges of the Biodesign Field

In the following subsection, the analysis themes will be linked to Team Effectiveness through the adapted version of McGrath's IPO Model, depicted in Figure 4.

Cognitive Team Processes in the Biodesign Field

The cognitive subgroup comprises five cognitive team processes: *Transactive Memory, Team Mental Models, Team Climate, Psychological Safety,* and *Cognitive Team Interactions*. In the following list, we establish the connections, depicted in Figure 17, between each cognitive team process and the themes analysed in Biodesign:

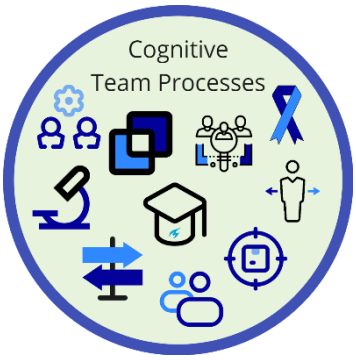


Figure 17 The Biodesign Analysis Themes that can be linked to the Cognitive Team Processes

- *Transactive Memory* refers to the shared understanding of how unique knowledge is distributed among team members or groups. Examining the interview data, it is evident that Transactive Memory in the Biodesign field faces challenges due to high diversity, large team size, and the distribution of resources and tools across different faculties at TU Delft. Therefore, it can be associated with the analysis themes of Team Size and Setting, Diversity of Team Members, Relationship to Other Teams, Working with Living Material, and Resources and Tools.
- On the other hand, *Team Mental Models* represent the shared understanding of goals, responsibilities, and tasks of each team member. In Biodesign, this team process can be

linked to the analysis themes of Leadership, Hierarchy, Task Demands and Goal, Goal Misalignment, and Diversity of Team Members. The interviewees explained that aligning goals can be challenging due to motivational differences (e.g., work ethics), the diversity among team members (application vs. curiosity-based research), and leadership (directive vs. supportive).

- *Cognitive Team Interactions* are the processes in which team members actively engage (e.g., problem-solving). All interviewees mentioned that their teams participate in team meetings to plan, coordinate, and manage resources, tools, and projects, even when collaborating with other research teams. Therefore, this team process is connected to Resources and Tools, Leadership, Diversity of Team Members, and Relationship to Other Teams.
- *Team Climate* shapes the overall behaviour and culture of a team. As mentioned in the literature, leaders have a significant impact on this dynamic, which was further emphasised during the interviews. In this context, Team Climate can be linked to Leadership, Hierarchy, and Organisational Structure.
- The *Psychological Safety* of a team is the shared understanding that each team member can safely contribute ideas and learn from mistakes. Inclusion in a team plays an important role in this team process. A lack of inclusion results in distrust and an increased feeling of disparity among team members, including their leader. Multiple interviewees advocated for inclusion and low-key interactions to increase this feeling of safety.

In conclusion, the cognitive team processes, Transactive Memory, Team Mental Models, Cognitive Team Interactions, Team Climate, and Psychological Safety, are all important in the Biodesign field. Transactive Memory faces challenges due to diversity, large team size, and resource distribution. Team Mental Models involve aligning goals amidst motivational differences and diversity. Cognitive Team Interactions involve active engagement in problem-solving and coordination. Team Climate is shaped by leaders and connected to leadership, hierarchy, and organisational structure. Psychological Safety emphasises inclusion and low-key interactions to foster trust and reduce disparities among team members and their leaders. These cognitive team processes play crucial roles in promoting effective collaboration and performance in Biodesign.

Motivational Team Processes in the Biodesign Field

The motivational team processes include *Team Cohesion, Team Efficacy,* and *Team Conflict*. These processes are interlinked with various analysis themes in the field of Biodesign, as illustrated in Figure 18 and below:

Figure 18 The Biodesign Analysis Themes that can be linked to the Motivational Team Processes

- *Team Cohesion* refers to the collective sense of unity and connection among individual team members within a team. Throughout the interviews, the participants highlighted the significant influence of inclusion and psychological safety on group dynamics. They further elucidated that a lack of a common goal contributed to a decline in Team Cohesion. Hence, this team process can be correlated with the analysis themes of Diversity of Team Members, Relationship to Other Teams, Organisational Structure, Hierarchy, and Leadership.
- *Team Efficacy* reflects the collective perception among team members regarding their team's ability to successfully achieve the common goal by effectively fulfilling the task demands. In

the context of Biodesign, Team Efficacy can be associated with themes such as Task Demands and Goal, Goal Misalignment, Working with Living Material, and Diversity of Team Members. For instance, one of the interviewees explained that when working with living materials, it becomes vital to remain flexible in setting goals and adjust their difficulty based on the belief in their attainability.

- *Team Conflict* encompasses three distinct types of conflicts: task conflict (related to content and outcome), process conflict (related to responsibility and role), and relationship conflict (related to values, personalities, and norms). The findings from the interviews confirmed that relationship and process conflicts are not uncommon in the Biodesign field. The interviewees explained that such conflicts hindered satisfaction, trust, and commitment within the teams. Consequently, Team Conflict can be associated with analysis themes such as Diversity of Team Members, Goal Misalignment, Hierarchy, Leadership, and Relationship to Other Teams.

In the Biodesign field, team dynamics are influenced by three motivational processes: Team Cohesion, Team Efficacy, and Team Conflict. Team Cohesion relies on the inclusion and psychological safety of team members, while a lack of a common goal can weaken the cohesion of Biodesign teams. Team Efficacy involves the collective perception of achieving goals, adaptability to task demands and diverse team settings. Team Conflict encompasses task, process, and relationship conflicts, impacting satisfaction, trust, and commitment. These motivational team processes relate to Biodesign themes such as diversity, goal alignment, hierarchy, leadership, and relationships with other teams.

Behavioural Team Processes in the Biodesign Field

The behavioural team processes consist of two team processes: *Team Process Competencies* and *Team Self-Regulation*. These processes focus on how team members act to combine their unique expertise and skill to translate resources into the team's task demands (National Research Council, 2015).

Figure 19 The Biodesign Analysis Themes that can be linked to the Behavioural Team Processes

The themes linked to the two behavioural processes are depicted in Figure 19 and further explanation is given in the following paragraphs:

- *Team Process Competencies* are concentrated around key activities in each phase of the team's workflow. During the transition phase, these competencies focus on the preparation, strategizing of goals, task management, and reflection and feedback. In the action phase, the competencies shift towards coordination and monitoring progress. Finally, in the interpersonal process phase, the competencies revolve around motivation and conflict resolution. Aligning all these phases across the team positively influences team effectiveness. The Biodesign experts mentioned that often there was a misalignment of goal or noise when conveying a message from one discipline to the other. This highlights the importance of good communication and giving or receiving feedback on ongoing projects. Hence, this team process and its three phases can be correlated with the analysis themes of Team Size and Setting, Diversity of Team Members, Resources and Tools, Goal Misalignment, Task Demands and Goal, Hierarchy, Relationship to Other Teams, and Leadership.
- *Team Self-Regulation* is the process that relates to resource selection to perform tasks and reach the common goal of the team. In the context of Biodesign, Team Self-regulation is

mostly associated to themes such as Resources and Tools, Task Demands and Goal, Goal Misalignment, Working with Living Material, Diversity of Team Members and Relationship to Other Teams. For instance, during one of the interviews, an interviewee highlighted the benefits of forming a network with other research teams, as it provides opportunities to use resources and tools from those teams. However, it also introduces challenges such as increased coordination efforts and a higher likelihood of mistakes.

The behavioural team processes in this study include Team Process Competencies and Team Self-Regulation. The Biodesign experts noted the importance of effective communication and feedback to address goal misalignment and message noise between disciplines. Team Process Competencies and its three phases correlate with analysis themes including Team Size and Setting, Diversity of Team Members, Resources and Tools, Goal Misalignment, Task Demands and Goal, Hierarchy, Relationship to Other Teams, and Leadership. On the other hand, Team Self-Regulation relates to resource selection for tasks and achieving the team's common goal, in the context of Biodesign, it is associated with themes such as Resources and Tools, Task Demands and Goal, Goal Misalignment, Working with Living Material, Diversity of Team Members, and Relationship to Other Teams. Forming networks with other research teams offer benefits but also poses challenges in terms of coordination efforts and the increase of potential mistakes.

The Seven Key Features That Pose Challenges to Biodesign Teams

Lastly, all ten Biodesign themes can be connected to at least one of the seven Key Features that pose challenges to team effectiveness, as shown in Figure 20.

The seven Biodesign team features, along with the Biodesign dimensions derived from the interpretations of the six expert interviews, are as follows:

1. *Large Size*: Large (+10),
2. *Permeability of Team and Organisational Boundaries*: Fluid,
3. *Knowledge Integration*: Transdisciplinary,
4. *Diversity of Membership*: Heterogeneous,
5. *Geographic Dispersion*: Co-located and/or Globally distributed,
6. *Task Interdependence*: Low and High,
7. *Goal Alignment with Other Teams*: Aligned and Divergent.

The following paragraphs provide a more detailed explanation of how these features pose challenges to Biodesign teams, drawing from the insights detailed by the Biodesign experts as well as the ones presented in "Enhancing the Effectiveness of Team Science" (National Research Council, 2015).

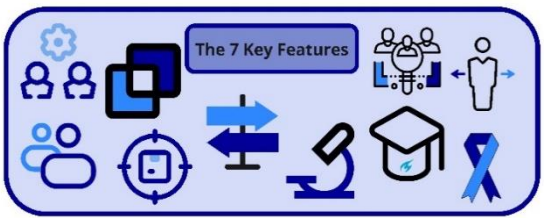


Figure 20 All of the Analysis Themes link to the 7 Key Features that pose Challenges to Team Effectiveness

As mentioned, the teams in the biodesign often consist of more than 10 team members, thus including the feature *Large Size*. The external Biodesigner was an exception to this, however, they work closely together with larger teams. As explained in "Enhancing the Effectiveness of Team Science", larger team size can enhance productivity by distributing the work but also increases the burden of communication and coordination. In these teams, scientists have fewer opportunities for face-to-face interactions, which can result in feeling less safe in or included by the team and in a decrease in a shared understanding of project goals and roles.

The second feature, *Permeability of Team and Organisational Boundaries*, was also discussed by the Biodesign experts. All the participants mentioned that the Biodesign field is characterised by uncertainties and changes in goals, which contribute to the need for a high fluidity of team and organisational boundaries. While this permeability offers the advantage of aligning expertise with emerging scientific or translational issues, it can also present obstacles to efficient team or group interaction.

In Subsection 3.1.1, the transdisciplinarity of Biodesign was extensively discussed, providing a thorough exploration of the highly diverse nature of Biodesign and the challenges this poses for the *Knowledge Integration* between team members or larger groups across the boundaries of their disciplines.

The *Diversity of Membership* is highly heterogeneous in the field of Biodesign, both on the personal as well as the professional level. The presence of diverse team members with varying backgrounds and expertise can lead to a lack of shared vocabulary, creating difficulties in effectively communicating research goals and determining collaborative approaches to accomplish scientific tasks.

As explained by the Biodesign experts, *Geographic Dispersion* is relevant in the Biodesign field. Teams can be dispersed over multiple locations, such as laboratories, faculties, universities, and even countries. While accessing expertise, scientific instrumentation, datasets, or valuable resources from different institutions can be advantageous for Biodesign teams, it also introduces challenges related to increased reliance on electronic communication methods. Additionally, coordinating work across institutions with diverse work styles, time zones, and cultural expectations regarding scientific work can prove to be challenging.

Task Interdependence in Biodesign teams varies between low and high levels. Some experts faced challenges in finding external assistance due to the uniqueness of their projects, resulting in feelings of loneliness and added pressure. However, within the team, there was a high level of interdependency as members collaborated towards a shared goal. Greater task interdependence among team members can lead to increased conflict, especially when geographically dispersed members are involved, requiring additional coordination and communication efforts (e.g. Fungigate).

The final feature, *Goal Alignment with Other Teams*, varied in terms of alignment. The overarching goal of Biodesign, which involves conducting research and developing applications for living materials, was well aligned. However, there were instances of misalignment due to motivational differences among team members and/or external parties. When goal misalignments emerge, this can lead to interpersonal conflicts that require careful management.

In summary, the seven key features of Biodesign teams pose challenges to their overall effectiveness. The features include large team size, permeable boundaries, transdisciplinarity, diversity of membership, geographic dispersion, task interdependence, and goal misalignment with other teams. The resulting challenges range from communication and coordination issues to conflicts arising from differing motivations and limited shared understanding. Overcoming these challenges is vital for successful collaboration and innovation in Biodesign.

3.2. Problem Statement

In Chapter 3.1, the characteristics of Biodesign have been explored from the perspective of Biodesign experts, providing valuable insights into the field. The themes explored in the literature, including disciplinarity, layers of social networks, hierarchical structures and leadership, and participatory design, provide valuable insights into how they affect overall team effectiveness in the Biodesign field.

Transdisciplinarity, as a key theme, highlights the importance of diversity among team members in working with living organisms in materials. Overcoming the challenges associated with diversity requires sharing experiences and fostering open communication within the team. Goal alignment is crucial for transdisciplinary teams to work effectively, and misalignments can lead to conflicts among team members. Additionally, managing geographic dispersion and combining problem-solving skills with creative thinking are essential for achieving success in transdisciplinary collaborations.

The theme of social networks reveals the impact of goal misalignment, team size and setting, hierarchy, and leadership on team effectiveness. The size and setting of Biodesign teams directly influence team dynamics, while goal misalignment can lead to interpersonal conflicts. Effective leadership, characterized by fluidity and adaptability, plays a significant role in team cohesion and output. Hierarchical structures, when balanced, promote low-key interactions and generate new ideas, but excessive rigidity can hinder communication and role clarity.

The organisational structure theme highlights the importance of addressing organisational aspects to enhance collaboration and efficiency within research and academic environments. Challenges such as bureaucracy, the need for a clearer direction, and flexible publishing policies need to be addressed to foster inclusivity and effective organisational practices.

The themes also impact the formation, structure, and dynamics of social networks within Biodesign teams and organizations. The relationships with other teams and working with living materials have implications at the macro-level, involving collaboration with scientific/technological teams and serving scientific/technical and socio-political/economic purposes.

In conclusion, the identified themes have significant implications for overall team effectiveness in the Biodesign field. Transdisciplinary collaborations require goal alignment and effective communication, while social networks need to be carefully managed to optimize team dynamics. Addressing hierarchical structures and organisational aspects is crucial for enhancing collaboration and efficiency. Understanding the impact of these themes provides valuable insights for improving team processes and project outcomes in the Biodesign context.

Therefore, this chapter provides an extensive answer to the second sub-question, "*How do these themes affect the overall team effectiveness in the Biodesign field?*". It is evident that the analysis themes link to the team processes discussed in the literature chapter and play an important role in affecting team effectiveness in the Biodesign field. The topics of Transdisciplinarity, Social Networks, and Hierarchical structures specifically pose challenges to the effectiveness of Biodesign teams.

In this research project, the goal is to address these issues and enhance overall team effectiveness in Biodesign teams. Chapter 4 proposes a tool specifically designed to mitigate the hierarchical gap between students and supervisors. By reducing the hierarchical gap, the tool aims to foster effective feedback exchange, decrease goal misalignment, provide a safe and structured platform for managing projects, and promote a collaborative and inclusive environment.

The proposed tool aims to empower PhD, MEP, and BEP students by offering them a platform that enables them to actively participate in project management, share their feelings and satisfactions, and receive and give constructive feedback to and from their supervisors. By bridging the hierarchical gap and promoting a culture of open communication and collaboration, the tool seeks to optimise team dynamics and enhance overall team effectiveness in Biodesign projects.

4. Phase 3: Develop

In the development phase, the problem statement of the previously described research will be used to design a tool that enables a conversation in the field of Biodesign. The focus lies in increasing awareness of team effectiveness. Several brainstorming sessions were needed to come to an idea that fits the previous research and in the end, a tool was designed to tackle the pressing and topical challenge that lies central in the academic world.

In the first part of this phase, Chapter 4, the boundary conditions are set and discussed. Next, the format options are laid down in Section 4.2 and after some iterations, the right format is selected. In Section 4.3, the final section of the "Develop" phase, the final design is selected and made ready to be tested and validated.

4.1. Exploring: Boundary Conditions

In the next section, the boundary conditions of the proposed tool in the context of Biodesign teams will be discussed. This includes the goal of the tool, the target group, contextual factors, and ethical considerations. Through this section, a comprehensive understanding of the tool's overarching goal will be established, setting the stage for further exploration of its features, implementation strategies, and potential impact on team effectiveness in the subsequent sections.

4.1.1. The Goal of the Tool

Drawing from the insights presented in Section 3.1 regarding the characteristics of Biodesign teams, the goal of the tool is to address the seven key challenges and enhance team effectiveness in Biodesign. The objective is to facilitate effective communication, collaboration, and project management within Biodesign teams by providing a platform that encourages open dialogue, feedback exchange, goal alignment, and inclusive participation.

Effective communication is vital for exchanging ideas, coordinating tasks, and fostering collaboration within Biodesign teams and smooth project management functionalities streamline workflow and enhance team productivity. Open dialogue and feedback exchange promote constructive discussions and improve decision-making within the team. Goal alignment ensures that team members are working towards a common objective, enhancing overall team effectiveness. Inclusive participation fosters a sense of belonging and encourages diverse perspectives, leading to innovative solutions.

Furthermore, the tool seeks to positively influence team dynamics, project outcomes, and the well-being and mental health of team members in the Biodesign field. By addressing team dynamics, the tool aims to enhance collaboration, trust, and cohesion within Biodesign teams. Improved project outcomes are achieved through better coordination, information sharing, and task distribution. Prioritising the well-being and mental health of team members promotes a supportive and healthy work environment.

4.1.2. Target Group

The target group for the proposed tool includes individuals who participate in transdisciplinary collaborations across various hierarchical and social levels, specifically targeting Biodesigners who work in large scientific teams as team members or leaders. The tool is designed to cater to the unique needs and challenges faced by Biodesigners, supporting them in effectively managing their teams and fostering a positive team culture.

However, it is important to acknowledge that the target group often consists of busy technical professionals who may have limited time to dedicate to initiatives like this proposed tool. In the interviews, they recognised the importance of communication but also mentioned having numerous other responsibilities that demand their attention. Moreover, Biodesigners may feel hesitant or uncomfortable stepping outside of their comfort zones.

To address these considerations, the tool aims to provide a supportive environment that encourages users to embrace new practices and approaches, recognising that change can be challenging. Additionally, since most users may not have a communication background, a user manual will be provided to help them effectively utilise the tool. In 0, the User Manual of DFS (2023) is added in the Figure B3.

Taken together, the tool's development takes into account the unique needs and challenges of Biodesigners in large scientific teams while also considering the time constraints and potential discomfort users may experience when stepping out of their comfort zones.

4.1.3. Contextual Factors

As mentioned in Chapter 3, several surrounding themes influence the effectiveness of teams in the Biodesign field. In this subsection, the most prominent factors will be selected and discussed.

Firstly, the transdisciplinarity of team members, encompassing diverse backgrounds and expertise, is a critical factor. While this diversity can foster innovation and problem-solving, it can also introduce challenges such as goal misalignment and reduced team cohesion. Implementing strategies like the Symbolic Convergence Theory, which encourages shared experiences and effective group communication, can help overcome these challenges.

Another crucial contextual factor is the availability and effective management of resources and tools. Access to necessary facilities and the establishment of a network for collaboration and knowledge sharing significantly contribute to team effectiveness. Regular meetings play a vital role in fostering shared understanding among team members, enhancing transactive memory, and developing shared mental models.

Additionally, an emphasis on leadership is essential. The leadership styles within Biodesign teams vary, ranging from supportive and coaching approaches to more directive styles. Finding the right balance between providing support and freedom to team members is crucial for maintaining a productive and cohesive team dynamic.

Connected to this is the presence of hierarchy within Biodesign teams, where a formal hierarchical structure is in place, with leading figures, such as PIs, and team members, including BEP, MEP, PhD students, and Postdocs. While hierarchy can provide coordination and structure, it can also create barriers to communication and hinder open discussions, particularly between students and PIs. Explained was that, low-key interactions among team members and team leaders can foster creativity and idea generation.

Furthermore, clear task demands and a shared goal are essential for creating a positive team environment. Participants emphasised the importance of having a common goal that guides the team's efforts. Goal misalignment, caused by personal and professional differences, can significantly impact team cohesion and increase conflict. Regular evaluation and flexibility in goal setting are necessary to ensure alignment and maintain team effectiveness.

The organisational structure, including the relationship with TU Delft, impacts team dynamics of the interviewed Biodesign experts. Participants highlighted communication tolerance within the academic setting, where the inclusivity of students was identified as an area for improvement.

In conclusion, the contextual factors that influence team effectiveness in the Biodesign field encompass the themes: Diversity of Team Members, Resources and Tools, Leadership, Hierarchy, Task Demands and Goal, Relationship to Other Teams, and Organisational Structure. Recognising and understanding these factors is vital for fostering effective team dynamics and achieving successful outcomes in Biodesign research. By leveraging the benefits of diversity, ensuring access to necessary resources, adopting appropriate leadership styles, managing hierarchy, establishing clear goals, promoting collaboration with other teams, and enhancing the organisational structures, researchers can enhance team effectiveness and contribute to advancements in the Biodesign field.

4.1.4. Ethical Considerations

Ethical considerations hold paramount importance in the development of the proposed feedback tool for the Biodesign field within the scope of this master thesis. To ensure ethical integrity, all data collected will be securely stored on a TU Delft server. Testing, validation, and implementation of the tool will only proceed with explicit user consent. Informed consent will be obtained through a detailed user manual and consent form, empowering participants to autonomously decide their level of involvement.

To ensure fairness and constructive feedback processes, measures will be implemented to prevent discrimination, bias and preferential treatment. The tool will prioritise psychological safety by providing guidelines that promote a supportive and non-retaliatory feedback culture. Continuous monitoring and evaluation will be conducted to assess the impact of the tool on well-being and team dynamics, enabling prompt identification and resolution of any ethical concerns that may arise.

By adhering to these ethical considerations, valuable insights will be gained, and a culture of ethical conduct, privacy protection, fairness, and psychological safety will be fostered in the field of Biodesign.

4.2. Exploring: Collaborative Tools for Biodesign

This section introduces an innovative tool concept, designed to create a safe and constructive feedback environment in Biodesign. Emphasising ethical considerations, the concepts offer features to support collaboration and feedback processes, inspiring researchers and practitioners to enhance teamwork and knowledge exchange. Here, the selected format will be explored, the implemented levers that enhance team effectiveness will be highlighted, and the final tool concept will be presented.

4.2.1. The Tool Format

In this subsection, the focus shifts to the tool format, taking into account the specific contextual factors identified in the previous chapter. One crucial aspect is ensuring the time efficiency of the tool, considering the busy schedules of the participants involved in Biodesign. Additionally, since communication may not be a primary expertise for scientists in the academic setting, a detailed user manual is necessary to ensure the smooth implementation of this communication tool in the field of Biodesign.

To enhance the user experience, the tool should be designed to be user-friendly, featuring an intuitive interface and easy navigation across different digital devices. Furthermore, privacy and security of users' data are essential considerations, with measures in place to store data securely on a TU Delft server, as discussed in Subsection 4.1.4. Scalability and integration with existing systems used by Biodesign teams are also key factors to be considered during the tool's design.

By understanding these factors, the design and functionality of the tool can be shaped to meet the specific needs and constraints of the intended users. This will ultimately create a safe and constructive feedback environment in the field of Biodesign.

4.2.2. Levers to Enhance Team Effectiveness in Biodesign

In Subsection 2.1.2, various “levers” or interventions were identified that can enhance the effectiveness of science teams. Building upon these findings, this subsection establishes a connection between these levers and the specific context of the Biodesign field. By carefully examining the unique requirements and dynamics of Biodesign teams, suitable levers will be selected as a foundation for the development of the tool. This approach ensures that the tool aligns with the specific needs and challenges faced by Biodesign teams, ultimately enhancing their overall effectiveness and collaborative outcomes.

One such lever, supported by research conducted by Pritchard et al. (2008), is the Productivity Measurement and Enhancement System (ProMES; Pritchard et al., 1988). This intervention focuses on improving team regulation through performance measurement and structured feedback. Meta-analytic evidence indicates that teams implementing ProMES experienced a significant increase in productivity (Pritchard, Harrell, DiazGranados, & Guzman, 2008). Furthermore, the need for formal leadership training in science teams has been highlighted in the chapter “Leadership for Team Science,” as many leaders in this domain are appointed based solely on scientific expertise (National Research Council, 2015). Thus, there can be a specific emphasis on the leader-team member interactions as a lever to enhance team effectiveness in the Biodesign context.

Another important lever for enhancing team effectiveness is the development of Transactive Memory and Team Mental Models, which emphasises the significance of shared experiences, training, face-to-face interactions, and effective leadership in shaping early team development. This lever promotes familiarity and fosters a collective understanding of team tasks and goals, positively influencing team processes and overall team effectiveness (Kozlowski & Ilgen, 2006; National Research Council, 2015).

Considering the challenges introduced by many of the seven features of team science described in Subsection 2.1.1, interventions that strengthen cognitive interaction, such as professional development or training to expose teams to different ways of interacting, may be particularly

beneficial for Biodesign teams. By addressing these challenges and bolstering cognitive interaction, teams can overcome obstacles and improve their collaborative performance.

In addition to the aforementioned levers, interventions targeting Team Climate can also have a significant impact. Organisations establish strategic imperatives through policies, practices, and procedures, which define the mission, goals, and tasks of teams (National Research Council, 2015). Furthermore, team leaders play a crucial role in shaping the climate by communicating organisational changes from higher levels of management and emphasising specific aspects to team members (Kozlowski & Doherty, 1989; Zohar, 2000; Zohar, 2002; Zohar & Luria, 2004; Schaubroeck, et al., 2012). Furthermore, by interacting, team members exchange their interpretations, and develop shared understandings of what is important within their specific context (National Research Council, 2015). These interventions can collectively contribute to fostering a positive and supportive team climate, which in turn enhances team performance and collaboration.

By keeping these levers in mind a tool can be designed that focuses on using already existing levers to tackle challenges found in the literature and interviews to enhance team effectiveness in the Biodesign field.

4.3. Developing the Prototype of the Dual Feedback System

This section presents the culmination of the "Develop" phase, where the tool is proposed and discussed, which has been designed to address the contextual factors and leverage the identified interventions for enhancing team effectiveness in Biodesign teams while keeping in mind the needs of the target group. This section outlines the key features, functionalities, and interface of the Dual Feedback System, or DFS, highlighting its potential to support collaboration, facilitate knowledge exchange, and ultimately enhance teamwork in Biodesign projects.

4.3.1. The Dual Feedback System: Key Features

DFS is a tool designed to enhance team effectiveness, project management, and mental health in research projects and serves as a platform where the users can engage in constructive feedback exchanges, represented by the blue arrows in Figure 21. DFS consists of two main components: a satisfaction survey and a feedback meeting.

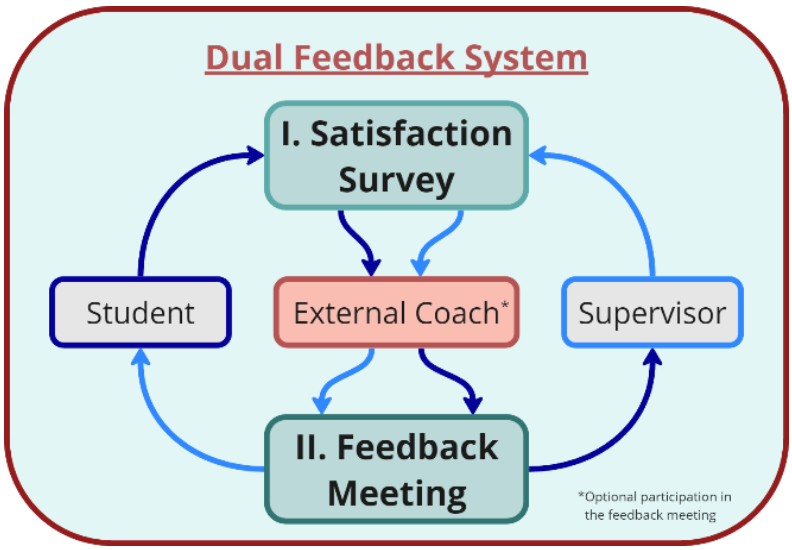


Figure 21 The Dual Feedback System and the Target Users

The Dual Feedback System

The purpose of the Satisfaction Survey is to delve into the user's sentiments regarding the project, teamwork, and their experience of supervision, enabling the identification of potential issues, areas for improvement, and successes. This in-depth exploration sets the foundation for fostering a constructive feedback environment.

The second component, the Feedback Meeting, facilitates a face-to-face interaction. In this meeting, DFS focuses on the lever of team member interaction (i.e. supervisor-student relationship), positive interpersonal climate and conflict management skills. Through collaborative problem-solving, decision-making, and discussions, the Feedback Meeting aims to address challenges uncovered in the surveys, set team goals and promote team effectiveness. It is recommended to integrate the use of DFS into the project timeline, scheduling the Feedback Meetings right after the surveys have been planned and conducted.

By focusing not only on content-related aspects but also on non-content-related elements such as project satisfaction, supervision satisfaction and team satisfaction, DFS aims to improve overall team effectiveness, mental health, and project management. As seen in Figure 21, additionally, DFS implements an external coach to manage the planning and the data acquisition of the Satisfaction Surveys. It also offers the flexibility of involving the coach to assist in conducting the Feedback Meeting, serving as an independent party and further enhancing the feedback process.

The Users

In the context of Biodesign, the target users of DFS include BEP, MEP, and PhD students, Postdocs, and PIs. Figure 22 visually represents the current hierarchical structure among these users, denoted by varying heights, as well as the supervisory relationships indicated by arrows. Upward arrows signify relationships that transcend hierarchical gaps, while downward arrows represent supervisory relationships.

The primary focus of DFS is to enhance communication between the different students and their supervisors, as this relationship holds significant importance in academic research projects and in the Biodesign field. However, DFS can be adapted for use in other types of teams as well, such as the postdoctoral-PI relationship or outside of Biodesign and academia.

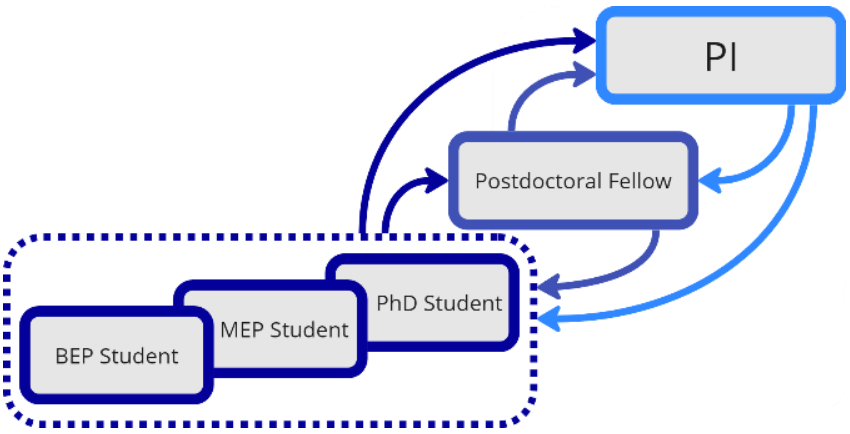


Figure 22 The Users of the Tool and their Hierarchical Structure

As mentioned before, DFS serves as a feedback platform throughout the research project, bridging the hierarchical gap between the users, in this case students and supervisors. In Figure 23, the hierarchical gap is illustrated and the arrows indicate the feedback between student and their supervisor. The left side shows the current or "old" feedback system in the Biodesign field. Here, the most prominent feedback is the feedback from supervisor to student. The reversed feedback is less prominent and happens more on a spontaneous note when students initiate this feedback themselves. On the right side, the Dual Feedback System is depicted. The hierarchical gap is bridged with the help of the two components of DFS and the external coach facilitates a safe environment to overcome this gap.

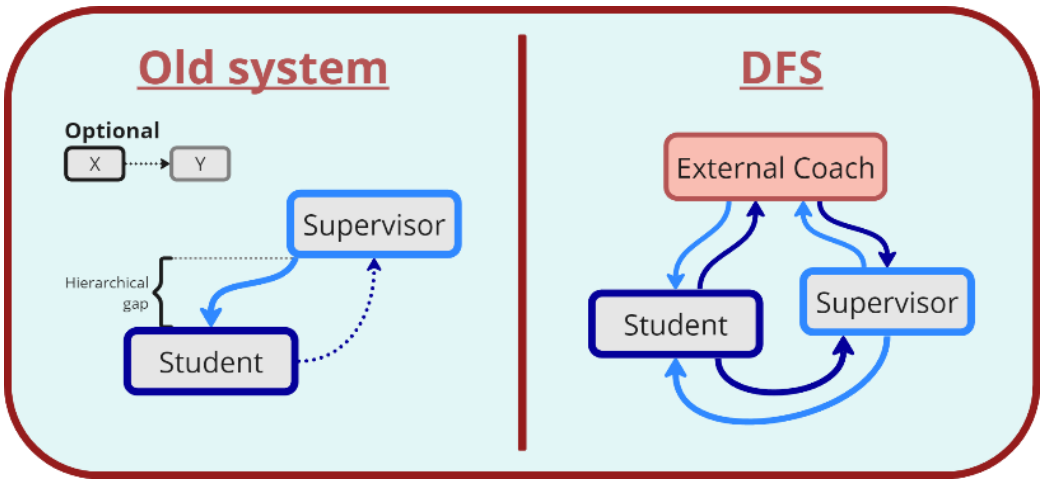


Figure 23 The "Old" Feedback System at TU Delft vs. the Proposed DFS

Part I: The Satisfaction Survey

Part I of DFS is the Satisfaction Survey, divided into three sections, each focusing on a different aspect of teams: Project, Team, and Supervision. The goal of the surveys is to gather detailed information on the satisfaction levels of both student and their supervisors regarding these topics.

Within the Satisfaction Survey, there are eight statements per section, resulting in a total of 24 statements for both the supervisor and the student (or team member). These final statements, along with the corresponding topics they address, are presented in Table 3 for reference.

Table 3 Satisfaction Survey Statements per Topic for Supervisors and Students

Theme	Supervisor Statement	Student Statement
Project Satisfaction	I feel confident about the direction of my student's project	I feel confident about the direction of my project
	I have the feeling that my student's project gives them a feeling of personal accomplishment	My project gives me a feeling of personal accomplishment
	I am happy with the current flow/pace of my student's project	I am happy with the current flow/pace of my project
	I feel like the project is intellectually challenging for my student	I feel like my project is intellectually challenging
	I know what my student's project is about (e.g. Content, goals)	I understand what my project is about (e.g. Content, goals)
	The workload of my student's project is clear to me (e.g. I know what their tasks are)	The workload of my project is clear to me (e.g. I know what my tasks are)
	I am happy with the workload my student has in the project (e.g. I am happy with the number of tasks they do)	I am happy with the workload of my project (e.g. I am happy with the number of tasks)
	I am happy with the way my student uses my feedback on their project (e.g. They implement the feedback in their research project)	I am happy with the feedback I get during my project (e.g. I am happy with the amount of feedback)
Team Satisfaction	I understand what my student's role is in the team	I understand what my role is in the team
	What is their role in the team? Please elaborate.	What is your role in the team? Please elaborate.
	I am happy with the amount of responsibility my student has in the team	I am happy with the amount of responsibility I have in my team
	My student is included by the team (e.g. They are included despite cultural differences)	I feel included by my team (e.g. I am included despite cultural differences)
	I am happy with my student's connectedness with other people in the team (e.g. On a personal level).	I am happy with the connectedness to other people in my team (e.g. On a personal level)
	I am happy with the number of social team activities facilitated (e.g. Friday drinks, lunch, bowling night, (online) bingo night)	I am happy with the number of social team activities I am included in (e.g. Friday drinks, lunch, bowling night, (online) bingo night)
	My student has the opportunity to contribute meaningful ideas to the team (e.g. They get time to speak during meetings)	I have the opportunity to contribute meaningful ideas to my team (e.g. I get time to speak during meetings)
	My student is encouraged to contribute to the team (e.g. Reach a common goal)	I feel encouraged to contribute to my team (e.g. Reach a common goal)
	My student is supported by the team (e.g. Solving problems together)	I feel supported by my team (e.g. Solving problems together, positive feedback)
Supervision Satisfaction	I have given the tools to let my student do their research project well (e.g. laptop, equipment)	I have the tools to do my research project well (e.g. Laptop, equipment)
	I have given the resources to let my student do their research project well (e.g. Money, network, location)	I have the resources to do my research project well (e.g. Money, network, location)
	I make sure to inform my student in time about policies or other changes that affect them (e.g. Meetings, holidays)	I am informed, in time, about policies or other changes that affect me (e.g. Meetings, holidays)
	I value my student for the work they perform during their project (e.g. Give positive feedback when due)	I feel valued by my supervisor for the work I perform during my project (e.g. Receiving positive feedback when due)
	I support my student during their project (e.g. I support them when they come up with new ideas)	I feel supported by my supervisor during my project (e.g. I feel supported when coming up with new ideas)
	I recognise the work of my student (e.g. use of data and authorship)	I feel that the work I do is recognised by my supervisor (e.g. Use of data and authorship)
	I motivate my student	I feel motivated by my supervisor
	I am happy with the amount of supervision I give to my student	I am happy with the amount of supervision by my supervisor

The three survey themes were selected to gather comprehensive insights into various aspects of the project experience. The first theme, “Project”, focuses on the overall perception of the project, encompassing statements that assess the student's and supervisor's views on, for example, the pace or the workload of the project. The second theme, “Team”, explores the student's participation within the team, examining views, such as, their sense of connectedness to the team and the support they receive. Finally, the third theme, “Supervision”, investigates the supervision provided during the project, aiming to understand elements like the perceived level of motivation offered to the student by the supervisor(s).

By addressing these three themes, the survey aims to capture a comprehensive understanding of the project dynamics, team collaboration, and supervisory experiences, linking them directly to the team processes (e.g. Team Cohesion), the key features (e.g. Knowledge Integration), the levers (e.g. Leadership, inclusion, or shared experiences), Hierarchical Structures and Leadership (e.g. team climate), transdisciplinarity (e.g. common goal) and thus, team effectiveness.

Each statement can be scored on a scale of 0 (not satisfied at all) to 10 (extremely satisfied). Additionally, after each statement, provides an opportunity to provide elaborations. These elaborations can serve as reminders during the feedback meeting, explaining the rationale behind the given score or offering additional information for the external coach to consider. Once both surveys are completed, the external coach calculates the average satisfaction scores per theme for both the student and the supervisor and identifies any significant differences. These six extracted averages will be stored in the TU Delft database to track the development of satisfaction of both student and supervisor over time.

In Figure 24, an example is given of this development. Here, a former MEP student filled in their Project Satisfaction every two months (dark blue line). The light blue line represents the student's perception of the supervisor's satisfaction.

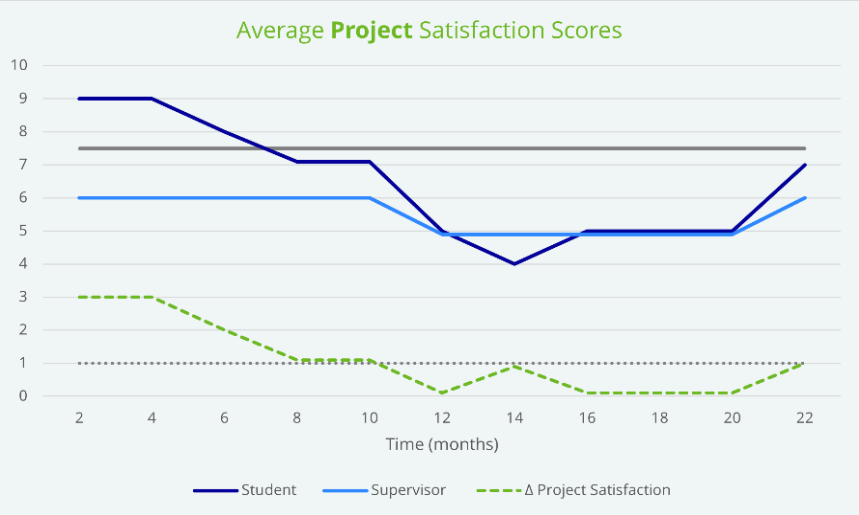


Figure 24 Example of the Average Project Satisfaction of a Former MEP Student and the Perceived Supervisor's Average Project Satisfaction over Time

Furthermore, two benchmarks are introduced. The first benchmark is based on the Employee Satisfaction Index (ESI) baseline proposed in an article published on LinkedIn News (Get Ahead by LinkedIn News, 2022). According to the article, an employee satisfaction score between 7 and 7.9 indicates a high level of satisfaction. In DFS, the aim is to achieve a score of 7.5, representing high satisfaction (dark grey line). When the satisfaction level drops below this upper baseline, it indicates the presence of issues that need to be addressed and discussed during the feedback meeting to find viable solutions.

The second benchmark is the baseline for the point difference (Δ), shown as a dotted green line. This benchmark represents the disparity in satisfaction between students and supervisors over time. When Δ rises above 1 (dotted grey line), it signals the presence of disparity in satisfaction. In such cases, students and supervisors must focus on addressing this gap and discuss potential compromises to close it. This benchmark was determined after brainstorming about the most suitable value.

Part II: The Feedback Meeting

The second part of DFS is the Feedback Meeting, where the student and supervisor come together in a face-to-face interaction to provide and receive constructive feedback on the three themes. The meeting aims to bridge the hierarchical gap and create a safe environment for discussing areas highlighted in the Satisfaction Survey.

As illustrated in Figure 25, the Feedback Meeting can involve only the student and supervisor or include the external coach as well. If the external coach participates, they act as a facilitator to promote a safe environment for constructive feedback.

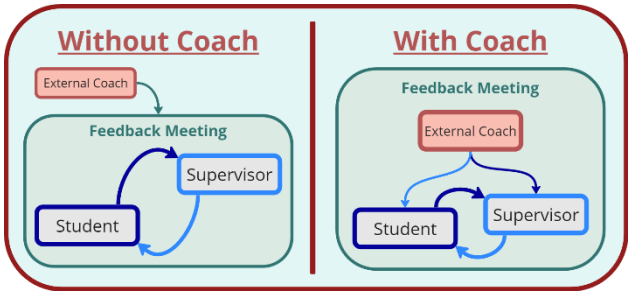


Figure 25 The Two Options of the Feedback Meeting

Feedback plays a crucial role in teams, not only in pathology resident education Jug et al. (2019) elaborated on, but also in Biodesign, where it can foster positive interpersonal relationships through face-to-face interactions and thus, enhance team effectiveness. Therefore, incorporating feedback practices in Biodesign can be essential for students and supervisors to optimize their potential and contribute to effective project management and innovation (Jug, Jiang, & Bean, 2019).

There are various feedback methods available, such as the Feedback Sandwich, the Ask-Tell-Ask, Pendleton, or One-Minute Preceptor method, each with its own advantages and disadvantages (Jug, Jiang, & Bean, 2019). Effective feedback involves creating a respectful interpersonal atmosphere, selecting an appropriate setting, establishing mutually agreed-upon learning objectives, encouraging self-reflection and self-assessment, providing descriptive feedback based on direct observations, and offering suggestions for improvement (Hewson & Little, 1998; Gharib, Rolland, Bateman, & Ellis, 2017). Regardless of the chosen method, feedback should adhere to the following guidelines shown in Table 4 (Jug, Jiang, & Bean, 2019):

Table 4 The Guidelines for Giving and Receiving Feedback, adapted from Jug et al. (2019)

When GIVING Feedback:	When RECEIVING Feedback:
Ask for understanding	Be an active participant
Establish a respectful dialogue	Ask clarifying questions
Label feedback	Recognise unlabelled feedback
Create shared goals	Create shared goals
Develop an action plan	Develop an action plan
Share descriptive, constructive details based on direct observations	Avoid defensive responses
	Identify and avoid triggers

Therefore, it is recommended to involve the external coach in the first meeting to guide the Feedback Meeting and apply a feedback method that suits the discussion and participants' needs. In an article by Ryan et al. (2017), it is highlighted that non-constructive feedback can have negative effects on student's mental health. Therefore, adapting to the needs of the student when using DFS and adhering to the aforementioned guidelines will ensure the well-being of the student (Ryan & Henderson, 2017). Involving the external, independent coach in and even alongside the meetings can further contribute to this process by focusing on cognitive interactions, behavioural management, and increasing the feeling of psychological safety. Additionally, it is recommended for problem-solving and promoting compromise (Luthans & Peterson, 2003).

After the meeting, the student and supervisor plan the new Satisfaction Survey and Feedback Meeting, allowing for ongoing development and follow-up by the supervisor, student, and external coach. The overall goal of these face-to-face meetings is to improve satisfaction, enhance communication, and reduce disparities between students and supervisors, leading to improved team effectiveness, project management, and mental health of both parties during the ongoing project.

4.3.1. User Interface, Integration and Compatibility

The Satisfaction Survey is conducted using Qualtrics, a widely used survey platform at TU Delft, which facilitates seamless integration into the Biodesign and other academic teams at TU Delft. The survey's user-friendly interface features sliders that make navigation and response input intuitive for participants. This platform choice ensures that the “24-statement” survey can be efficiently completed within a reasonable time frame. Moreover, Qualtrics is compatible with various digital devices, such as computers and mobile phones, allowing participants to access and complete the survey conveniently. For a visual reference, the user interfaces for both computer and mobile phone versions are available in Appendix A, respectively Figure B1 and Figure B2.

The collected results from both students and supervisors are processed using Qualtrics. The data is then exported to Excel for further analysis by the external coach. To guarantee data confidentiality, the results are securely stored on the server of TU Delft. These collected responses serve as valuable information for the subsequent Feedback Meeting, where the student and supervisor can make data-informed decisions and address areas of improvement.

4.3.2. DFS as a Lever to Improve Team Effectiveness

DFS leverages some of the recommended interventions for enhancing team effectiveness as proposed in “Enhancing the Effectiveness of Team Science” (National Research Council, 2015) and the ones discussed in Subsection 4.2.2, which identified areas in Biodesign that could benefit from specific interventions.

The incorporated levers in DFS include face-to-face interaction, shared experience, team member interaction, inclusion, positive interpersonal climate, team goals, conflict management skills, and leadership behaviour. The proposed tool integrates and combines these levers to enhance team effectiveness in the Biodesign field, as indicated in bold in Table 5.

Table 5 The adapted table from section 8.1.2, highlighting the levers that are used in DFS

Team Process	Interventions or "levers"
Transactive Memory	**Face-to-face interaction; Shared experience**
Team Mental Models	**Training; Leadership; Shared experience**
Cognitive Team Interactions	**Training;** Team composition
Team Climate	Strategic imperatives - team goals - policies, practices and procedures; **Leadership; Team member interaction**
Psychological Safety	**Leader coaching, inclusion; Positive interpersonal climate**
Team Cohesion	Team composition (theory); **Leadership (theory)**; Antecedants (ambiguous)
Team Efficacy	Mastery experiences; Vicarious observation; Verbal persuasion; **Leader behaviour (theory)**
Team Conflict	Team composition, faultlines; **Conflict management skills**
Team Process Competencies	**Training; Leadership (theory)**
Team Self-Regulation	System design; **Leadership (theory)**

These levers that DFS uses enhance team effectiveness by leveraging the identified themes. The diversity in personal or professional motivations among team members can be effectively addressed by reaching compromises, such as considering Supervision Statement #7 or Project Statement #3, respectively. Resolving issues related to inadequate tools or resources can be achieved through discussing Supervision Statements #1 and #2.

Furthermore, by addressing the themes of Hierarchy and Leadership through the Supervision statements, the hierarchical gap can be bridged, fostering a sense of psychological safety within the team. To tackle the themes of Task Demands and Goal, and Goal Misalignment, relevant project statements such as Project Statement #1 and #5, as well as team statements like Team Statement #1 and #2, can be utilized to ensure alignment and clarity.

Insights gained from the Satisfaction Survey's Team Statements provide further understanding of the theme Team Size and Setting. These statements offer an opportunity for fruitful discussions between students and supervisors, covering aspects such as inclusivity and team cohesion. The theme of Working with Living Materials, while specific to the Biodesign field, can be viewed more broadly, allowing for the exploration of technical challenges within the project using, for instance, Project Statement #3.

Additionally, the Team Statements and statements concerning resources and tools shed light on potential obstacles that students may encounter when collaborating with different teams, including the use of tools from other faculties. This aspect also relates to the overarching theme of Organisational Structure.

By leveraging the themes identified in the preceding chapters and sections, this research aimed to address the last sub-question, "*How can these themes be leveraged to enhance the team effectiveness of a Biodesign research group?*". The insights gained from the analysis of team processes, social networks, hierarchy, disciplinarity, and participatory design contribute to understanding the key factors that impact team effectiveness in the Biodesign context. Furthermore, the examination of specific themes and the utilization of corresponding statements and levers, as discussed in the previous sections, offers a practical approach to enhance team effectiveness within a Biodesign research group.

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5. Phase 4: Deliver

The “Deliver” phase involves utilising the feedback provided by the 14 MEP students to iterate and refine DFS, resulting in a final design. The final design will then undergo validation by testing it with a Postdoc and their supervisor at TU Delft. Additionally, a student counsellor will carefully review the design. The validation and review results, along with the initial iteration tests, will be analysed for convergence in a discussion, marking the conclusion of the research project.

Following the conclusion and discussion of the results, the report will present future recommendations for enhancing team effectiveness in the field of Biodesign. This will involve suggesting strategies and practices to improve collaboration and project management within Biodesign teams. Furthermore, the report will include a personal reflection on the experience gained throughout the project, providing insights into the challenges faced and lessons learned.

5.1. DFS Prototyping: Testing by MEP Students

This section delves into the prototyping process of the Dual Feedback System, focusing on the involvement of 14 (former) MEP students, including the procedures followed to obtain their consent. The feedback provided by these students played a crucial role in refining and iterating DFS, ensuring that the survey effectively captures the relevant dimensions of team effectiveness in the field of Biodesign.

In addition to gathering insights into the students' experiences related to the three themes of the survey (project, team, and supervision), they also provided feedback on the Satisfaction Survey itself. This valuable qualitative data enriches the overall findings of the research and adds depth to the understanding of team effectiveness. This section highlights the importance of respecting and integrating the perspectives of MEP students into the final survey design, which will be further validated in Section 5.2 and 5.3. By incorporating the feedback of these students, the survey becomes more relevant and comprehensive for exploring team dynamics in Biodesign projects.

5.1.1. DFS Prototyping Protocol

This subsection provides an overview of the protocol followed during the DFS prototyping process, including obtaining consent from participants and gathering essential information. The parts within this subsection focus on the consent form and the participants involved in the study.

Prototype Testing: Consent Form

As part of their involvement in testing the Satisfaction Survey of DFS, the students were required to complete a consent form. This form ensured their voluntary participation and provided information on data handling and storage.

A blank copy of the consent form will be included in Appendix C, specifically in Annex C2.

Prototype Testers

The input and feedback for the prototype of DFS were gathered from a group of 14 MEP students who were currently or had previously participated in a Master End Project. Among the participants, eight students had already graduated, and six students were currently engaged in their MEPs. These students were selected from various faculties at TU Delft, covering seven out of the eight faculties. The team sizes ranged from two to five members, as indicated in Table 6.

Table 6 Prototype Testers' Study Status, Number of Team Members, and Faculty at TU Delft

Tester	Status of Studying	# Team Members	Faculty at TU Delft
1	MEP Student	2	Applied Sciences
2	Former MEP Student	5	Mechanical, Maritime and Materials Engineering
3	MEP Student	2	Electrical Engineering, Mathematics & Computer Science
4	Former MEP Student	5	Aerospace Engineering
5	Former MEP Student	4	Industrial Design Engineering
6	Former MEP Student	4	Industrial Design Engineering
7	MEP Student	4	Aerospace Engineering
8	Former MEP Student	4	Technology, Policy and Management
9	MEP Student	4	Electrical Engineering, Mathematics & Computer Science
10	MEP Student	2	Mechanical, Maritime and Materials Engineering
11	MEP Student	3	Civil Engineering and Geosciences
12	Former MEP Student	5	Aerospace Engineering
13	Former MEP Student	4	Mechanical, Maritime and Materials Engineering
14	Former MEP Student	4	Civil Engineering and Geosciences

The information collected from these diverse participants was instrumental in refining the survey's effectiveness and relevance. To maintain confidentiality, participant information will be presented in an anonymous manner.

Analysis of Satisfaction Survey Scores

After the students filled in the Satisfaction Survey prototype, the scores were analysed and processed in Excel. This comprehensive analysis provided a deeper understanding of the students' perceptions and overall satisfaction levels across the three survey themes.

The average scores per statement and the overall average per survey theme, derived from the Excel sheet, are illustrated in Table 7. The table presents an overview of the students' satisfaction levels based on their responses to the survey statements. The eight statement of the Project theme, which is illustrated in Table 3, was added after this prototyping round. Notably, the first Team Statement includes a special elaboration question aimed at capturing alignment between the student and supervisor regarding the student's role within the team.

Additionally, the eighth Team Statement was added later and was only filled in by two students. Since the scores for these two students were considerably low, they are considered outliers and were not included in the calculation of the average Team Satisfaction Score.

To illuminate the students' perspectives on their levels of satisfaction, below a short overview will be given of the most interesting statements per survey theme. In these paragraphs the testers are indicated with their number, for example Tester 2 is T2. Furthermore, T1's feedback did not comprise the additional elaboration on the statements, so only the scores provided by this tester are included.

Table 7 Average Student Satisfaction Scores per Statement and per Survey Theme

Theme	Student Statement	Average Score
Project Satisfaction	I feel confident about the direction of my project	6.57
	My project gives me a feeling of personal accomplishment	5.29
	I am happy with the current flow/pace of my project	4.86
	I feel like my project is intellectually challenging	7.36
	I understand what my project is about (e.g. Content, goals)	7.21
	The workload of my project is clear to me (e.g. I know what my tasks are)	6.29
	I am happy with the workload of my project (e.g. I am happy with the number of tasks)	6.14
	Overall Average of PROJECT Satisfaction of the 14 MEP Students	6.24
Team Satisfaction	I understand what my role is in the team	7.00
	What is your role in the team? Please elaborate.	-
	I am happy with the amount of responsibility I have in my team	6.36
	I feel included by my team (e.g. I am included despite cultural differences)	7.43
	I am happy with the connectedness to other people in my team (e.g. On a personal level)	6.29
	I am happy with the number of social team activities I am included in (e.g. Friday drinks, lunch, bowling night, ...)	4.93
	I have the opportunity to contribute meaningful ideas to my team (e.g. I get time to speak during meetings)	7.29
	I feel encouraged to contribute to my team (e.g. Reach a common goal)	6.14
	I feel supported by my team (e.g. Solving problems together, positive feedback)	1.00*
	Overall Average of TEAM Satisfaction of the 14 MEP Students	6.49**
Supervision Satisfaction	I have the tools to do my research project well (e.g. Laptop, equipment)	8.14
	I have the resources to do my research project well (e.g. Money, network, location)	7.57
	I am informed, in time, about policies or other changes that affect me (e.g. Meetings, holidays)	6.07
	I feel valued by my supervisor for the work I perform during my project (e.g. Receiving positive feedback when due)	6.00
	I feel supported by my supervisor during my project (e.g. I feel supported when coming up with new ideas)	6.86
	I feel that the work I do is recognised by my supervisor (e.g. Use of data and authorship)	6.29
	I feel motivated by my supervisor	6.36
	I am happy with the amount of supervision by my supervisor	6.36
	Overall Average of SUPERVISION Satisfaction of the 14 MEP Students	6.71

*Stament was added later, filled in by T11 (score = 0) and T12 (score = 2)
**Average of all scores, excl. team statement 8

5.1.2. MEP Student Experience: DFS Satisfaction Survey

The MEP student experience with the DFS Satisfaction Survey is examined in this subsection, offering valuable insights into their satisfaction levels and feedback related to their master thesis projects. This survey was conducted to gather feedback and assess the students' perceptions of their experience. The objectives of the survey were to evaluate their satisfaction with the master thesis projects and to obtain specific feedback on the DFS tool.

Satisfaction of MEP students on Project

This part explores the satisfaction of MEP students regarding their projects. The overall satisfaction level with the project topic is relatively low, with an average score of 6.24. The most notable scores related to the statements with regard to personal accomplishment, flow of the project, and happiness with workload as these received low scores.

Regarding the statement of personal accomplishment, students expressed diverse perspectives. Some students expressed a desire for more achievement and felt pressured by high expectations set by TU Delft. They found the current graduation format arbitrary and disconnected from

personal satisfaction. Stress, confusion, and lack of interest in the project content were mentioned as factors hindering the feeling of accomplishment for some students. However, there were also students who set clear learning objectives and felt a sense of accomplishment in meeting them. The choice of topic, project direction, and the distinction between working on the project and its results also influenced students' perception of personal accomplishment.

T2 (score = 2): "I would have liked to do more. And I wanted to achieve more. But that is mainly because of the image created by TU Delft about theses (that you have to do something ground-breaking)."

T3 (score = 3): "The graduation process at TU Delft in its current form is an arbitrary hoop for a society with a fetish for the academic."

The students indicated mixed feelings about the flow and pace of their projects. While some students expressed contentment and a sense of support in their progress, others felt frustrated by the need to backtrack and explore multiple directions that led to dead-ends, resulting in a perception of wasted time. Some students felt stuck and faced barriers they struggled to overcome, disrupting the natural flow they once experienced. Delays and the need to redo work contributed to a sense of dissatisfaction with the project's pace. Comparisons with peers and difficulties in finding the right workflow and balance further added to the perception of slow progress.

T11 (score = 4): "I often feel like I'm working quite slowly and not making progress as quickly as my peers who are doing similar projects (i.e., other interns at my office/students in Geosciences). Also, now that I have started to work on the CDI part of my thesis I am still struggling to find the right workflow/balance. For example, trying to set aside time for technical research, CDI research, and also starting to write the report."

Lastly, students' opinions on the workload of the projects varied. Some students expressed satisfaction, finding the workload manageable, varied, and aligned with their tasks and plans. However, others expressed concerns and stress about the workload. These concerns stemmed from sudden additions of tasks beyond their control, lack of background knowledge in their topic, or feeling overwhelmed by a long list of tasks. Despite the challenges, some students maintained a positive outlook, focusing on their ability to handle the workload and finding contentment in completing the assigned tasks.

T4 (score = 2): "The tasks that I had to perform, of course, I am happy with that workload, but because of the sudden addition of many more tasks (that were out of my control), the workload is suddenly very high which makes me less motivated for the ones that actually matter."

In the other remarks, the students suggest a need for clearer communication and agreement on project goals, deliverables, and timelines. Testers expressed a desire for discussions to ensure they are on the right track and to alleviate anxiety regarding their project outputs. They also mentioned difficulties in aligning their timelines with supervisor expectations and the challenge of reaching agreement on planning and deliverables. The feedback highlights the importance of establishing clarity and alignment in project expectations and milestones.

In summary, the satisfaction levels of MEP students regarding their projects and workload exhibited a diverse perspective. While some students expressed satisfaction and support in their project progress and workload, others reported dissatisfaction and faced challenges. High expectations, arbitrary graduation processes, lack of interest in project content, and difficulties in finding the right workflow and balance were identified as factors contributing to students'

dissatisfaction. However, there were also students who set clear learning objectives and felt a sense of accomplishment in meeting them.

Satisfaction of MEP students on Team

In the next part, the satisfaction of MEP students regarding their team experiences is examined. The overall team satisfaction level is slightly higher than the project satisfaction level, with an average score of 6.49. Several statements related to team satisfaction scored lower, indicating areas of concern. The statements that received the lowest scores are: "I am happy with the amount of responsibility I have in my team", "I am happy with the connectedness to other people in my team (e.g. On a personal level)", "I am happy with the number of social team activities I am included in (e.g. Friday drinks, lunch, bowling night, ...)", and "I feel encouraged to contribute to my team (e.g. Reach a common goal)".

Regarding the statement on the amount of responsibility within the team, students expressed a wide range of perspectives. Some students expressed dissatisfaction with their level of sole responsibility or unclear expectations, while others felt motivated and satisfied with the autonomy and responsibility given to them. The lack of knowledgeable supervisors in their specific subject area was mentioned as a contributing factor to students' perceptions. Overall, there is a diversity of opinions regarding the amount of responsibility, with some students being content and others facing challenges in team dynamics and role clarity.

> *T4 (score = 10): "I have a lot of responsibility, and my team also expects such levels of autonomy which helps a lot with motivation."*
>
> *T7 (score = 3): "Too many responsibilities, my supervisors are not knowledgeable enough regarding my subject."*

Concerning the connectedness to team members, students shared both positive and negative experiences. Some students highlighted strong personal connections and active responsibility from their supervisors, while others mentioned a lack of personal connection and feeling rushed due to supervisors' busy schedules. Limited contact or infrequent project meetings were also mentioned. Some students expressed a sense of loneliness and a desire for more personal bonding and guidance from their supervisors.

> *T4 (score = 10): "It is amazing how well we connect on a personal level, my supervisors also take active responsibility regarding personal connectivity."*
>
> *T7 (score = 3): "I have a big cultural issue with my direct supervisor (PhD). He's Indian and I find it very hard to collaborate/communicate effectively with him. I almost never have project meetings (less than 1 per month)."*
>
> *T8 (score = 1): "I feel kind of lonely to be honest."*
>
> *T14 (score = 1): "There was absolutely no interest or time made for personal bonding."*

In terms of social team activities, students expressed a lack of such activities within their teams or mentioned the absence of social opportunities. While occasional activities or past events were mentioned, there was a perceived recent decline in social interactions. Some students noted that social activities were more prevalent in the company or when interacting with other interns, but within their specific teams or labs, the social aspect was limited.

> *T6 (score = 10): "I didn't do any of those things but I didn't miss them."*
>
> *T8 (score = 2): "There was a BBQ a month back but that's about it."*

T11 (score = 8): "The external company has a pretty active social life for young people, and when there are other interns in the department we also socialize. On the Geosciences side it's more difficult as I don't think the lab has much social activity."

T12 (score = 1): "There are none and I miss that."

The analysis of responses to the statement "I feel encouraged to contribute to my team (e.g., reach a common goal)" revealed diverse perspectives. Some students felt encouraged and satisfied with their ability to contribute, highlighting effective communication and an equal footing in discussions. However, others mentioned a decrease in encouragement over time and a perception that their proposals and contributions were undervalued by the team. Additionally, some students felt that the team made efforts to encourage their contributions but acknowledged that knowledge gaps hindered their effectiveness. One student expressed feeling highly encouraged but questioned the authenticity of the positive feedback received. Overall, while some students experienced a positive team dynamic and felt encouraged, others indicated the need for improvement in terms of feedback mechanisms, team bonding, and addressing knowledge gaps.

T4 (score = 10): "No worries here, when discussing topics I have the feeling as if we speak on the same level."

T5 (score = 4): "At the beginning yes but now it feels like they are not satisfied, I have to propose solutions and they only turn them down."

T12 (score = 1): "Team bonding was lacking."

To summarise, the satisfaction of MEP students on their teams shows a mixed picture. While some students express contentment and positive experiences, others face challenges and highlight areas for improvement. The findings highlight the importance of addressing issues related to role clarity, personal bonding, feedback mechanisms, and knowledge gaps within the teams. By addressing these concerns, it is expected to enhance team satisfaction, student engagement, and overall effectiveness in the Master End Projects.

Satisfaction of MEP students on Supervision

This part focuses on the satisfaction levels the 14 MEP students with regard to supervision. The average score for supervision satisfaction, 6.71, was lower than the DFS benchmark of 7.5, although it still ranked the highest among the three survey themes. Out of the eight statements, five scored lower than the overall average, and the three lowest-scoring statements will be discussed in the next paragraphs.

Regarding the statement "I am informed, in time, about policies or other changes that affect me (e.g. Meetings, holidays)," the responses from students indicate a lack of adequate communication regarding important updates and changes related to their thesis and literature research, particularly when the tracks were altered. While some students expressed satisfaction with the communication, mentioning no additional comments (T4, score = 9), others raised concerns about late notifications regarding supervisors' holidays and insufficient information provided about significant changes, such as a direct supervisor's extended absence in India. Additionally, some students mentioned a lack of encouragement to take holidays and limited communication between the university and themselves. These findings highlight the need for

improved communication channels and timely dissemination of relevant information to ensure that students are well-informed about policies and changes that impact their work.

T2 (score = 1): "People did not inform me about the changes in the thesis and literature review when the tracks changed."

T6 (score = 6): "Sometimes I would find out late that my supervisors are on holiday."

T7 (score = 0): "My direct supervisor went to India for 3 months with little to no heads up."

In relation to the survey statement "I feel valued by my supervisor for the work I perform during my project (e.g. Receiving positive feedback when due)," this statement received the lowest average score within this survey theme, with a score of 6. The responses from students reflect mixed sentiments regarding their perceived value by their supervisors. Some students received compliments on their progress but expressed a desire for feedback that focuses more on the content of their work. Conversely, some students felt that their work was being excessively praised, while others felt that their supervisors were not particularly impressed with their efforts. Some students indicated feeling valued by their supervisors but mentioned the absence of explicit positive remarks. On the other hand, a few students mentioned a lack of positive feedback and felt that their hard work often resulted in criticism. Overall, these responses highlight the importance of supervisors providing constructive and balanced feedback, recognizing and appreciating students' efforts, while also offering guidance for improvement.

T4 (score = 8): "Yes always, however sometimes some critical words might also be nice! I have the feeling my work is being rated too positively."

T10 (score = 8): "I get compliments but still there is that inside voice..."

T12 (score = 6): "Actually I feel like often when I've worked very hard I only get criticism - while sometimes if I haven't done a thing they will be very complimenting and positive."

T14 (score = 0): "Absolutely zero positive feedback."

Concerning the statement "I feel that the work I do is recognized by my supervisor (e.g. Use of data and authorship)," the responses from participants were mixed. Some students expressed a lack of recognition from their supervisors regarding their work. They felt that their contributions were not acknowledged or valued, and there was a perceived disconnect between their efforts and the recognition received. Conversely, some students mentioned receiving recognition from their supervisors, particularly for specific achievements, such as designing a new method. However, they noted that this recognition was not reflected in publications or authorship. Some students attributed the high value placed on their work by their supervisors to the supervisors' limited background knowledge on the subject matter. Furthermore, a few students expressed zero interest and a lack of recognition from TU Delft itself. Overall, these responses emphasize the importance of supervisors acknowledging and appreciating the work done by their students, including proper attribution and recognition in publications and authorship, as well as the need for consistent recognition and support from the university.

T7 (score = 8) : "They value it a lot because they have such little background knowledge on the subject themselves."

T14 (score = 1): "Zero interest from TU Delft."

In summary, the satisfaction of MEP students on supervision was examined, with the overall satisfaction score being lower than the DFS benchmark. The analysis highlighted deficiencies in

communication regarding important updates and changes, indicating a need for improved channels and timely dissemination of information. Students expressed mixed sentiments regarding feeling valued by their supervisors, emphasizing the importance of constructive and balanced feedback. The recognition of students' work by supervisors also varied, underscoring the significance of supervisors acknowledging and appreciating students' efforts, as well as the need for proper recognition from the university. Addressing these areas of improvement will contribute to enhancing the satisfaction and engagement of MEP students, ultimately leading to more successful outcomes in their projects.

5.1.3. MEP Student Feedback on DFS

At the conclusion of the Satisfaction Survey, the MEP students provided feedback to gain insights into their perceptions of the Satisfaction Survey and other features of DFS, such as the Feedback Meeting and the external coach. This feedback consisted of eleven statements, which are presented in Table 8, along with the average score given by the 14 MEP students. Similar to the scoring system used in the Satisfaction Survey, the students rated the statements on a scale from "0" (representing "Not at all") to "10" (representing "Perfect"). Additionally, students had the opportunity to elaborate on each statement and provide a final remark on the tool.

Table 8 Feedback Statements and Average Scores Given by 14 MEP Students

Feedback Statement	Average Score
I feel comfortable to use this survey during my project	6.79
I would share the information with a confidant (the confidant is the person who will lead the feedback sessions after each time you fill in the survey)	8.64
I would share the information with my first supervisor (e.g. principal investigator), without the help of a confidant	6.64
I would share the information with my second supervisor (e.g. PhD student/Postdoc), without the help of a confidant	6.90
I would feel more comfortable sharing negative information with my supervisor(s) in the presence of a confidant	6.33
I wish this tool already existed when I started	7.57
I feel that this tool could have helped me open up to my supervisor(s) about problems or issues during my project	7.50
I would want to have the opportunity to give feedback to my supervisor(s) during my project at set moments (e.g. every one to two months). This is feedback on things that are not content related	7.75
I would want to have the opportunity to receive feedback from my supervisor during my project at set moments (e.g. every one to two months). This is feedback on things that are not content related.	8.17
Currently, I feel comfortable sharing all information with my supervisor, despite the hierarchical difference	5.33
Currently, I feel comfortable sharing all information with my supervisor, even though I will be graded by my supervisor	5.82

Statement 1

"I feel comfortable to use this survey during my project", score = 6.79

The feedback provided by the students regarding their comfort in using the survey during their project reveals a range of perspectives. While some students appreciate the survey as a tool for meaningful discussions and providing structure, others express concerns about time constraints (i.e. busyness of the supervisors) and the feasibility of using it in different project phases. Some students value the opportunity for direct and nuanced discussions, while others highlight the need for guidelines and options such as "not applicable" in certain cases. The lack in trust in supervisors' openness to feedback is also emphasized, advocating the use of DFS to incorporate compulsory feedback into the project. Overall, students recognize the importance of the survey in improving student well-being and note the potential positive impact of supervisor dynamics and the possible need for mandatory participation.

T4 (score = 10): "Yes I think this is amazing, and opens up doors to have meaningful discussions about the project on another level."

T11 (score = 7): "The questions are really helpful for actually understanding how I'm feeling with the project! Because a lot of times I have a lot of emotions but they also obscure the facts of whether the project is going well or not, and why it might/might not be. I would be kind of nervous to discuss them with my supervisor and hear what they have said in their questionnaire, but I guess being scared is not a good reason not to do it."

T13 (score = 7): "I think the survey asks the right questions. But I think it only works when the supervisors will embrace this survey, and incorporate the feedback in the remaining of the project. And right now I don't have 100% trust that the supervisors are this open to feedback. But they should be, so starting to use a survey to improve student wellbeing during their graduation project is a very necessary and important step. Good work!"

T14 (score =3): "My supervisor isn't that empathetic so I don't really feel that this survey would land very well with him. However I do think that this should been done, however it feels to me that this needs to be mandatory in order to get me to use this."

Statement 2

"I would share the information with a confidant (the confidant is the person who will lead the feedback sessions after each time you fill in the survey)", score = 8.64

The students' feedback regarding their willingness to share the survey information with a confidant (i.e. the external coach) indicates varying, but overall positive perspectives. Some students express the need for clarification regarding the role and identity of the confidant and whether they need to find that person themselves. They mention being open to sharing the information if it is feasible and action will be taken to improve their thesis process based on the feedback. The involvement of an external perspective is appreciated by students, as it provides a valuable viewpoint outside of the project and sharing with the external coach feels less intimidating compared to sharing with the supervisor. Overall, students indicate a positive inclination to share the information with a confidant, provided the process and individuals involved are well-defined and supportive.

T7 (score = 7): "Much more comfortable. I would still be a little bit more nuanced because this person works for TU Delft thus is closer to my supervisor than to me."

T9 (score = 10): "Else DFS wouldn't really make sense for me. It's a good way to vent and gain insight into your progress, but I would want to act upon it and improve my thesis process."

Statement 3

"I would share the information with my first supervisor (e.g. PI), without the help of a confidant", score = 6.64

The students' feedback regarding their willingness to share the survey information with their first supervisor (e.g., PI) without the help of a confidant shows a lower average score of 6.64 compared to the previous statement, 8.64. Students express concerns and reservations about sharing negative or value judgments about their supervisors. Some students feel uncomfortable discussing certain aspects and fear potential repercussions. However, there are also students who express trust and comfort in sharing the information with their supervisors, particularly if there is a strong bond or positive working relationship. The level of comfort varies depending on the

student's perception of their supervisor's openness to feedback and the quality of their personal relationship. Overall, while some students are willing to share with their first supervisor, there is a higher level of hesitation and concerns compared to sharing with an external coach.

T4 (score = 10): "Yes, because I really trust my supervisor, I would definitely feel totally comfortable opening up to him."

T5 (score = 4): "Hmmm, not really. Doesn't feel like there is space for that."

T10 (score = 10): "But again, knowing my supervisor yes. having other supervisors maybe not."

T14 (score = 3): "Nope, personal bonding was lacking so that would not make me feel comfortable."

Statement 4

"I would share the information with my second supervisor (e.g. PhD student/Postdoc), without the help of a confidant", score = 6.90

The students' feedback regarding their willingness to share the survey information with their second supervisor (e.g., PhD student/Postdoc) without the help of a confidant reveals an average score of 6.90. This score is slightly higher than the previous statement but still significantly lower than the score for sharing with a confidant, indicating that students generally prefer the idea of a coach. Some students have had limited or no contact with their second supervisor and feel more comfortable sharing with their primary supervisor. Others perceive their second supervisor as having a similar role to their first supervisor and therefore feel similar levels of comfort or discomfort in sharing with them. The preference for an external coach remains prominent in the students' feedback, highlighting the value they see in having someone outside of the supervisory relationship to share their thoughts and experiences with.

T5 (score = 4): "They both feel like chairs."

T7 (score = 5): "I see my professor as my second supervisor. I level much better with him and feel like I can share things with him better than the PhD (score = 3) who is supposed to be my direct supervisor."

T12 (score = 10): "Yeah much more comfortable sharing this with my PhD - he's the 3rd supervisor in my case."

Statement 5

"I would feel more comfortable sharing negative information with my supervisor(s) in the presence of a confidant", score = 6.33

Students' responses vary regarding this statement. Some students feel neutral or have a good enough relationship with their supervisor(s) that they feel comfortable sharing negative information directly. However, for others, having an external coach present during the Feedback Meeting would be beneficial. This could be due to various reasons, such as finding it difficult to bring up certain topics or feeling that their concerns have been dismissed in the past. In such cases, the presence of a confidant could help facilitate the conversation and bridge any discomfort between the student and supervisor. Overall, while some students feel comfortable sharing negative information directly, the idea of having an external coach present is seen as a valuable support mechanism that can help address sensitive issues and bridge hierarchical gaps.

T7 (score = 6): "For me the filtering function of the confidant (selecting talking points, etc.) feels even more valuable than them being present for the conversation itself, but also the 'moderator' function would be nice."

T9 (score = 5): "Really depends. Usually I can bring up the strength to mention such things. But if it is something I find hard to bring up or I have brought up but it was dismissed, a confidant would be helpful. Unless that just strains the relationship with my supervisor."

T13 (score = 10): "Definitely, this would decrease the natural gap between student and supervisor "

Statement 6

"I wish this tool already existed when I started", score = 7.57

The majority of students express a positive sentiment toward the idea of having DFS available from the beginning of their projects. They believe that it could have been beneficial in several ways. Some students mention that the tool would have provided clearer insights to their supervisors about how the project was influencing them at an earlier stage. It could have facilitated more open and structured feedback sessions, making it easier to address concerns and frustrations. Students also appreciate the potential for data-driven insights and the ability to track progress over time. However, a few students mention potential challenges, such as the need for time management during meetings and the importance of ensuring that DFS is time-efficient. Overall, the general sentiment is that using DFS from the start would have been valuable and could have improved the student-supervisor relationship and project outcomes. Some students even express a desire for the tool to be mandatory for all students to use.

T5 (score = 6): "It would maybe have been a nice idea to really speak up per person each meeting about their level of satisfaction. However I always already felt what they were feeling, they were very direct and honest. So this could also pose a threat for me, seeing all their dissatisfaction lined up. Maybe they would have stopped the project? Or implemented serious measures??"

T7 (score = 7): "Starting from the beginning is much better than introducing it now, because now my frustrations have built up and that makes it more confrontational and more difficult to introduce."

T8 (score = 10): "Yes. As I said, great tool to structure my feedback sessions with my supervisor. My supervisor was also supervising 10 students at a time. I think this would have helped her a lot too. It also gives data/insight into the progress during the whole tedious thesis process. I think the graphs will help the supervisor make out whether a student is doing well or not and if intervention is needed."

T12 (score = 10): "Yes it's great I love it."

T14 (score = 8): "Existed and mandatory to be used."

Statement 7

"I feel that this tool could have helped me open up to my supervisor(s) about problems or issues during my project", score = 7.50

Students generally agree that DFS could have been beneficial in facilitating open communication with their supervisors regarding problems or issues that arose during their projects. Some students mention that certain problems only became clear to them later on, while their supervisors might have had earlier indications of these issues. DFS is seen as a means to address such problems in a more timely manner. Students also express that DFS would have provided them with a better understanding of their project progress and could have alleviated concerns. While some students state that they did not personally feel any barriers to opening up, they

acknowledge that the effectiveness of DFS may vary depending on the student-supervisor relationship. Suggestions are made to flag significant decreases in scores or major issues and involve student psychologists if necessary. Overall, students believe that DFS could have played a valuable role in fostering open communication with their supervisors and addressing problems more effectively.

T3 (score = 5): "I think some of the problems only became clear to me too late, which my teachers should have picked up signals of earlier."

T6 (score = 8): "It would give me a better understanding and would ease my mind more."

T7 (score = 8): "Yes, also to think better (more structured and specific) about how things are going."

Statement 8

"I would want to have the opportunity to give feedback to my supervisor(s) during my project at set moments (e.g. every one to two months). This is feedback on things that are not content related", score = 7.75

The MEP students express a desire for the opportunity to provide feedback to their supervisors at regular intervals, typically ranging from one to two months. While some students suggest less frequent feedback sessions, such as once every three months, others emphasise the importance of consistent communication to improve the supervisory relationship. Students acknowledge the potential workload increase for supervisors, particularly when they are responsible for multiple students. However, they believe that implementing such feedback sessions would enhance the overall project experience for everyone involved, as long as it is executed respectfully. They express varying levels of comfort and emphasize the importance of open-mindedness and receptiveness from their supervisors for such feedback sessions to be effective. Overall, students support the idea of scheduled feedback sessions during their projects and perceive it as a valuable opportunity for constructive communication and relationship improvement.

T6 (score = 7): "Every one or two months would be maybe a bit too often for me, but maybe once every 3 months."

T7 (score = 6): "Feels a bit scary because of the asymmetrical relationship, but I think it would be good afterwards."

T10 (score = 9): "Would be nice, maybe 3 to 4 times during the whole project is enough. Can you specify what you mean with not content related?."

T13 (score = 4): "I would prefer to use it whenever I feel is necessary."

Statement 9

"I would want to have the opportunity to receive feedback from my supervisor during my project at set moments (e.g. every one to two months). This is feedback on things that are not content related.", score = 8.17

Students express a strong desire to receive feedback from their supervisors at regular intervals, with some suggesting more frequent sessions, such as every month or bi-monthly. Students appreciate the opportunity to check in and receive feedback on their progress and non-content-related aspects of their projects. They believe that regular feedback sessions would provide valuable insights into their working methods, personal development, and overall understanding of where they stand in their projects. Students also mention that the use of a tool for structured

and specific feedback would enhance the feedback process. Overall, students emphasize the importance of respectful and frequent feedback from their supervisors to support their growth and improve their project experiences.

T5 (score = 7): "I already got that loads!."

T10 (score = 10): "I would want this more often than to give feedback. Bi-monthly would be nice.."

T14 (score = 7): "It would be nice to know where you stand."

Statement 10

"Currently, I feel comfortable sharing all information with my supervisor, despite the hierarchical difference", score = 5.33

Students express varying levels of comfort in sharing information with their supervisors, with some indicating that they do not feel comfortable sharing all information. Students mention that their comfort level depends on factors such as the supervisor's openness to feedback and the specific nature of the information being shared. The hierarchical difference between students and supervisors is acknowledged by some, while others state that they do not perceive a significant hierarchical gap. Overall, the score suggests that there is room for improvement in creating an environment where students feel more comfortable sharing all types of information with their supervisors, regardless of the hierarchical difference.

T5 (score = 2): "Not really."

T7 (score = 2): "No, not with the answers as I have formulated them this time. But if I would know that he would see the results, I would nuance them and then I would be much more comfortable."

T8 (score = 9): "I feel no real hierarchical difference. Depends on the student and supervisor I guess."

T10 (score = 8): "Define all information... most of it yes. regarding my process and how I feel about it yes. Regarding giving feedback to my supervisor yes but I would be more reserved even though I know he is open to feedback."

Statement 11

"Currently, I feel comfortable sharing all information with my supervisor, even though I will be graded by my supervisor", score = 5.82

The grading scheme and its impact on the willingness to share information with a supervisor are highlighted in the responses. Some students express concerns about giving harsh or negative feedback if their supervisor is responsible for grading them. The asymmetrical relationship and the fear of influencing their grade make some students more reserved in sharing information. However, other students emphasize that grading is a part of their supervisor's job, and they hope that sharing personal information will provide their supervisor with better insight into their struggles and potentially improve their grade. All in all, the score indicates that while students may feel somewhat comfortable sharing information, the grading component of the relationship does have an impact on their willingness to be fully open.

T6 (score = 7): "I wouldn't want to give too harsh/negative feedback if they still have to grade me."

T7 (score = 4): "Grading is a part of the asymmetrical relationship I mentioned before, but not the whole thing. So therefore slightly less uncomfortable than the previous question."

T11 (score = 7): "I would hope that anything personal I share just gives them more insight into me as a person, which should increase my grade if anything 😆 (because then they would know what I actually struggle with)."

T14 (score = 3): "No, I would be afraid to influence my grade."

In the other remarks, the students' general feedback on the DFS tool includes positive sentiments and curiosity about its development and implementation. Testers expressed liking the idea of the tool and found it to be a great concept. Some testers highlighted the confusion they experienced regarding team-related questions, particularly if they didn't feel part of a team. Overall, the feedback indicates enthusiasm for DFS and its potential benefits.

In summary, the feedback from 14 MEP students who tested the DFS prototype was mixed. While some students found the survey useful and believed it could lead to meaningful discussions, others expressed concerns about time constraints, especially with regard to the busyness of the supervisors, and its feasibility across different project phases. The preference for sharing survey information with a confidant rather than supervisors was notable, as it provided an external perspective and felt less intimidating. Sharing information directly with supervisors, especially the first and second supervisors, scored lower due to hesitations and concerns. Comfort levels in sharing negative information with supervisors varied among students. Overall, students believed that DFS had the potential to improve the student-supervisor relationship and project outcomes by facilitating open communication. They expressed a desire for regular feedback sessions with supervisors to address non-content-related aspects. However, creating an environment where students feel more comfortable sharing all types of information, regardless of hierarchical differences, remains an area for improvement.

5.1.4. Student Experience: DFS Prototyping Summary

The feedback provided by the 14 MEP students who tested the Satisfaction Survey of DFS is crucial in understanding the diverse perspectives and experiences of students in their projects, teams, and supervision. The findings highlight the need for improvements in communication and agreement on project goals, deliverables, and timelines. Students expressed concerns regarding high expectations, arbitrary graduation processes, and difficulties in finding the right workflow and balance. Leadership plays a significant role in providing guidance and facilitating effective communication to ensure project success and address these concerns.

Additionally, issues related to role clarity, personal bonding, feedback mechanisms, and knowledge gaps within teams were identified as areas for improvement. Constructive feedback and open communication are essential in fostering team cohesion and creating a shared experience that promotes collaboration and synergy among team members. Moreover, deficiencies in communication and mixed sentiments regarding feeling valued were observed in the context of supervision. This emphasizes the need for better communication, timely information dissemination, and balanced feedback moments. Recognising students' efforts and providing proper recognition from both supervisors and TU Delft are crucial for enhancing student satisfaction and engagement.

By actively seeking and incorporating feedback from students, supervisors can gain insights into the challenges students face and tailor their guidance and support accordingly. Feedback serves as a communication channel for students to express their concerns and suggestions for improvement, contributing to the ongoing enhancement of their project and its processes. It also

enables supervisors to identify specific areas where adjustments can be made to manage workload, improve project flow, and align expectations. Constructive dialogue between students and supervisors fosters collaboration and empowers students to actively participate in shaping their learning experience and professional development.

By acting upon student feedback and creating a supportive and motivating environment, supervisors can address the identified concerns and improve the overall satisfaction level of students. This, in turn, enhances learning outcomes and contributes to the personal and academic growth of students within their MEPs. The integration of DFS and its Satisfaction Survey provides a valuable tool for facilitating open communication, gathering feedback, and fostering a positive student-supervisor relationship. The input provided by students through the DFS prototype testing underscores the importance of incorporating their perspectives and continuously improving the MEP process to create an environment conducive to student success.

5.1.5. Changes of DFS after Prototyping

The feedback received from the 14 MEP students through the Satisfaction Survey led to several noteworthy changes in the DFS tool. One significant change involved the inclusion of an additional statement within the “Project” section of the survey. This new statement, “I am happy with the way my student uses my feedback on their project (e.g., They implement feedback in their research project) / I am happy with the feedback I get during my project (e.g., I am happy with the amount of feedback),” was introduced to address the need for information on the satisfaction regarding the manner in which feedback is provided and received, both in terms of project content and non-content related aspects. The rationale behind this addition stemmed from the observation that many students expressed concerns about receiving excessive positive feedback (which did not highlight areas for improvement) or experiencing a lack of feedback altogether. By incorporating this statement, it aims to open up the conversation, during the Feedback Meeting, about feedback practices in the project phase and consider potential adjustments that may be necessary.

As mentioned before, during the prototype testing, an eighth Team Statement was added to the survey, which was completed by only two out of the fourteen students. However, the scores provided by these two students were significantly low, classifying them as outliers. Consequently, their scores were not taken into account when calculating the average Team Satisfaction Score. The inclusion of this statement, “My student is supported by the team (e.g., Solving problems together) / I feel supported by my team (e.g., Solving problems together, positive feedback),” aimed to obtain a more comprehensive understanding of the teamwork perceived by the student or supervisor during the project. Furthermore, this statement also relates to the fifth statement in the “Supervision” section of the Satisfaction Survey.

Some students expressed that the team-related statements in the Satisfaction Survey were not applicable to them, leading to confusion when the corresponding graphs in the “Team” section were explained. However, it is important to include these statements in an academic setting where teamwork is integral. Therefore, the “Team” statements were not excluded from the Satisfaction Survey It is important to note that a team can consist of two people, such as a student and a supervisor, and their collaboration should also be considered as a team. However, it may be worth considering adapting the survey to better accommodate the needs and experiences of the individuals completing it.

Another notable modification implemented in the Satisfaction Survey and DFS in general was the renaming of the role previously referred to as “confidant” to “external coach”. This alteration aimed to reduce the perception of requiring mediation and instead foster a sense of coaching rather than problem-solving. The intention was to ensure that students and supervisors who did not face significant issues would not perceive the presence of problems where none existed. By repositioning the role as an external coach, the focus shifted towards support and guidance rather than solely addressing difficulties, thereby promoting a more positive and proactive perspective.

Finally, several modifications were made to the Feedback questions in response to the need for greater clarity. For instance, the question “I feel comfortable to use this survey during my project” was revised to “I would feel comfortable to use this survey during my project”. Additionally, two feedback statements were introduced in the supervisor Satisfaction Survey, and one statement was included in the student Satisfaction Survey. Furthermore, three additional open-ended questions were incorporated based on the feedback received from the fourteen MEP students. These adjustments aimed to enhance the comprehensiveness and effectiveness of the Satisfaction Survey and DFS in capturing valuable insights.

5.2. Validation of DFS: A Joint Assessment by a PI and a Postdoc

The next “Validation” section delves into the comprehensive validation process of the Dual Feedback System (DFS) within the context of team effectiveness in Biodesign. It encompasses the real-life validation, by a PI and their Postdoc, of both components of DFS: the Satisfaction Survey and Feedback Meeting. A key focus during the validation process was ensuring voluntary participation and providing participants with detailed information on privacy, data processing, and storage to uphold their rights and confidentiality.

In this first validation phase, a PI and one of the Postdocs of their team actively participated in the validation of DFS. They read the User Manual of DFS, completed the Satisfaction Survey and engaged in the subsequent Feedback Meeting, while the researcher observed the session. The insights and feedback received from them on DFS as a whole significantly enriched the research findings, providing a deeper understanding of team dynamics in the Biodesign field.

The section concludes with a validation summary that establishes a significant connection between the findings of the validation process and the earlier prototyping phase discussed in this Chapter 5. This connection highlights the iterative nature of DFS development and showcases the successful integration of feedback from various stakeholders, contributing to the ongoing refinement and effectiveness of the system.

The received feedback from all participants, including both the validation and prototyping phases, will be thoroughly analysed and discussed in Section 5.4 to provide insights on how DFS can be further refined and enhanced. This iterative approach ensures the development of a robust and tailored system that meets the specific requirements and dynamics of Biodesign projects and beyond.

5.2.1. DFS Validation Preparation Protocol: Satisfaction Survey

This subsection presents the comprehensive protocol designed for preparing the DFS Satisfaction Survey validation, by a PI and Postdoc. This protocol encompasses essential components such as consent forms for the Satisfaction Survey, as well as a detailed description of the involved validators. By following this protocol, a rigorous validation process is ensured, yielding valuable insights into the efficacy and utility of the DFS Satisfaction Survey.

DFS Satisfaction Survey Validation: Consent Form

During their participation in the validation process of the Satisfaction Survey of DFS, all validators were requested to complete a consent form. This consent form was designed to ensure their voluntary involvement and provided comprehensive information regarding the handling and storage of their data.

For reference and convenience, blank copies of the consent forms for the Satisfaction Survey is included in Appendix C, specifically in Annex C3. These forms serve as documentation of participants' consent and reinforce the ethical principles and guidelines governing the research process.

Validators Phase 1

The validation of DFS involved multiple participants who played different roles in the process. The validation was conducted in two phases.

In the first phase, the validation of DFS involved two participants: Validator 1 (V1), who is a Principal Investigator (PI) of a Biodesign lab at TU Delft, and Validator 2 (V2), a Postdoc in their team, which consisted of 18 members. Both participants thoroughly reviewed the User Manual of DFS and subsequently completed the Satisfaction Survey. During this process, the PI provided answers to the supervisor statements, while the Postdoc provided answers to the student statements. Next to this the validators both scored the feedback statements and answered three open questions, namely “What did you like most about DFS?”, “What did you like least about DFS” and “What was missing in DFS?”.

5.2.2. Satisfaction Survey: PI and Postdoc Validation

This subsection presents the analysis of the DFS Satisfaction Survey, focusing on the Project theme as an exemplar for the overall survey process. The satisfaction scores from both the Postdoc and their supervisor serve as valuable indicators, offering insights that can be applied to the other key themes, namely “Team” and “Supervision.” Additionally, the elaborations provided by the participants contribute to a deeper understanding of their perspectives. The ensuing subsection highlights the feedback received from the validators, further enriching the evaluation of the Satisfaction Survey of DFS.

Project Satisfaction of the Validators

$[\text{Average Project Score}]_{postdoc} = 8.00$; $[\text{Average Project Score}]_{supervisor} = 4.63$; $\Delta_{Project} = 3.38$

The average project satisfaction score reported by the Postdoc is 8.00, while the average score provided by their supervisor is 4.63, indicating a notable disparity of 3.38. Although the Postdoc did not offer comments for most of the statements, they did provide elaboration for the first and second Project statements, offering specific insights into certain aspects of their projects.

Overall, the Postdoc expressed relatively high levels of satisfaction for the Project statements, with scores ranging from 6 to 9. However, it is important to note that the statement "*I am happy with the feedback I get during my project (e.g., I am happy with the amount of feedback)*" received the lowest score of 6. Unfortunately, without accompanying elaboration, it is challenging to fully comprehend the reasons behind this lower score and gain a comprehensive understanding of the Postdoc's perspective on this statement.

In contrast, the supervisor's satisfaction levels were considerably lower, with scores ranging from 2 to 8 for the Project statements. The supervisor expressed confidence in the project's direction and viewed it as promising. However, there were concerns about the Postdoc's personal sense of accomplishment and satisfaction, suggesting potential discomfort or stress. The pace of progress was perceived as slower than desired to achieve the ambitious goals of obtaining a professorship and publishing high-impact papers. On a positive note, the project was recognized as intellectually challenging, offering opportunities for growth and learning. While the overall goals of the project were understood, there was limited clarity regarding the workload and the specific challenges faced by the Postdoc. Feedback implementation was generally acknowledged, although occasional resistance to feedback was observed. The supervisor reiterated their commitment to the Postdoc's happiness and the pursuit of their personal goals.

By analysing these satisfaction scores and the accompanying elaborations, valuable insights can be gained to guide discussions on improving satisfaction, addressing disparities, and fostering a more productive and supportive research environment.

It is important to note that the scores and elaborations were collected in an external Excel file and will be generalised in this report to provide insights for the validation process conducted by the researcher. In the applied version of DFS, the processing of satisfaction scores would be handled by the external coach who would use this data to generate advice and recommendations.

Feedback on DFS Satisfaction Survey

To evaluate the satisfaction and comfort level of the validators using the Satisfaction Survey, as well as their willingness to share information with their supervisor or student, a similar set of feedback statements was presented as in Subsection 5.1.3. The validators were asked to provide scores for these statements, providing valuable insights into their perspectives.

Analysing the validators' scores to these feedback statements gives a better understanding of their overall satisfaction with the survey and their potential discomfort in sharing information with their supervisor or student. The scores assigned by the postdoctoral fellow and supervisor on the Student and Supervisor Statements, respectively, are presented in Table 9.

Table 9 The Feedback statements and respective scores, filled in by the Postdoctoral Fellow and Supervisor

Student Statement	Score		Supervisor Statement
I would feel comfortable to use this survey during my project	9	10	I would feel comfortable to use this survey during my student's project
I would feel comfortable to share the information with an external coach	9	10	I would feel comfortable to share the information with an external coach
I would feel comfortable to share the information with my first supervisor (e.g. PI), without the help of the coach	7	10	I would feel comfortable to share the information with my student, without the help of a coach
I would feel comfortable to share the information with my second supervisor (e.g. PhD student/Postdoc), without the help of the coach	-	10	I would feel comfortable to share the information with the second supervisor of my student (e.g. PhD student/Postdoc), without the help of the coach
I would feel comfortable sharing information with my supervisor(s) in the presence of an external coach	9	10	I would feel comfortable sharing negative information with my student in the presence of the coach
I wish this tool was implemented when I started	8	5	I would like to see this tool be implemented in future projects
I feel that this tool could have helped me open up to my supervisor(s) about problems or issues during my project	8	3	I feel that this tool could have helped my student to open up to me about problems or issues during their project
-		2	I feel that this tool could have helped me open up to my student about problems or issues during their project
I would want to have the opportunity to give feedback to my supervisor(s) during my project at set moments (e.g. every one to two months). *This is feedback on things that are not content-related.*	9	5	I would want to have the opportunity to give feedback to my student during their project at set moments (e.g. every one to two months). *This is feedback on things that are not content-related.*
I would want to have the opportunity to receive feedback from my supervisor during my project at set moments (e.g. every one to two months). *This is feedback on things that are not content-related.*	9	5	I would want to have the opportunity to receive feedback from my student during their project at set moments (e.g. every one to two months). *This is feedback on things that are not content-related.*
I would feel comfortable sharing all information with my supervisor, despite the hierarchical difference	7	4	Currently, I feel that my student is comfortable in sharing all information with me, despite the hierarchical difference
I would feel comfortable sharing all information with my supervisor, even though I will be graded by my supervisor	7	10	I feel that my student is comfortable in sharing all information with me, even though I will be grading their project

In the validation feedback for DFS, both the postdoctoral fellow and the supervisor provided insights on various statements. They expressed a high level of comfort and willingness to use the survey during the project, along with their comfort in sharing information with an external coach.

However, a slight difference was observed between the postdoctoral fellow's willingness to share information with the supervisor and the supervisor's willingness to share with the postdoctoral fellow without the help of an external coach. This difference suggests the potential benefit of having an external coach, particularly from the perspective of the postdoctoral fellow.

Furthermore, there was also a disparity regarding the perception of the tool's effect on openness. While the supervisor expressed uncertainty about whether the tool would have helped the postdoctoral fellow open up, the postdoctoral fellow gave a significantly higher score, indicating that the tool would have indeed facilitated their openness.

The supervisor also mentioned that they already implement open communication within their team and did not feel the need to give or receive extra feedback or need help opening up, as evidenced by their scores of “2”, “5”, and “5” for the eighth to tenth statements. On the other hand, the postdoctoral fellow gave higher scores, expressing their desire for the opportunity to provide and receive extra non-content-related feedback.

Additionally, the supervisor noted that they feel the postdoctoral fellow holds back to some extent in sharing information due to the hierarchical difference, while the postdoctoral fellow also assigned lower scores to their comfort level in sharing all information, considering both the hierarchical difference and the “grading” scheme.

On the open feedback questions, the postdoctoral fellow expressed a desire for the ability to track different projects with the survey and appreciated the convenience of the slider feature for selecting the satisfaction scores quickly. However, they also pointed out that certain sections of

the survey were vague and did not align with their specific team size. This further emphasises making the survey more adaptable to individual needs. On the other hand, the supervisor did not mention any specific missing elements in the survey but highlighted the positive aspect of the survey's timing, aligning with their annual review. However, they expressed that the survey was too long, echoing the concerns raised by the six interviewees in the case study and some of the MEP students in the prototyping phase about the time constraints faced by PIs.

In conclusion, the feedback provided by the postdoctoral fellow and supervisor during the validation phase of the DFS survey offers valuable insights for its further development. Both the postdoctoral fellow and supervisor expressed a high level of comfort and willingness to use the survey, indicating its potential effectiveness in facilitating communication and feedback within the research project. The slight disparity between their willingness to share information without the help of an external coach suggests the potential benefits of incorporating such coaching support. Additionally, the differences in their perceptions regarding the tool's effect on openness highlight the need for further exploration. The postdoctoral fellow's desire for additional non-content-related feedback and the supervisor's emphasis on open communication within the team further emphasize the importance of tailoring the survey to meet individual needs. Addressing the specific suggestions, such as incorporating project tracking and streamlining the survey's length, will enhance the user experience and improve the effectiveness of the DFS survey in fostering supervisor-student relationships and communication in research projects.

5.2.1. DFS Validation Preparation Protocol: Feedback Meeting

To facilitate the DFS Feedback Meeting, a comprehensive analysis was undertaken to evaluate the average satisfaction scores and disparities between the supervisor and Postdoc for each statement within the relevant themes. This subsection specifically delves into the “Project” theme, offering an illustrative example of the obtained scores. Additionally, the guidance provided by the DFS tool to enhance satisfaction and promote team effectiveness will be discussed, shedding light on areas of improvement and generating valuable insights for the upcoming Feedback Meeting. Lastly, both validators had to read and sign the Feedback Meeting consent form.

Points for Discussion: Project Satisfaction

In preparation for the DFS Feedback Meeting, the average project satisfaction scores per statement and the disparities between the PI and Postdoc were calculated to identify areas requiring attention within the “Project” theme. These scores serve as valuable indicators for the ensuing discussions.

Table 10 illustrates the Project scores, highlighting them in green when the average score is above 7.5 or the disparity is equal to or lower than 1. Scores that do not meet these criteria are displayed in red.

For instance, in statement 7, which addresses satisfaction with workload, the student statement “I am happy with the workload of my project” and the supervisor statement “I am happy with the workload my student has in the project” have a significant disparity score of 6,

Table 10 The Average of and Difference in Satisfaction Scores per Statement for the Project Theme

Statement	Average Satisfaction	Difference (Δ)
1	6.5	3.0
2	5.5	5.0
3	4.5	5.0
4	8.0	0.0
5	7.5	3.0
6	7.0	4.0
7	6.0	6.0
8	5.5	1.0

indicating a notable difference in satisfaction levels. While the average score is not extremely low, it suggests room for improvement. Therefore, DFS will advise that the focus during the meeting should be on reducing the disparity by enhancing the supervisor's satisfaction, while considering the guidelines presented in Table 4 in Subsection 4.3.1 (Jug, Jiang, & Bean, 2019). In addition to the scores of statement 7, the supervisor's elaboration on this statement will contribute to further improving satisfaction.

Similarly, DFS recommends focusing on statements 1, 2, 3, 6, and 8 to address any disparities. For statement 5, although there is a high disparity, the average satisfaction score is just sufficient to meet the desired benchmark. It is advisable to discuss the uncertainties surrounding the project's content and goals, taking into account the elaboration provided by the supervisor.

As for statement 4, which pertains to the intellectual challenge of the project, both the supervisor and the Postdoc demonstrate high satisfaction scores that exceed the benchmark. Thus, statement 4 does not require immediate attention during the Feedback Meeting due to the high satisfaction scores from both the supervisor and the Postdoc.

Overall, these findings guide the agenda for the Feedback Meeting and facilitate discussions on specific areas to enhance satisfaction and address any notable disparities.

Sharing Satisfaction Survey Results with Validators

The validators expressed their interest in receiving a comprehensive overview of both the "Student" and "Supervisor" Satisfaction Surveys, including the complete analysis and recommendations. Therefore, the calculated scores and corresponding advice for all three themes were compiled and shared with the validators as requested.

DFS Feedback Meeting Validation: Consent Form

The two participants involved in the validation of the Feedback Meeting of DFS were also required to sign a separate consent form prior to the meeting.

The consent form for the validation of the Feedback Meeting is provided in Appendix C, specifically in Annex C4. This form serves as an important document to ensure the ethical conduct of the validation process, outlining the participants' voluntary participation and agreement to the terms and conditions of the meeting.

5.2.2. DFS Feedback Meeting: Validation by the Observer

As an observer, the writer of this report had the opportunity to attend the Feedback Meeting of DFS for validation purposes. During the meeting, a passive role was taken on, refraining from actively participating in the discussions or influencing the conversation in any way. The primary purpose of the meeting, as stated by the supervisor at the beginning of the meeting, was to engage in a constructive feedback exchange, highlighting that both the supervisor and the Postdoc could benefit from this experience as a valuable learning opportunity.

Furthermore, the supervisor set the tone by emphasising the importance of giving and receiving constructive feedback. This signalled a collaborative and supportive environment, conducive to open dialogue. The supervisor aimed to create a safe space where both parties could openly share their perspectives and insights. In this context, the supervisor inquired whether any of the results presented during Satisfaction Survey were surprising to the Postdoc. In response, the Postdoc

acknowledged that while certain aspects of the feedback were expected, there were also elements that came as a surprise.

The meeting provided an opportunity for the postdoctoral fellow to reflect on their experiences and receive valuable input from the supervisor. It fostered a culture of continuous learning and improvement, where feedback was seen as an essential component for personal and professional growth. By actively engaging in this feedback exchange, both the supervisor and the Postdoc were able to gain new perspectives and insights, enhancing their understanding of the dynamics within their working relationship.

During the Feedback Meeting, the supervisor and the Postdoc sought to address any identified issues and find compromises to improve the team effectiveness. Notably, they focused on resolving concerns related to the “Project” section of DFS. This collaborative effort showcased their commitment to enhancing the Feedback Meeting, by tailoring it to their specific needs.

Moreover, an interesting outcome highlighted during the meeting was how DFS facilitated better communication and understanding between the supervisor and the Postdoc, who identified themselves as an extrovert and an introvert. Despite their contrasting personality traits, DFS provided a platform for them to find common ground and bridge the gap between their communication preferences. This finding indicates that DFS can help individuals with different communication styles and preferences establish effective channels of interaction, fostering a more harmonious and productive working environment.

Overall, the Feedback Meeting served as an invaluable opportunity for the supervisor and the Postdoc to address concerns, find compromises, and leverage DFS as a tool to enhance their collaboration and team effectiveness. It highlighted the positive impact of the tool in promoting effective communication and understanding, even between individuals with diverse communication preferences. These outcomes will contribute to the continuous improvement and refinement of DFS, making it a valuable resource for fostering successful supervisor-student relationships and enhancing team effectiveness in academic teams.

5.3. Validation of DFS: Assessment by a Student Counsellor

During the last validation process, a student counsellor from TU Delft provided valuable feedback on DFS. The student counsellor was asked several questions to assess the potential benefits and challenges of implementing DFS in the context of student and supervisor feedback.

When asked if the tool would be helpful, the student counsellor responded with a resounding “YES!”. They emphasized that feedback plays a crucial role in project development and that DFS could be a valuable addition to projects that are either facing difficulties or running smoothly. The student counsellor also highlighted the lack of explicit attention given to feedback in existing programs, making DFS a beneficial exercise for students to learn how to give and receive feedback effectively.

Regarding the difficulty students and supervisors face in giving feedback, the student counsellor acknowledged that hierarchy and grading influence students' hesitance to provide feedback. They expressed that students often lack experience in giving proper feedback and may feel intimidated by the process. The student counsellor also noted that supervisors may find it challenging to provide (spontaneous) feedback or may approach it in a less constructive manner, leading to student concerns. DFS was seen, by the student counsellor, as a tool that could facilitate more

constructive and equal conversations between students and supervisors by providing a standardized set of questions for both parties to answer.

When asked if a similar system already exists, the student counsellor was not aware of any comparable tools. However, they mentioned a recently established “intervisiespel” called “Campfire Talk - Unsupervised intervision game”.

Regarding personal contact between TU Delft and students, particularly in terms of mental health, the student counsellor acknowledged the university's efforts in this area. They felt that TU Delft is already taking responsibility for mental health matters. They expressed support for activities that foster students’ inclusion in activities, both socially and academically, as it can create a sense of belonging and make it easier for students to seek help from people, also beyond their supervisors.

Lastly, the student counsellor inquired about the role of the external coach in the BEP/MEP context. They noted that a person fulfilling this role from the same lab as the supervisor would not create a safe environment for the student. They also emphasized that being a neutral coach requires specific skills and training to maintain a safe and supportive environment for students.

The feedback provided by the student counsellor offers insights into the potential benefits of DFS in enhancing feedback processes within collaborations in the Biodesign field and highlights the importance of addressing hierarchical dynamics, promoting constructive conversations, and considering the role of external coaches in student projects.

5.3.1. DFS Validation Summary

The validation feedback for DFS revealed valuable insights from various stakeholders, including a Postdoc, supervisor, observer, and student counsellor. Overall, both the Postdoc and the supervisor expressed a high level of satisfaction and comfort in using the DFS survey, indicating its potential effectiveness in facilitating communication and feedback within academic teams. However, some disparities were observed, emphasising the need for further refinement and tailoring of the tool to individual needs.

The Postdoc expressed a greater willingness to share information with the help of an external coach, suggesting the potential benefits of incorporating such coaching support. Additionally, the Postdoc assigned higher scores to the tool's effect on openness, highlighting the ability of DFS to facilitate willingness to share and open communication. On the other hand, the supervisor stated they already implemented open communication within their team and expressed less need for extra feedback or assistance in opening up. Also, expressing concerns with regards to the length of the Satisfaction Survey.

During the Feedback Meeting, the supervisor and the Postdoc actively sought to address identified issues, particularly in the “Project” section of DFS, demonstrating their commitment to improving team effectiveness. Notably, the meeting showcased how DFS facilitated better communication and understanding between people with different communication styles, underlining the tool's ability to bridge communication preferences and foster a harmonious working environment and enhance team effectiveness. The Feedback Meeting provided both validators with valuable insights into the benefits of feedback, particularly in relation to teamwork, emphasising the importance of addressing non-related aspects of the project.

In the assessment by a student counsellor, DFS was highly regarded as a valuable tool for project development, providing students with the opportunity to learn effective feedback skills. It was

seen as a means to facilitate constructive conversations between students and supervisors, promoting equality and standardization in the feedback process. The student counsellor also highlighted the importance of addressing hierarchical dynamics and the potential role of external coaches in creating a safe and supportive environment for students.

In conclusion, the validation feedback from these stakeholders highlights the potential benefits and challenges of implementing DFS in research projects. The feedback emphasizes the need for addressing hierarchical dynamics, being flexible when needed and considering the role of external coaches. By incorporating these insights and continuously improving DFS, it has the potential to enhance supervisor-student relationships, foster effective communication, and improve team effectiveness in academic settings.

5.4. Conclusion

In this master thesis, three sub-questions were explored to understand the factors influencing team effectiveness in the Biodesign field and how they can be leveraged to enhance team performance, ultimately addressing the main research question.

5.4.1. Identifying Key Themes for Team Effectiveness in Science Teams to

"What themes, connected to team processes, social networks, hierarchy, disciplinarity, and participatory design, have an impact on or are significant for team effectiveness in science teams?"

The first sub-question aimed to identify the themes connected to team processes, social networks, hierarchy, disciplinarity, and participatory design that have an impact on team effectiveness in science teams. Through the analysis of interview data, ten analysis themes were selected, including team size, diversity of team members, resources and tools, leadership, hierarchy, task demands and goals, goal misalignment, relationship to other teams, organisational structure, and working with living materials. These themes provided a comprehensive framework that intertwined with the literature topics and team processes, answering the first sub-question.

5.4.2. Challenges to Team Effectiveness in the Biodesign Field

"How do these themes affect the overall team effectiveness in the Biodesign field?"

The topics explored in the literature, including disciplinarity, social networks, hierarchical structures and leadership, and participatory design, shed light on how they affect overall team effectiveness in science teams. In Biodesign, transdisciplinarity emphasizes the importance of diversity and open communication within teams, while goal alignment is crucial for successful collaboration. Challenges related to the themes of team size, goal misalignment, leadership, and hierarchy impact team dynamics and interpersonal relationships. Addressing organisational aspects is necessary to enhance collaboration and efficiency within research and academic environments. These themes also influence the formation and structure of social networks within Biodesign teams and organizations. Overall, these findings contribute to a comprehensive understanding of how these themes affect team effectiveness in the Biodesign field and thus answer the second sub-question.

5.4.3. Leveraging Themes for Enhanced Team Effectiveness

"How can these themes be leveraged to enhance the team effectiveness of a Biodesign research group?"

The third sub-question focused on leveraging the identified themes to enhance the team effectiveness of a Biodesign research group. Drawing upon the levers proposed in "Enhancing the Effectiveness of Team Science," the proposed tool, called DFS, integrated levers such as face-to-face interaction, shared experience, team member interaction, inclusion, positive interpersonal climate, team goals, conflict management skills, and leadership behaviour. By drawing on these levers and addressing the identified themes, DFS aimed to enhance team effectiveness in the Biodesign field. This gave a complete answer to the third sub-question.

Overall, this master thesis provides valuable insights into the themes, team processes, and levers that impact team effectiveness in the Biodesign field. The findings contribute to a comprehensive understanding of the interconnectedness between these factors and offer practical approaches for enhancing team performance. By leveraging the identified themes and utilizing the proposed tool, Biodesign research groups can optimize their team dynamics, improve collaboration, and achieve their project goals more effectively.

5.4.4. The Dual Feedback System: A Validated Approach to Improving Team Effectiveness in Biodesign Projects

"How can a transdisciplinary design tool contribute to team effectiveness in the process of Biodesign?"

The Dual Feedback System (DFS) has undergone rigorous testing and validation, encompassing three distinct phases: prototype testing with 14 MEP students, validation by a PI and a Postdoc, and validation by a student counsellor from TU Delft. Each phase has provided valuable insights into the potential benefits and challenges of implementing DFS in the context of student and supervisor feedback.

During the prototype testing phase, the feedback from MEP students shed light on crucial areas for improvement. Communication, goal alignment, and leadership guidance were identified as key factors in ensuring project success and addressing concerns such as high expectations and difficulties in finding workflow balance. The prototype testing also highlighted the need for constructive feedback, open communication, and better recognition of students' efforts to enhance satisfaction and engagement.

In the validation phase involving a PI and a Postdoc, the enthusiasm of the Postdoc for DFS was evident, with a strong desire to see the progress of results over time. The constructive nature of the Feedback Meeting and open communication were confirmed by an observer. The PI emphasized the effectiveness of different situational leadership styles and acknowledged the superiority of DFS with its numerical sliders compared to other employee performance methods. However, the PI expressed concerns about the time commitment required.

The validation by a student counsellor from TU Delft further supported the implementation of DFS. The student counsellor recognized the crucial role of feedback in project development and emphasized the lack of explicit attention given to feedback in existing programs. DFS was seen as a valuable tool for facilitating constructive and equal conversations between students and supervisors, providing a standardized set of questions. The student counsellor also highlighted the

importance of addressing hierarchical dynamics, promoting constructive conversations, and considering the role of external coaches in creating a safe and supportive environment for students.

In conclusion, the tested and validated Dual Feedback System offers a promising solution to enhance team effectiveness in the Biodesign field. The feedback received from MEP students, the PI, Postdoc, and the student counsellor provides valuable insights into the potential benefits of DFS. It addresses the main research question.

By actively incorporating feedback, promoting open communication, and addressing hierarchical dynamics, DFS has the potential to improve student satisfaction, project outcomes, and the overall learning experience in the MEP process.

5.5. Discussion

This section aims to provide a comprehensive analysis and discussion of key topics relevant to the integration and effectiveness of the tool developed for Biodesign groups at TU Delft. This comprehensive exploration encompasses a range of important aspects, including the role of the external coach, the challenges posed by the busy schedules of the PIs at TU Delft, and therefore the optimal length and format of DFS and the feasibility of transforming it into an application, the necessity for systematic change within TU Delft and the broader academic landscape, the integration of DFS with an existing program at TU Delft to facilitate such transformative change, and finally, recommendations for the future improvement of DFS.

Role of External Coaches: Creating a Safe Environment

As mentioned before, the integration of an external coach in DFS is highly recommended to bridge the hierarchical gap between students and supervisors and create a safe environment for open communication. The hierarchical gap between supervisors and students can hinder truthful and open communication, the development of trust and collaboration within the team. This might impede students to speak openly about struggles and they may feel hesitant to express their opinions or concerns due to perceived power dynamics and fear of consequences. By involving an external coach, a safe environment for open dialogue can be created, where students feel comfortable sharing their ideas, seeking clarification, and providing feedback.

The presence of an external, independent coach also mitigates the “Halo” effect and addresses further challenges regarding hierarchy and the grading scheme perceived by students. By acting as a mediator, the coach facilitates discussions, encourages diverse perspectives, and provides guidance on effective communication strategies and conflict resolution techniques. This establishes an atmosphere of trust and respect, where students feel empowered to freely express their thoughts and concerns. Additionally, the coach's involvement offers an additional perspective and guides students and supervisors through the decision-making process, clarifying expectations and promoting transparency. These actions reduce anxieties (i.e. improving mental health), improve team dynamics, and ensure a fair evaluation process.

Furthermore, without the possibility of an external coach the workload on student counsellors might increase when DFS is implemented. While the integration of DFS and external coaches does not eliminate the need for student counsellors, it alleviates some of their burdens, allowing them to focus on the aspects of their role. By involving external coaches, a more comprehensive support system can be established for students and supervisors alike, enhancing their overall experience.

In summary, integrating an external coach into Biodesign teams within the academic world bridges the hierarchical gap, fosters open communication, and addresses concerns related to hierarchy and grading. The involvement of external coaches within DFS creates a safer environment for constructive feedback and enhances team dynamics. Additionally, it will lighten the workload on student counsellors if DFS is implemented. By embracing the role of external coaches in DFS and connecting it slightly to the student counsellor's role, Biodesign teams can improve communication, team effectiveness, and ultimately contribute to the success and satisfaction of students and supervisors.

Enhancing Team Effectiveness Despite Busy PIs

The busy schedules of PIs pose a challenge when it comes to effectively implementing DFS. Feedback from the MEP students and the Postdoc regarding the length of the Satisfaction Survey was positive. However, the PI expressed concerns about their limited availability. These concerns about the busyness of PIs are further reinforced by the experiences shared by all interviewees and most students who tested the DFS prototype.

To address this challenge, clear guidelines and expectations should be provided to PIs regarding their involvement in the DFS process. By communicating the significance of their engagement and allocating dedicated time for DFS, PIs can be encouraged to participate in using the tool.

Furthermore, by actively participating in the DFS process, PIs can gain valuable insights into the concerns and perspectives of students, enabling them to address any issues and create a supportive environment to effectively help manage their projects. The tool serves as a platform for open communication, constructive feedback, and trust-building, thereby strengthening the collaboration and effectiveness within the team.

Moreover, it is worth noting that the tool's format has been validated and deemed acceptable by prototype testers and validators. This indicates that, while the concerns raised by PIs regarding their busy schedules are valid, the current format of the tool is suitable for implementation. However, it is essential to continuously monitor and assess the impact of the tool on the workload of PIs to ensure a sustainable balance between their responsibilities and the benefits derived from utilizing the tool. Nonetheless, it is important to recognise that while the tool may initially increase the workload for PIs, its implementation will bring long-term benefits to the overall team effectiveness in their teams.

In conclusion, the implementation of the tool within Biodesign teams may initially increase the workload for PIs. However, by providing clear guidelines and emphasizing the long-term benefits of the tool, the aim is to enhance team effectiveness and foster a supportive environment. While addressing the busyness of PIs is crucial, it is important to recognize that the tool's implementation is a step towards creating open communication, constructive feedback, and trust within teams. Continuous monitoring and assessment will shed light on the progress of projects and help PIs manage these projects.

A Need for Systematic Change at TU Delft

The findings from the prototyping test, where 14 MEP students gave their opinions about their projects, provided valuable insights into the areas that require change within the MEP program at TU Delft. Key concerns raised by students include communication gaps, project alignment issues, workflow challenges, and difficulties in managing expectations. To address these concerns and

foster student success, it is essential to actively incorporate student feedback and tailor guidance and support accordingly.

One of the primary feedback points received from the students (and the Postdoc) regarding DFS was their perception that the statements regarding “Team” felt misplaced, as they did not experience a sense of teamwork during their MEP projects. The students emphasized that the responsibility for the project solely rested on their shoulders, without the involvement of a team. This raises the question of whether the current format of the MEP should be reconsidered in order to better cater to the needs of the students.

To address this concern, exploring alternative formats for graduation projects becomes crucial. These alternative formats should aim to ensure inclusivity, foster teamwork, and promote interdisciplinary collaborations. By implementing such formats, students would have the opportunity to align their work with their respective disciplines while still benefiting from the team environment and dynamics. This shift could contribute to a more well-rounded educational experience, better preparing students for future professional undertakings. An alternative approach could involve examining the structure of DFS and adapting it to better suit the individual-focused nature of the MEP format. However, this approach does not align with TU Delft's objective of promoting transdisciplinary and inclusive collaboration (Reflective Engineer).

Furthermore, the results of the prototype testing show that there is a potential benefit in implementing DFS in teams beyond Biodesign teams. This is indicated by the low average satisfaction scores observed across the themes of Project, Team, and Supervision. The tool's emphasis on enhancing constructive feedback and improving team dynamics makes it applicable and adaptable in various team settings where hierarchy plays a significant role. As a result, DFS can provide advantages across the university, benefiting students and supervisors from different faculties. The validation of DFS by the Postdoc further supports its potential for broader application. Reaching beyond the initial student-supervisor relationship.

Next to this, inclusivity and diversity are crucial elements in fostering innovation and creativity within Biodesign teams and across the academic fields. Efforts should be made to ensure representation from diverse backgrounds, disciplines, and perspectives. This diversity enriches team dynamics, promotes transdisciplinary collaboration, and enhances problem-solving abilities. Diversity does come with challenges that can be faced by integrating a transdisciplinary tool such as DFS.

Another aspect of diversity that can pose challenges to team effectiveness is the motivational gap between students and supervisors. This gap can affect communication, expectations, and mutual understanding within the team. However, DFS, in combination with the involvement of an external coach, can help bridge this gap by finding compromises and addressing motivational differences, such as the ones expressed in the case study. To further improve inclusivity, it is important to involve both MEP and BEP students in team activities that are planned for TU Delft employees. This will foster a sense of belonging and enhance team processes, such as team cohesion, team mental models, and team climate, ultimately leading to more successful project outcomes.

In conclusion, the findings from the prototyping test and student feedback shed light on the need for systematic change within the MEP program at TU Delft. Communication gaps, project alignment issues, workflow challenges, and managing expectations are among the key concerns that require attention. Incorporating student feedback and tailoring guidance accordingly will

contribute to fostering student success. Moreover, the perception of a lack of teamwork and the responsibility solely falling on the students' shoulders raises the question of reconsidering the current MEP format to better cater to their needs. Exploring alternative formats that prioritize inclusivity, teamwork, and interdisciplinary collaborations can enhance the educational experience and prepare students their careers. Additionally, the potential benefits of implementing DFS extend beyond Biodesign teams, offering advantages in various team settings where hierarchy plays a role. Efforts should also be made to promote inclusivity and diversity, as they contribute to innovation and creativity in academic fields.

Integration with the Reflective Engineer Program

Integrating the tool with the Reflective Engineer program is highly recommended to leverage its existing focus on transdisciplinary working skills and enhance team effectiveness. The Reflective Engineer program aims to embed reflection as a core skill in engineering education, making it an ideal platform for incorporating the features of the Dual Feedback System (DFS). By integrating the tool within this program, the emphasis on open communication and constructive feedback can be further strengthened, leading to improved learning outcomes and student success.

The Reflective Engineer program aligns with the vision of TU Delft to foster a reflective co-creation environment. It aims to tailor interventions that promote reflection in various forms, which directly relates to the goals of the DFS. The program's approach emphasizes multi-stakeholder co-creation, enabling the development and implementation of tools within lectures, courses, programs (such as MEP/BEP programs), or training sessions for TU Delft employees, such as supervisors. By integrating DFS into the Reflective Engineer program, a platform is created for facilitating constructive feedback and reflection specifically on transdisciplinary collaborations, aligning with the program's core objectives.

Furthermore, it is noteworthy that participatory design (PD) and co-creation approaches have not yet been fully integrated into the Biodesign field, as revealed by the interviewees. However, the Reflective Engineer program, with its focus on reflection and co-creation, can help address this gap. The importance of engaging users in the design process was addressed in Chapter 3 and suggests that PD can offer valuable insights into realistic applications for users when implementing Biodesign in everyday life.

By integrating DFS with the Reflective Engineer program, the Biodesign field can benefit from a structured platform that promotes reflection, co-creation, and active user involvement. This integration will not only enhance the effectiveness of DFS but also contribute to the broader goal of fostering transdisciplinary collaboration and practical applications of Biodesign.

Future Recommendations for Improvement

Based on the analysis and discussion presented in this chapter, the following recommendations are suggested for further improving the integration and effectiveness of DFS developed for Biodesign groups at TU Delft and other academic teams:

1. Conduct additional research and gather more extensive feedback from a larger sample size to further validate the tool's effectiveness and benefits.
2. Develop a comprehensive training program for PIs to ensure they are well-equipped to interpret and act upon the Dual Feedback System.

3. Explore the possibility of making the tool compulsory for teams at TU Delft, while providing clear guidelines and expectations to both students and supervisors.
4. Integrate the tool with the Reflective Engineer program to enhance its impact on team effectiveness and communication skills.
5. Consider transforming the tool into a mobile application linked to the TU Delft app, My TU Delft, to improve accessibility, efficiency and user-friendliness.
6. Address the challenge expressed by the prototype testers and the Postdoc in understanding the Team statements, either by changing the DFS format or providing alternative formats for graduation projects to foster inclusivity and engagement.
7. Extend the applicability of the tool beyond the student-supervisor relationship to benefit a wider range of team settings within the university.
8. Encourage the involvement of external coaches to bridge the hierarchical gap and create a safe environment for open communication and feedback.

By implementing these recommendations, the integration and effectiveness of the tool can be further enhanced, contributing to improved team dynamics, student satisfaction, and overall project outcomes within Biodesign groups at TU Delft.

5.6. Personal Learning Experience

During my master's thesis project, I went through an interesting personal journey as well. Starting in May 2021, I felt like I could easily take on this project. Then, I started struggling with my mental health. Several setbacks in my personal life made working for my double degree harder than expected. It was a challenge to find the right balance in managing both the thesis for Nanobiology and Communication Design for Innovation. As one might expect balancing my always high expectations and perceived quality of work, further complicated matters.

A happy moment in this journey was when I got inspired to create the DFS tool. It happened during a conversation with my brother, who had just finished his MEP at TU Delft. Surprisingly, he struggled to receive feedback that truly met his needs during his graduation process. This, along with stories from others, motivated me to design a tool that could make a real difference. Seeing the enthusiasm of my fellow graduate students for DFS, further confirmed the potential impact in the academic community. As a student, I sometimes doubted the value of my own work, but the positive feedback I received on DFS changed that and made me proud of what I accomplished.

Next to these low-key interactions with peers, one of the most fascinating parts was getting the chance to talk to different Biodesigners, both within and outside of TU Delft. It was my first experience conducting interviews, and it provided me with incredible insights into team effectiveness in Biodesign. In the end, I had some really interesting conversations with individuals who had a different approach to handling struggles than I did. They preferred a more nuanced way of dealing with their struggles, unlike my usual direct and open communication style. This made me realize just how diverse people's perspectives and preferences can be when it comes to solving problems and resolving conflicts. Understanding these differences has been crucial to designing DFS in a way that helps people with all kinds of different communication styles, and it also made me think about the importance of adding the external coach to the tool.

Reading and talking about team effectiveness made me more aware of the importance of team dynamics. Encountering the story of the Tenerife aircraft accident showed me another aspect interesting to team effectiveness: hierarchical systems can deeply affect work dynamics. It resonated with my observations of similar hierarchical gaps and the “Halo” effect within the academic environment at TU Delft. Hearing about the experiences of fellow students made me realize that this gap more often than not creates challenges for students during their MEP. Especially during a time when these students should be celebrating the final phase of their time at TU Delft, it is sad to hear they are struggling due to problems in communicating with their supervisors. The described accident at Tenerife gives me hope that change can indeed happen in large organisations, but only if all stakeholders are on the same page. This hope is further strengthened when I hear about steps taken by TU Delft to increase open communication, collaboration, and reflection (i.e., the “Reflective Engineer” program).

As someone who loves working with people (yes, I am an “I”), working almost always solo on this project for over two years made me realize that there is no other option to get a master's degree at TU Delft. This raises questions, not only for me: Should there be another format for the Master End Project? Shouldn't collaboration be more important as an engineer? When will I ever do a project like this, where you work almost alone for one year, again in your life? These questions, I have asked myself many times. They even made me think about quitting (as some people I know did, before even starting their MEP), but then I remembered why I was doing this research. And I

thought about that: “How can I help future generations feel less alone during their Master End Projects?”

In conclusion, the personal learning experience gained from finishing this master thesis has been a journey. Engaging with participants, understanding diverse perspectives, and researching team effectiveness in Biodesign have contributed to my growth as a future engineer. By combining the understanding of team effectiveness and the importance of feedback, we can hopefully work towards continuous improvement in communicating more openly and empower people to reach their full potential. That is why I hope my research will help cultivating a culture of constructive and open communication in academic teams.

What I learned before I started this thesis project is to never quit and so I persevered. And to the TU Delft, I want to say to you, this quote by Starhawk: “Systems don't change easily. To change a system, you need to shake it up, disrupt the equilibrium. That often requires conflict.”

Thank you for reading my report, and for these learning experiences.

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Appendix A – Interview Analysis MIRO

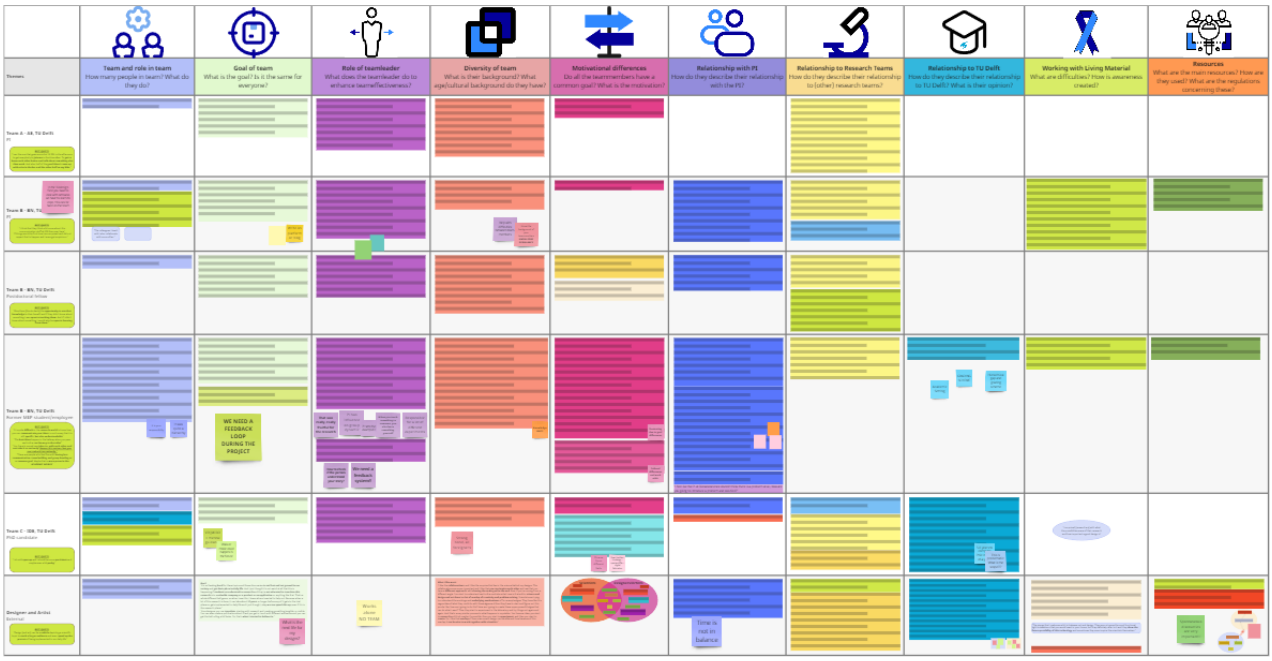

Figure A1 The Thematic Analysis Done in MIRO

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Appendix B – DFS

B1– DFS User Interfaces

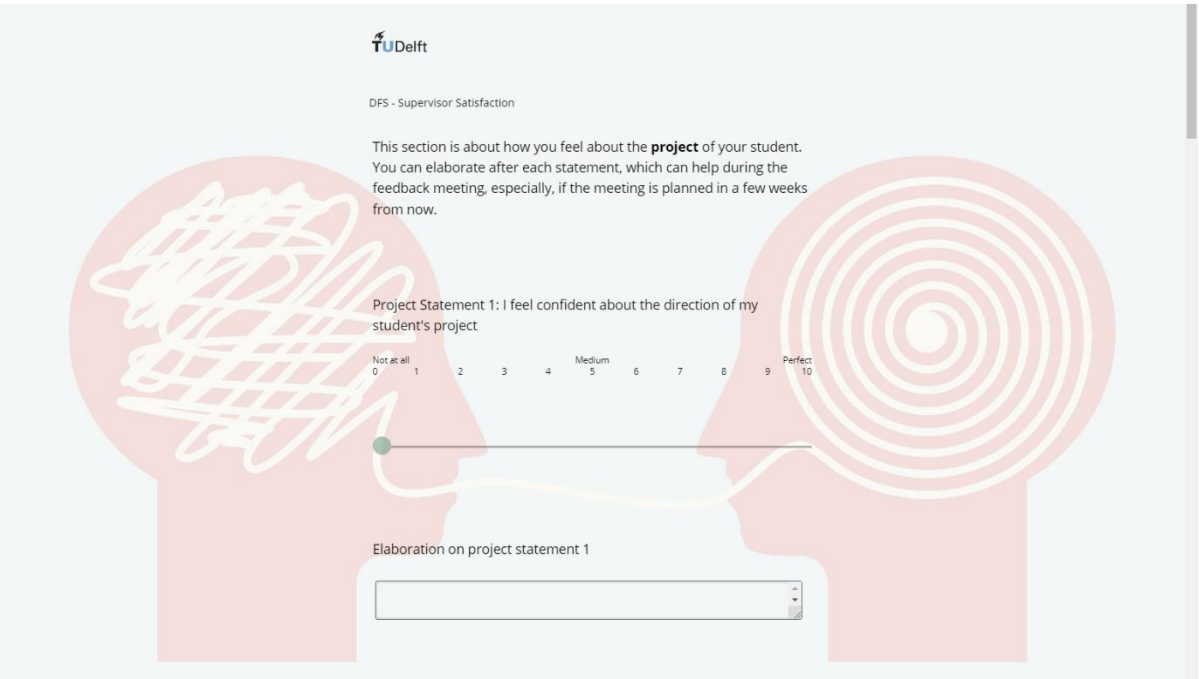


Figure B1 Computer User Interface of DFS

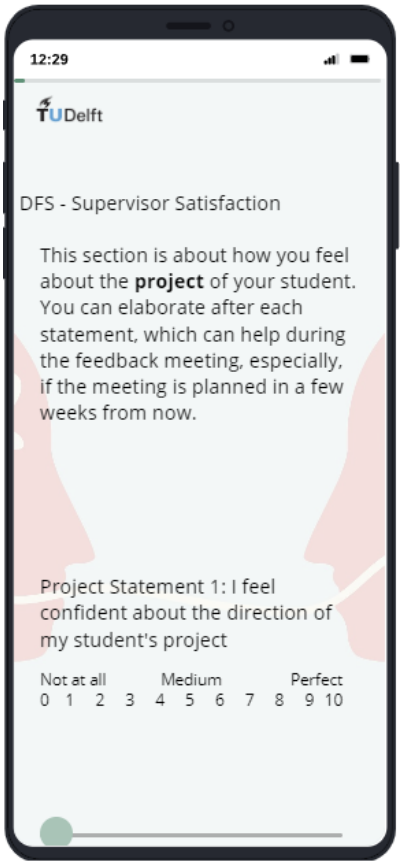


Figure B2 Mobile User Interface of DFS

B2– DFS User Manual 2023

DFS – User Manual

Content

Chapter 1

Introducing the Dual Feedback System

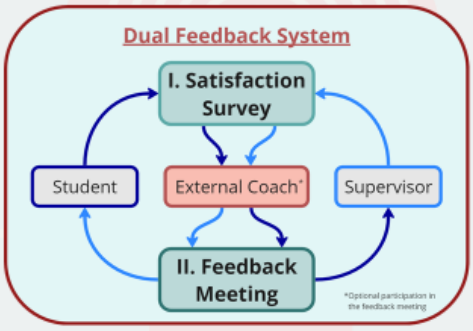
1. Introducing DFS

The purpose

The Dual Feedback System, or DFS, creates a platform where students and supervisors can give and receive **constructive feedback** (blue lines) at defined moments during the research project.

DFS consists of two parts, a **survey** and a **meeting**. In addition, DFS allows for the possibility of engaging an external coach to assist in conducting the meeting.

By enhancing communication around **non-content-related aspects** of research projects, such as project satisfaction and team satisfaction, this tool will improve team effectiveness, mental health and project management.

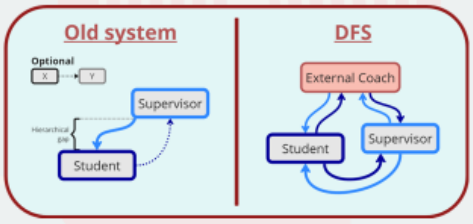


1. Introducing DFS

The users

DFS is designed to improve the communication between BSc, MSc and PhD **students** and their **supervisors**, as this relationship plays a central role in academic research projects. An adapted DFS can be used in other types of teams.

DFS is a platform to give feedback (blue lines) **during** the research project. It is a bridge that overarches the hierarchical gap between the student and supervisor. At **set moments**, the student and their supervisor fill in the survey, after which they have a feedback meeting, with or without an **external coach**.



Chapter 2

Part I: The Satisfaction Survey

2. Part I: The Satisfaction Survey

The three themes

Every 4 - 8 weeks, the student and supervisor fill out their own DFS satisfaction survey. Both surveys focus on three themes:
1) **Project**, 2) **Team**, and 3) **Supervision**.

Each theme has eight **statements** that can be scored from 0 (not satisfied at all) to 10 (extremely satisfied).

When both surveys are filled in, the external coach calculates the **average** satisfaction score for each theme and discloses the most **notable differences**.

This information is used in the feedback meeting, planned by the student and the supervisor. If desired, the external coach can take part in this meeting.

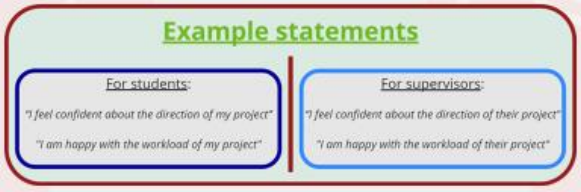
2. Part I: The Satisfaction Survey

Project Satisfaction

Project Satisfaction

This section of the survey is about how you feel about the **project** in general.

In this section, **eight statements** are given where you can give a score from 0 to 10 about the satisfaction you feel project-wise. After each statement, there is the opportunity to elaborate. This **elaboration** can be a useful reminder during the feedback meeting.



2. Part I: The Satisfaction Survey

Team Satisfaction

Team Satisfaction

This section of the survey is about how you feel about the **team**work experienced during the project.

In this section, **eight statements** are given where you can give a score from 0 to 10 about the satisfaction you feel project-wise. After each statement, there is the opportunity to elaborate. This **elaboration** can be a useful reminder during the feedback meeting.

Example statements

For students:

"I am happy with the connectedness to other people in my team"

"I feel supported by my team"

For supervisors:

"I am happy with my student's connectedness with other people in their team"

"The student is supported by the team"

2. Part I: The Satisfaction Survey

Supervision Satisfaction

Supervision Satisfaction

This section of the survey is about how you feel about the **supervision** given during the project.

In this section, **eight statements** are given where you can give a score from 0 to 10 about the satisfaction you feel project-wise. After each statement, there is the opportunity to elaborate. This **elaboration** can be a useful reminder during the feedback meeting.

Example statements

For students:

"I have the tools to do my research project well"

"I feel motivated by my supervisor"

For supervisors:

"I have given the tools to let my student do their research project well"

"I motivate my student"

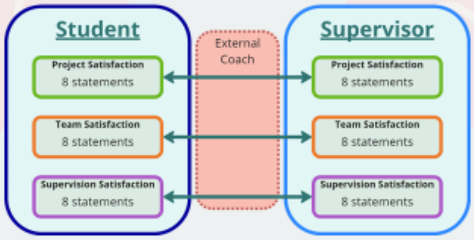
2. Part I: The Satisfaction Survey

Survey Results

After filling in the survey, the results of the **student** and the **supervisor** are compared to one another by the **external coach** (dark green lines).

The six extracted averages of the student and the supervisor will be saved in the database to keep track of the **development throughout the project**.

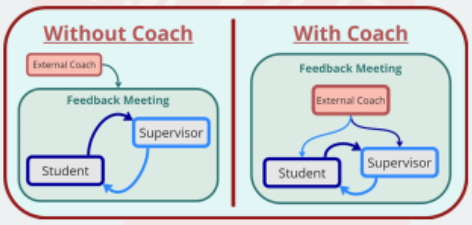
You can find examples of these graphs in Chapter 4.



Chapter 3

Part II: The Feedback Meeting

3. Part II: The Feedback Meeting



Setting Up the Meeting

The second part is the **feedback meeting**. Each time the surveys were filled in, the **student** and **supervisor** come together to give and receive feedback on the three themes.

If the student and supervisor opt for doing the feedback session by themselves, they will receive information from the coach. This information can then be used in the meeting.

If the **external coach** takes part in the meeting, they will be the bridge between both parties, enhancing the feeling of a safe environment for **constructive feedback**.

Chapter 4

Important Features of DFS

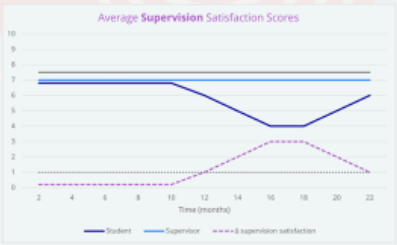
4. Important Features

Theme Satisfaction Scores

Below the average **project** and **supervision** satisfaction scores of a **student** and their **supervisor** are shown. The project lasted 22 months and every other month the survey was filled in.

When the satisfaction level drops **below 7.5** (grey line), it signals the presence of issues that require resolution. As such, the student and the supervisor must focus on addressing these concerns and discuss them during the feedback meeting to find viable solutions.

Involving the **external coach** in these meetings can be beneficial to come these solutions.



DFS – The Satisfaction Survey – The Feedback Meeting – **Features** – FAQs

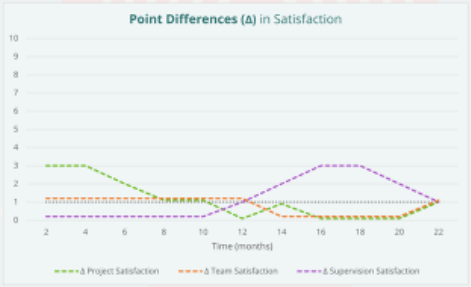
4. Important Features

Point Difference

Another important feature is the **point difference** or Δ. These lines show the difference in satisfaction between the student and the supervisor each time the surveys are filled in.

When **Δ rises above 1** (dotted grey line), it signals the presence of disparity between the satisfaction of student and supervisor. As such, the student and the supervisor must focus on addressing this gap and discuss how they can come to compromises to close it.

Next to improving the **project**, **team** and **supervision** satisfaction, the intent is to also gradually decrease the disparity in satisfaction levels between the student and the supervisor. This will lead to an increase in team effectiveness, mental health and project management , during the project.

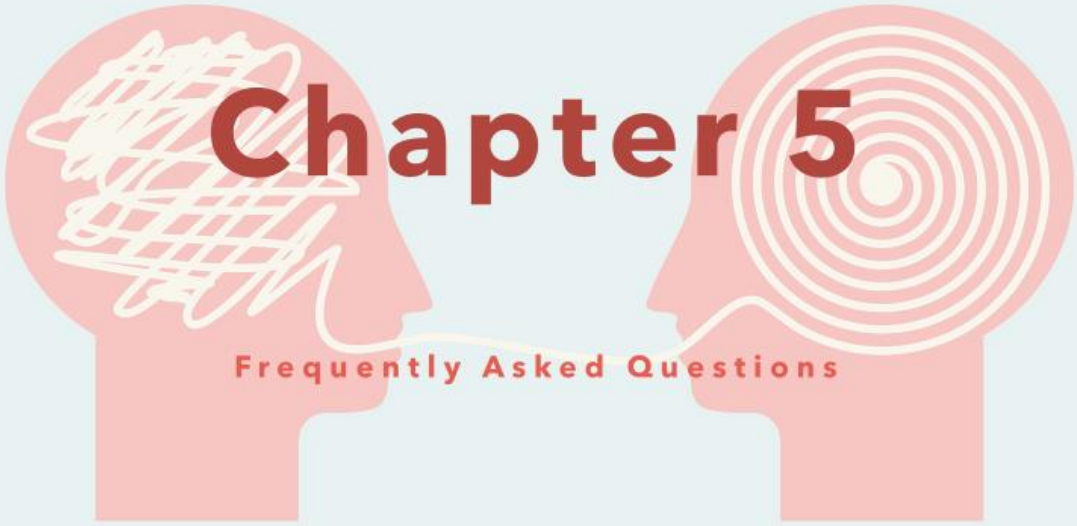


4. Important Features

Student and Supervisor Satisfaction

Next to the previous graphs DFS also combines the three themes in one graph for the **student** and the **supervisor** separately.

These graphs and the filled in elaborations can be shared with both parties **during** the project or **at the end** of the project.



5. Frequently Asked Questions

Q1 – "Are all the data shared with my supervisor or student?"

Only if you want to. The purpose of this tool is to create an environment where all participants feel safe. Only the averages are shared, and the most pressing issues will be discussed during the Feedback Meeting.

Q2 – "Is DFS mandatory?"

Hopefully, universities will implement this tool and make it mandatory. For now, it is a choice to use DFS if you feel like it can help you talk about problems during the project. The aim is that both students and supervisors will become more aware on how social interactions and discussing non-content-related matter can enhance team effectiveness, mental health and project management.

Q3 – "Will my satisfaction scores influence my final grade?"

No, the scores filled in during the Satisfaction Survey will not be used to influence your final grade. One of the most important aspects of DFS is, that it is implemented by the university to enhance communication between the supervisor and the student in a positive manner.

DFS – The Satisfaction Survey – The Feedback Meeting – Features – **FAQs**

5. Frequently Asked Questions

Q4 – "Do I need to invite the external coach to the Feedback Meeting?"

That is up to you. The external coach is assigned to supervisors and their students to analyse the data obtained in the Satisfaction Surveys. They are specialised in teamwork in the scientific field. It is advised to invite the coach to the Feedback Meeting if the levels of satisfaction obtained from the Satisfaction Survey are lower than 7.5 or if the gap (Δ) between student and supervisor is higher than 1. However, if you want extra coaching before or after the meeting you can always ask the coach for help.

Q5 – "Can I exclude the external coach and analyse the data myself?"

It is advised to let an external, independent coach analyse the data. DFS aims to create a safe environment where both parties can give and receive feedback, regardless of hierarchical differences. Students in general might feel restrained to give sincere feedback to their supervisors due to the grading scheme and hierarchy.

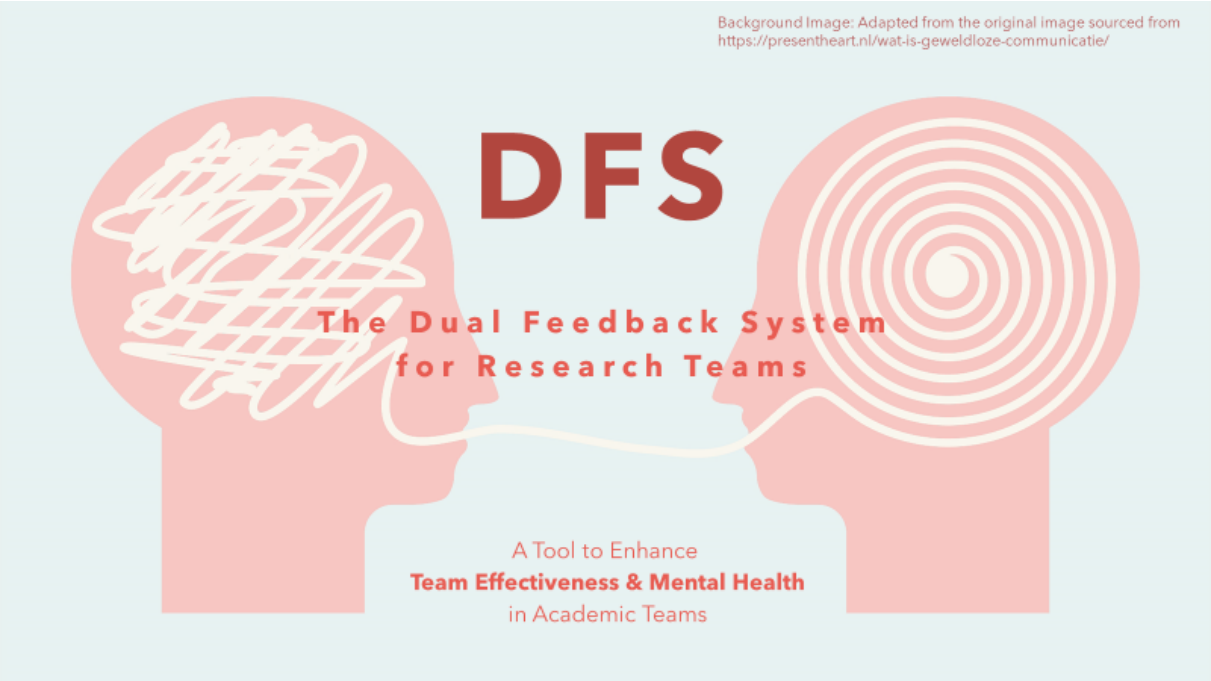


Figure B3 The User Manual of DFS, Background Image: Adapted from the original image sourced from https://presentheart.nl/wat-is-geweldloze-communicatie/

Appendix C – Consent Forms

C1 – Consent Form Interviews

Information about the study

This interview is conducted for the thesis of Josine Beets and will be used to get a better insight into the process of biodesign and how stakeholders in the biodesign field interact with one another. The information of this interview will be recorded and this recording will be saved on a TU Delft based data storage. The information of the recording will be extracted, can be quoted anonymously and will be used as a basis for the case study, of this thesis, in the biodesign field. The data is used in an anonymous way and no personal information will be used in the report.

Consent Form for Interview Thesis Josine Beets

I have read the information mentioned above, I have been able to ask questions about the study and my questions have been answered to my satisfaction.

I consent voluntarily to be a participant in this study and understand that I can refuse to answer questions and I can withdraw from the study at any time, without having to give a reason.

I understand that taking part in the study involves participating in a semi-structured interview that will be recorded to retract data afterwards.

I understand that I will receive no direct benefit for participating in this study and that the information I provide will be used for a suggested design to help collaboration in the biodesign field and other fields where interdisciplinary collaboration plays a central role.

I understand that if any personal information is collected about me that can identify me, [e.g. my name or where I live], this information will not be shared, will not be copied into the research and will be deleted after the thesis is done.

Name:

Date:

Signature:

C2 – Consent Form: Prototype DFS Student Satisfaction Survey

Information about the Dual Feedback System Student Satisfaction Survey Validation

This Satisfaction Survey is conducted for the thesis of Josine Beets and will be used to get a better insight into the relationship and feedback system between supervisor and student. The information from this survey will be processed and the data will be saved on a TU Delft-based data storage. The information from the survey will be extracted, can be quoted anonymously and will be used as a basis for the validation of the tool "DFS". The data is used anonymously and no personal information will be used in the report.

Consent Form for Validation on Student Satisfaction Survey of DFS
for the Thesis of Josine Beets

I have read the information mentioned above, I have been able to ask questions about the validation of the satisfaction survey of the tool and my questions have been answered to my satisfaction.

I consent voluntarily to be a participant in this research project and understand that I can refuse to answer questions and I can withdraw from the project at any time, without having to give a reason.

I understand that taking part in the research project involves participating in the validation of the satisfaction survey of the tool "DFS" and that the data will be retracted afterwards.

I understand that I will receive no direct benefit for participating in this study and that the information I provide will be used for the validation of a suggested design to help collaboration in the biodesign field and other fields where interdisciplinary collaboration plays a central role.

I understand that if any personal information is collected about me that can identify me, [e.g. my name or where I live], this information will not be shared, will not be copied into the research and will be deleted after the thesis is done.

Name:

Date:

Signature: X

C3 – Consent Form: Validation DFS Satisfaction Survey

Information about the Dual Feedback System Survey Validation

This Satisfaction Survey is conducted for the thesis of Josine Beets and will be used to get a better insight into the relationship and feedback system between supervisor and student. The information from this survey will be processed and the data will be saved on a TU Delft-based data storage. The information from the survey will be extracted, can be quoted anonymously and will be used as a basis for the validation of the tool "DFS". The data is used anonymously and no personal information will be used in the report.

Consent Form for Validation on Satisfaction Survey of DFS
for the Thesis Josine Beets

I have read the information mentioned above, I have been able to ask questions about the validation of the satisfaction survey of the tool and my questions have been answered to my satisfaction.

I consent voluntarily to be a participant in this research project and understand that I can refuse to answer questions and I can withdraw from the project at any time, without having to give a reason.

I understand that taking part in the research project involves participating in the validation of the satisfaction survey of the tool "DFS" and that the data will be retracted afterwards.

I understand that I will receive no direct benefit for participating in this study and that the information I provide will be used for the validation of a suggested design to help collaboration in the biodesign field and other fields where interdisciplinary collaboration plays a central role.

I understand that if any personal information is collected about me that can identify me, [e.g. my name or where I live], this information will not be shared, will not be copied into the research and will be deleted after the thesis is done.

Name:

Date:

Signature:

C4 – Consent Form: Validation DFS Feedback Meeting & Feedback on DFS

Information about the Dual Feedback System Feedback Meeting and Feedback on DFS

This Feedback Meeting is observed, by Josine Beets, for the thesis of Josine Beets and will be used to get a better insight into how the tool contributes to the feedback between supervisor and student. The information from this observation and feedback survey will be processed and the data will be saved on a TU Delft-based data storage. The information from the observation and survey will be extracted, can be quoted anonymously and will be used as a basis for the validation of the tool "DFS". The data is used anonymously and no personal information will be used in the report.

Consent Form for Validation on Feedback Meeting of DFS and Feedback on DFS for the Thesis of Josine Beets

I have read the information mentioned above, I have been able to ask questions about the validation of the feedback meeting of the tool and my questions have been answered to my satisfaction.

I consent voluntarily to be a participant in this research project and understand that I can refuse to answer questions and I can withdraw from the project at any time, without having to give a reason.

I understand that taking part in the research project involves participating in the feedback meeting of the tool "DFS" and a small survey after the feedback meeting. I understand that the feedback meeting is observed by Josine Beets and that the data of the meeting and the feedback survey on DFS will be retracted afterwards.

I understand that I will receive no direct benefit for participating in this study and that the information I provide will be used for the validation of the suggested tool to help collaboration in the biodesign field and other fields where interdisciplinary collaboration plays a central role.

I understand that if any personal information is collected about me that can identify me, [e.g. my name or where I live], this information will not be shared, will not be copied into the research and will be deleted after the thesis is done.

Name:

Date:

Signature:

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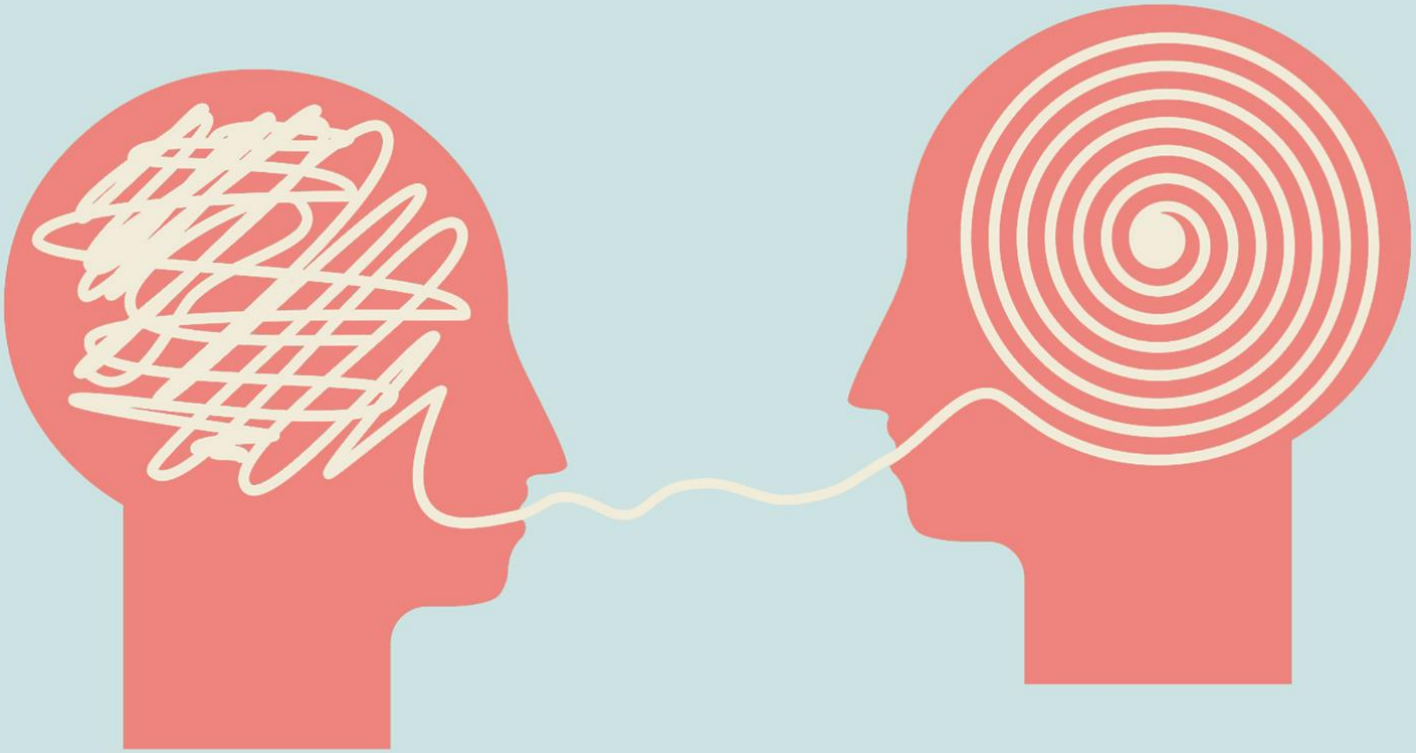
The Dual Feedback System



A Tool to Enhance

Team Effectiveness & Mental Health

in Academic Teams