Imperial College London
Dyson School of Design Engineering
Faculty of Engineering

Towards Supporting Shared Cognition in Distributed Multidisciplinary Teams: Design and Evaluation of an AI-based Affective Recognition System for Online Collaboration

Decentralised Tower of Babel: Challenges in virtual work and opportunities for machine learning in multidisciplinary collaboration - where design meets engineering and art meets tech.

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Doctor of Philosophy in Design Engineering of Imperial College London in 2024

Declaration of Originality

I hereby declare that this thesis is composed by myself, and the work it presents is my own, except where otherwise stated. All sources of information, including books, articles, websites, and any other resources, have been appropriately referenced and attributed. The coding for the machine learning app-based prototype Mood Man was accomplished in collaboration with Milad Laly and Mana Search. Parts of this thesis have been disseminated through conference or journal publications and are reused according to the respective copyright agreements. This research was conducted in the Dyson School of Design Engineering at Imperial College London, Faculty of Engineering between March 2019 and 2023. I certify that this thesis has not been submitted in whole or in parts as consideration for any other degree or qualification at this or any other institute of learning.

Copyright Declaration

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Abstract

This thesis investigates the challenges and opportunities of multidisciplinary design collaboration in distributed teams, with a particular focus on creativity and shared understanding. Using a Design Research Methodology (DRM) structure, this thesis leverages a literature review and qualitative research for the Descriptive Study, proposes a prototype for the Prescriptive Study, and provides an evaluation of the tool for the Descriptive study to help multidisciplinary teams improve distributed collaboration based on rigorous guidance on how to do so in practice: 1. What is our current understanding of multidisciplinary collaboration in relation to design teamwork? 2. How have previous studies been conducted through their experimental choices, and adopted setups? 3. How do we build a shared cognition with our teammates in distributed design collaboration? 4. How does affective recognition (including sentiment and emotion) affect shared understanding and creativity in text-based communication?

To answer these, we conducted a systematic literature review that identifies the main patterns and discrepancies in previous studies on multidisciplinary design collaboration, followed by an interview-based qualitative study that investigates the use of virtual collaboration tools and their impact on distributed collaboration and shared cognition. We developed a prototype with a machine learning-based dynamic affective recognition feedback system and conducted mixed-methods evaluation studies of the tool. Research shows that the prototype was effective in increasing both creativity and shared understanding in distributed multidisciplinary design collaboration.

The work draws on the research at the intersection of design studies, human-computer interaction, and team management, providing a better understanding of multidisciplinary distributed collaboration and suggests directions for AI solution designers looking to augment decentralised teamwork. Key contributions of this research include findings from a systematic literature review of prior empirical studies, insights from a qualitative study for improving the use of virtual tools in multidisciplinary design, an evidence-based prototype with an affective recognition feedback system which increases shared understanding and creativity in distributed design collaboration, and a set of guidelines for designing future AI-based tools.

"We two - if we could ever think as one, the Trojans' evil day would be postponed no longer."

Homer, The Iliad, 2.356-428

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Chapter 1

Introduction

Multidisciplinary design collaboration has become increasingly prevalent in today's dynamic and uncertain world. The integration of diverse knowledge, skills, and perspectives is seen as an effective means of generating creative solutions to complex problems.

Past research into multidisciplinary collaboration has produced a complex discourse with conflicting findings, lines of questioning, and methodologies. It is consequently unclear as to what exactly has been concluded and debunked, as well as how and what to study next. On the one hand, an extensive body of literature highlights the benefits of multidisciplinary collaboration (Milliken and Martins, 1996; Troy et al., 2008; De Luca and Atuahene-Gima, 2007). On the other hand, there remain numerous challenges to integrating plural knowledges – the higher the discrepancy in the functional diversity among team members, the higher the risk of task disagreement (Cronin and Weingart, 2007; Van Der Vegt and Bunderson, 2005; Lovelace et al., 2001).

Moreover, with the recent rise of hybrid and remote working, multidisciplinary design collaboration has become even more challenging. The physical separation of team members, differences in time zones, and lack of face-to-face communication can all pose significant barriers to creative collaboration. As a result, it is essential to explore new ways of facilitating multidisciplinary design collaboration in distributed teams. This thesis investigates the challenges and opportunities of multidisciplinary design collaboration in distributed teams, with a particular focus on creativity and shared understanding.

1.1 Motivation and Objectives

It has been suggested in the report by McKinsey & Co (Sheppard et al., 2018) that there is a strong correlation between employing design practices - MDI McKinsey Design Index scores - and high business performance. The study shows that companies in the top-quartile scores have managed to increase their revenues by 32 percent over the five years comparing to their competitors. In the case of the total returns to shareholders, this growth has reached 56 percent. This phenomenon appeared true in all three studied industries - medical technology, consumer goods, and retail banking. Following such findings, it has been underlined by the authors that design practices are applicable, and yet even beneficial for the development of physical goods, digital products and services, or a combination of these.

In addition to design practices, leaders from most innovative companies from the BCG 2019 report (Ringel, 2019), in the last few decades, have extensively referred to the importance of team collaboration in the innovation design processes. Microsoft co-founder Bill Gates describes for BBC (2007):

> Communication skills and the ability to work well with different types of people are very important, software innovation, like almost every other kind of innovation, requires the ability to collaborate and share ideas with other people.

Another example from the co-founder of Apple - Steve Jobs - mentioned in his biography (Isaacson, 2011):

> My model for business is The Beatles. They were four guys who kept each other's kind of negative tendencies in check. They balanced each other and the total was greater than the sum of the parts. That's how I see business: great things in business are never done by one person, they're done by a team of people.

Team collaboration discourse is undergoing a remarkable revolution as its virtual factor

has become a widespread common practice in companies of all industries. At Alphabet\Google, another company from the top 5 most innovative ones, 100 000 employees are spread out over 150 cities from more than 50 countries already in 2019. A company report (Gilrane, 2019) highlights that nearly half (48%) of meetings in Google involve employees working from different buildings, and 4 out of 10 meetings involve different cities.

Previous study of Olson and Olson (2000) on remote work suggests that distributed teams may still face challenges due to the inherent impact of physical distance. The success of remote collaborations depends on factors such as strong common ground (see Clark and Brennan (1991)), or shared perspectives (see Whittaker (2003)), and loosely coupled work, with readiness both for collaboration and collaboration technology, where any deviations from these factors can strain team relationships and necessitate adjustments in work processes. Yet the groundbreaking report from Guinney et al. (2017) refers to the global competition for cancer survival rates prediction, that took place entirely virtually via a crowdsourcing platform. In the light of such event, there is now concern about how online presence is influencing the way we work and collaborate? Another interesting characteristic of the winning Finnish team is the fact that they have not been active in cancer research. This raises the question for our interest in how is discipline knowledge affecting creativity and design processes?

Design studies, and especially design thinking in previous research used to mean something different than nowadays, as Goldschmidt (Christensen et al., 2017) mentions:

> It was not meant to be a methodology (...) it was just a way of talking about how designers in different disciplines think.

As a result, the theme has evolved in the last decades and evolved from the study of design practices to wide-ranging research of co-creation across various disciplines, including team communication and cross-cultural collaboration. The DTRS (Design Thinking Research Symposium) meetings started in 1991 with the research on design practices have developed into extensive researches on co-design and co-creation (D'Souza and Dastmalchi, 2017). An extensive literature body highlights the benefits of these, especially in terms

of multidisciplinary collaboration, however, there has not yet been a comparative investigation on multidisciplinary design collaboration research and thorough analysis of how the studies can help to solve the issues of the current innovation creation needs.

The primary objective of this thesis is to explore the challenges and opportunities involved in augmenting multidisciplinary collaboration. Firstly, we address the overarching topic through the literature review addressing following questions:

1. What is our current understanding of multidisciplinary collaboration in relation to design teamwork?
2. How have previous studies been conducted through their experimental choices, and adopted setups?

Our next investigation inspired by the findings from that review focuses on the question:

1. How do we build a shared cognition with our teammates in distributed design collaboration?

Lastly, to examine the AI-based prototype for virtual teamwork, the last study looks at the research question:

1. How does affective recognition (including sentiment and emotion) affect shared understanding and creativity in text-based communication?

The main goal of this thesis is to examine multidisciplinary design collaboration in the context of distributed teamwork and suggest a machine learning-based tool for augmenting design creativity and shared cognition.

1.2 Overview

The structure of this thesis adopts DRM - a Design Research Methodology, proposed by Blessing and Chakrabarti (2009), and a brief overview of each chapter is demonstrated as follows:

Chapter 1 provides the background and context for the research projects included in this thesis, with the aim of providing an overview of the main topics covered in this work. While the review of past research may not be exhaustive, its primary purpose is to provide context for the main topics discussed in this thesis. Additionally, this chapter outlines the research questions and objectives of this study. The structure of the thesis is also outlined in this chapter to give an overview of the overall organisation of the work.

Chapters 2 and 3 provide a detailed and comprehensive Descriptive Study (see Blessing and Chakrabarti (2009)). In chapter 2, a systematic literature review of empirical studies on multidisciplinary design collaboration is presented. This includes the introduction and analysis of fundamental concepts that are analysed in this work: multidisciplinary collaboration, shared cognition, and design context. Through a co-occurrence analysis using natural language processing (NLP) and in-depth meta-analysis, this chapter presents an overview of the findings, methods, and challenges of previous research on the topic of multidisciplinary design collaboration, providing a foundation for the subsequent studies in the thesis. Since the findings highlight lack of studies for shared cognition in distributed collaboration, chapter 2.6 delves deeper into multidisciplinary collaboration through the lenses of CSCW (Computer-Supported Cooperative Work) and current technology enablement. This study discusses how technology can facilitate or hinder collaboration, and shared cognition among designers and team members from different disciplines, and how asynchronous distributed teamwork is challenged most in terms of shared understanding and trust.

Chapter 3 presents a qualitative study focusing on the challenges of distributed multidisciplinary creative teamwork in the context of shared cognition. The paper "We're Still People And Not Only Emails That We're Sending" investigates how team members in different locations collaborate and share knowledge on creative work, despite being physically separated. Through the analysis of the virtual communication ecology, the study reveals attitudes and beliefs being the most vulnerable for team shared understanding.

Finally, in chapter 4, we explore the use of affective recognition technology through machine learning and natural language processing to improve multidisciplinary distributed creative teamwork. The Prescriptive Study, namely the design of the tool (Blessing and

Chakrabarti, 2009), includes "Moody Man" - a case study of a Slack-based prototype that uses dynamic affective recognition to monitor and support the emotional portrayal of team members during the design process. The evaluation of the tool for the Descriptive study (Blessing and Chakrabarti, 2009), includes the mix-methods study that examines:

- quantitatively, the improvement in measures of team creativity and shared understanding,
- and qualitatively, the challenges and design guidelines for machine learning-based tools and useful context for affective recognition in virtual collaboration.

Together, these chapters provide a comprehensive examination of the challenges and opportunities of distributed multidisciplinary design collaboration, and offer insights into how technology can be leveraged to improve shared cognition and creativity in such teamwork. To provide a visual overview of the structure of this thesis, Fig. 1.1 presents a flow diagram for each chapter.

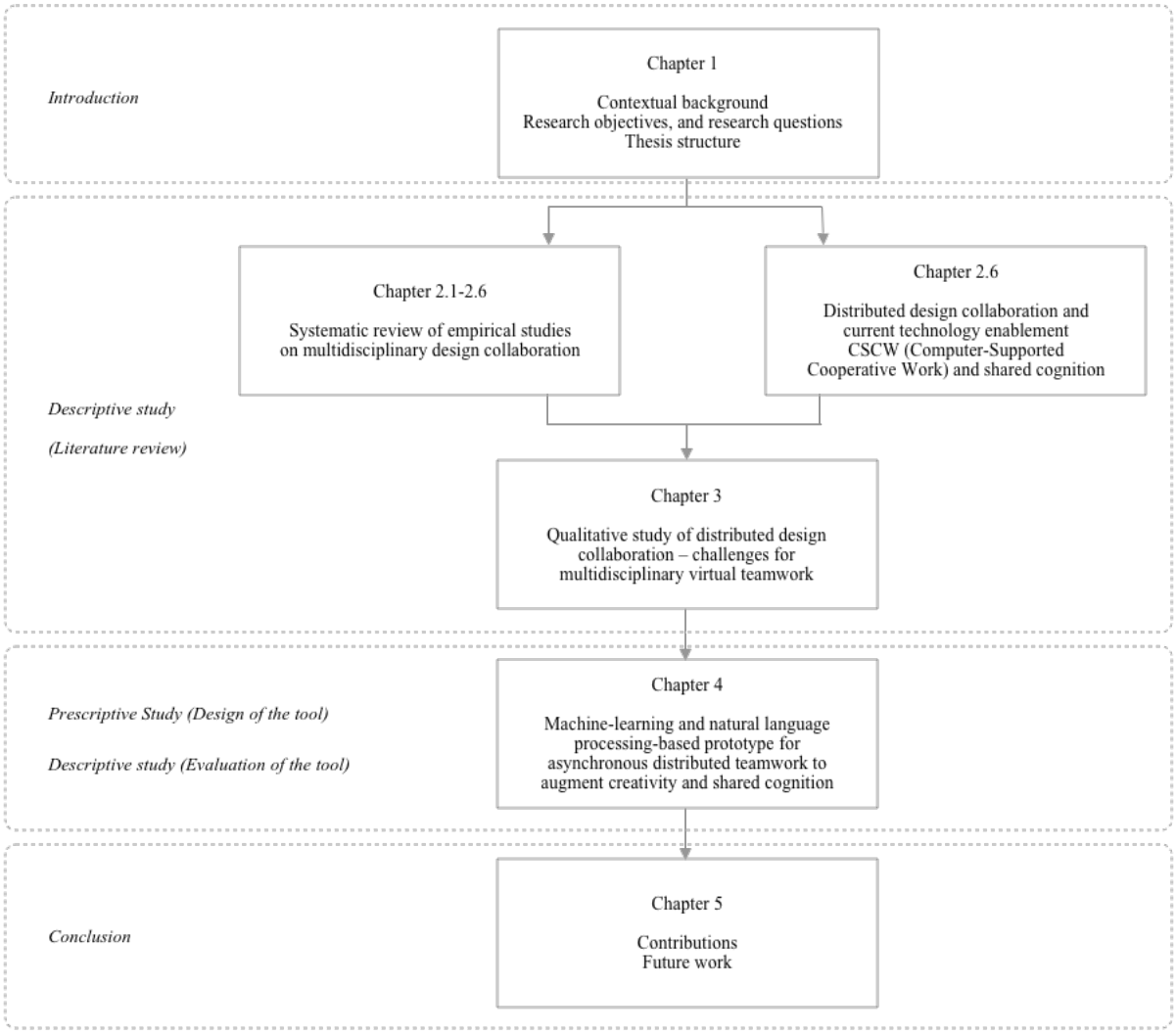

Figure 1.1: Structure of the thesis based on DRM: Design Research Methodology (based on Blessing and Chakrabarti (2009)).

1.3 List of Publications

Title	Year	**Publication**	**Chapter**
A systematic review of empirical studies on multidisciplinary design collaboration: Findings, methods, and challenges	2022	Design Studies 81, 101120	2
Dimensions of multidisciplinary collaboration: a comparative literature review within design context.	2020	DESIGN Conference. Vol. 1. Cambridge University Press (Reviewers' Favourite Award)	2
Multidisciplinary design collaboration in the lenses of CSCW and current technology enablement	2020	DRS International Conference	2.6
We're Still People And Not Only Emails That We're Sending-Shared Cognition In Distributed Design Collaboration	2022	International Electronics Communication Conference (IECC), 40-46, ACM	3
Moody Man: Improving creative teamwork through dynamic affective recognition	2022	CHI Conference on Human Factors in Computing Systems Extended Abstracts, 1-14, ACM	4

Table 1.1: Publication list

Interlude

The first book of Moses narrates how "the whole earth had one language and (...) the men said to each one another – come, let's us build ourselves a city, and a tower with its top in the heavens" (Genesis 11:1–9). But their efforts were thwarted by the Lord, who ordained: "Come let us go down, and there confuse their language, that they may not understand one another's speech (...) therefore its name was called Babel, because there the Lord confused the language of all the earth" (Ibid.). The myth of the Tower of Babel is a cautionary tale about the dangers of overconfidence and the importance of communication to achieving success. Innovation today demands multidisciplinary collaboration, with teams comprised of varied backgrounds, perspectives, and expertise.

Figure 1.2: Pieter Bruegel the Elder, 1563. The Tower of Babel.

Chapter 2

Systematic literature review of multidisciplinary design collaboration

2.1 Introduction

Collaboration lies at the heart of design activity, and in the past thirty years, a significant body of research has focused on the empirical study of team collaboration during designing activities, for example, the Design Thinking Research Symposium (DTRS) series that launched in 1991. Over the years, research into multidisciplinary design collaboration has rendered a complex discourse with differing findings. While an extensive body of literature highlights the benefits of multidisciplinary collaboration (De Luca and Atuahene-Gima, 2007; Milliken and Martins, 1996; Troy et al., 2008), the latter is also found to be associated with challenges related to integrating diverse knowledge (Cronin and Weingart, 2007; Lovelace et al., 2001; Van Der Vegt and Bunderson, 2005). As a result, it is unclear to conclude what has already been investigated and explored, as well as how, and what to study next.

However, there has not yet been a systematic review of the findings and methodological analysis of how these studies on multidisciplinary design collaboration were conducted.

Our systematic review on the relevant studies bears threefold objectives: (1) to synthesise and identify patterns in the literature, (2) to acknowledge the diversity of results through a methodological analysis, and (3) to clarify current challenges and provide recommendations for future research (Figure 2.1). This paper aims at answering the following research questions: (1) What is our current understanding of multidisciplinary collaboration in relation to design teamwork, and (2) How previous studies have been conducted through their experimental choices and adopted setups? The paper is structured as follows: We first present the scope of the paper, i.e. multidisciplinary design collaboration (Section 2.1.2). We then describe our methodological approach (Section 2.2) which consists of a systematic review of the literature (PRISMA), supported by a co-occurrence analysis of the findings of the papers and a meta-analysis of the designs and variables of the studies. We then present the results of our literature review: Section 2.3 presents what has been studied, i.e. the findings of previous studies organised in thematic clusters, and Section 2.4 reports how it has been studied, i.e. a methodological analysis reporting the designs of the studies, and their variables. Finally, we provide a synthesis of the results, as well as recommendations for future research.

2.1.1 Overview of the study

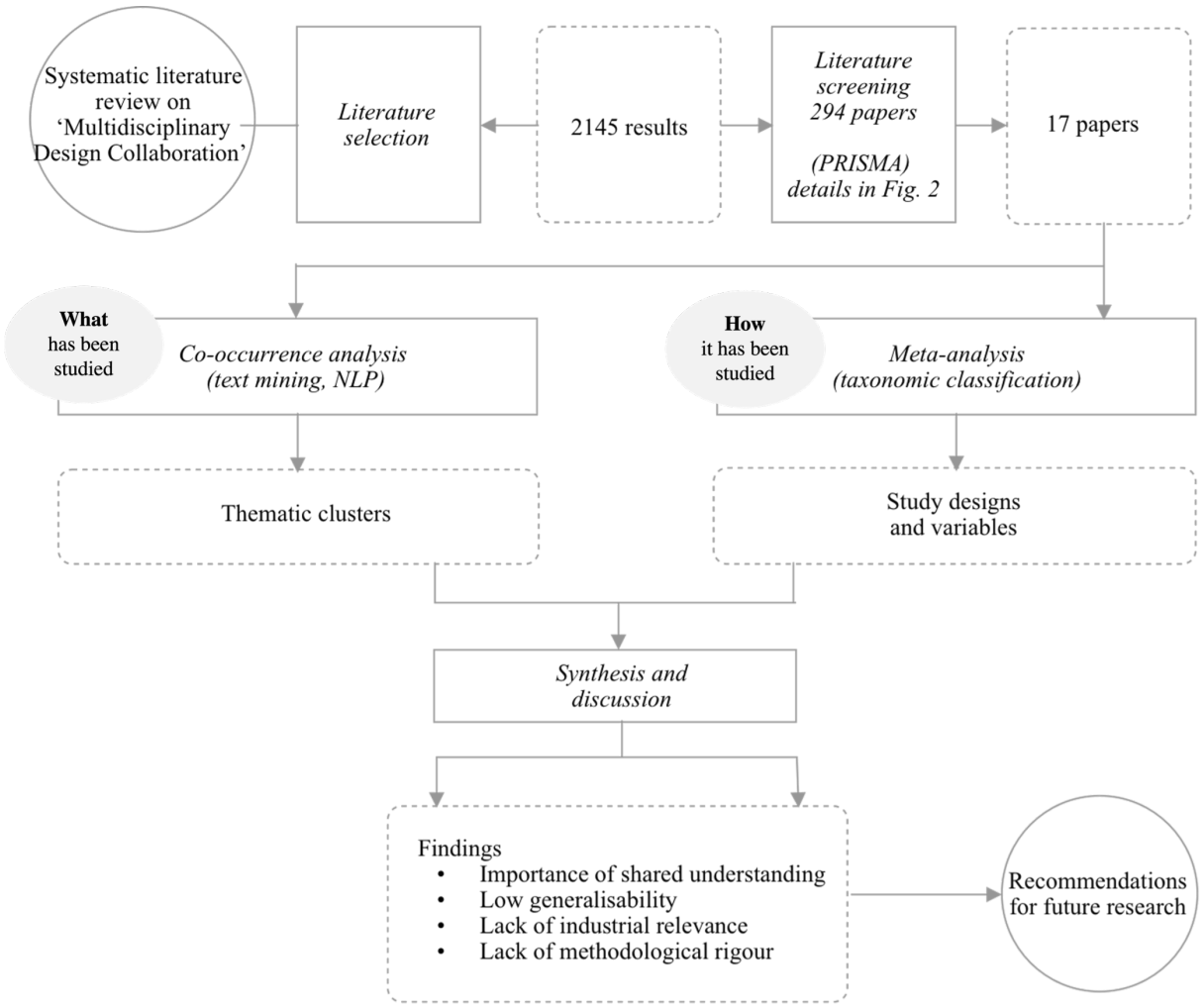

Figure 2.1: Overview of the study

The originality of this paper lies in the combination of a common approach for systematic literature review, i.e. PRISMA (Preferred Reporting Items for Systematic reviews and Meta-Analyses) (Moher et al., 2009; Page et al., 2021) with a novel approach to semantic analysis and knowledge mapping, i.e. co-word analysis with co-occurrence network, based on text mining and natural language processing – NLP (Callon et al., 1983; Van Eck and Waltman, 2014).

2.1.2 Scope of the paper: Multidisciplinary design collaboration

The main focus of this paper is the study of multidisciplinary design collaboration, specifically the scientific examination of the teamwork mechanisms and behaviours, in functionally diverse teams, that aim to produce creative outputs. Agogué et al. (2014) suggest that disciplinary backgrounds might also affect the scope of solution analysis: e.g. industrial designers might be more capable of overcoming design fixation than engineers, where engineers tend to create less variety of solutions compared to designers. On the other hand, Gero et al. (2019) noted that engineering design education plays a significant role in the development of design creativity. In fact, engineering firms now integrate various types of knowledge in their projects (Sonnenwald, 1996), where such a skill-set combination created for a particular purpose is defined in the industry as cross-functional teamwork (Parker, 2003).

Three different terms are used in the literature to describe cross-disciplinary practice where transgression into and across other disciplines takes place (Adams et al., 2009):

- multidisciplinary - joining together of disciplines to work on common problems and split apart when work is done,
- interdisciplinary - joining together of disciplines to work or identify common problems, and interaction may form new knowledge, and
- transdisciplinary - beyond interdisciplinary combinations to a new understanding of relationships between science and society.

Few studies refer to interdisciplinary as a separate level or practice in the disciplinary integration differentiation (see Miller and Miller (1982); Stember (1991); Porter et al. (2006)). Van den Besselaar et al. (2001) define a higher level of synthesis with the term "transdisciplinary", where the process of convergence between disciplines occurs with mutual integration of disciplinary epistemologies. While a set of scholars who focus on cross-disciplinary work have attempted to draw theoretical or philosophical distinctions among terms (Choi and Pak, 2006), in practice many researchers studying such collaboration use the terms interchangeably (see Kasali and Nersessian (2015)). In other words,

Klein (2008) is attempting to theorise different modes of collaborating across disciplinary boundaries, but the people interested in how the collaborations work are often less concerned with the terminology and more concerned with the collaboration itself. In fact, while solving complex problems, all team participants do cross their knowledge boundaries and synthesise practices from each other's disciplines (Kleinsmann et al., 2012). So, for ease and consistency throughout the paper, we refer to all layers of collaboration by the term multidisciplinary. Given the importance of communication as a core concern in cross-disciplinary collaborations, significant work in this area exists in a variety of domains, including the body of literature on communication. For this review, we limit the scope of the work to design studies in order to survey design researchers' existing understanding of such collaboration.

2.2 Methodology

This review of literature consisted of (1) a comparative theoretical synthesis of patterns and themes, supported by co-occurrence analysis, and followed by (2) a methods-oriented perspective inquiry of a meta-analysis (Robson and McCartan, 2016). The systematic review protocol ensures a rigour in screening and selection of the literature, as inclusion and exclusion criteria are applied in a systematic way. This approach is argued to provide completeness and depth of the analysis (Hay et al., 2017). The following critical review covers the themes unearthed by the co-occurrence analysis, whereas the meta-analysis acknowledges and surveys the diversity in the findings based on methodological factors, as in Vasconcelos and Crilly (2016), and raises questions for further research.

2.2.1 Literature screening and selection

Search protocol

The selection of the literature followed the Preferred Reporting Items for Systematic reviews and Meta-Analyses (PRISMA) protocol – a widely used method for systematic review of scientific publications (Moher et al., 2009; Page et al., 2021). In order to mitigate

biases related to selective reporting of outcomes, the protocol involves the selection of all publications on a given topic that meet pre-specified inclusion criteria (Shamseer et al., 2015). Although there are examples of systematic reviews in other areas of design studies, i.e. design cognition (Hay et al., 2017; Jin and Benami, 2010), this paper is the first systematic review of the literature on multidisciplinary design collaboration (Figure 2.2). The following databases were searched for articles published in peer-reviewed journals: Science Direct, Thomson Reuters Web of Knowledge, MIT Press Direct, and Taylor & Francis Online.

Selection protocol

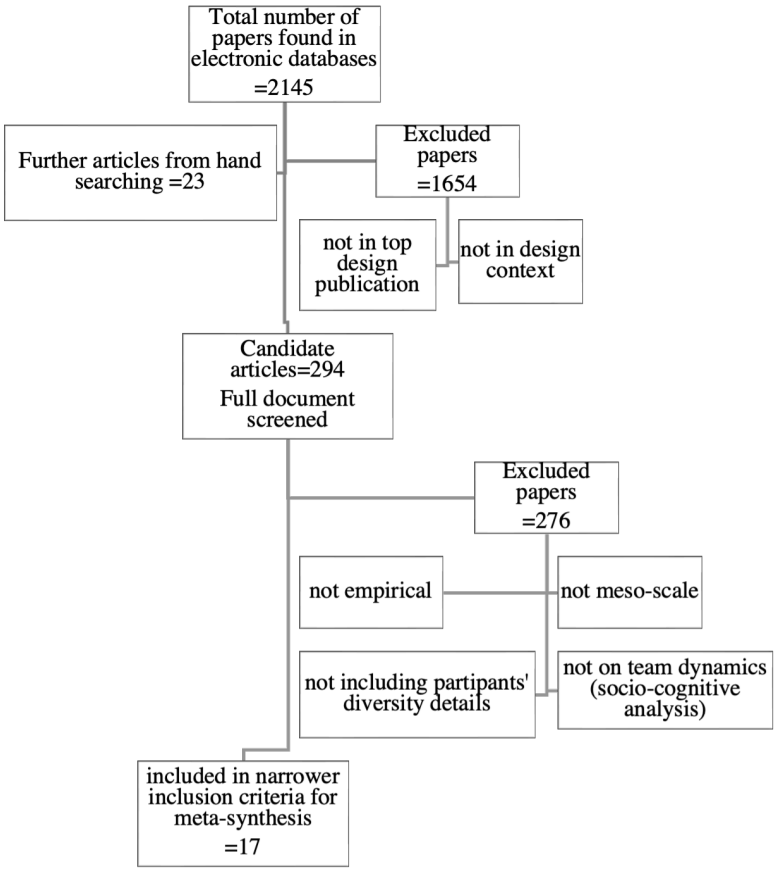

Figure 2.2: PRISMA diagram for systematic review (based on Moher et al., 2009)

From a pool of 2145 publications on multidisciplinary collaboration, only 294 articles reported studies within a design context. To ensure that the selected papers met high-quality standards, we screened the top four general design research journals suggested

by Gemser et al. (2012, p.12) and Cash (2018): Design Studies, Design Issues, Journal of Engineering Design (JED), and International Journal of Design (IJD), and included CoDesign (since DTRS7 and DTRS10 were published in its Special Issues) in our search within the bibliometric databases using the structure of the search terms in 2.1. We additionally included other relevant publications by searching citations from included articles to broaden the candidate articles dataset, from journals, conferences, and books (see Christensen et al. (2017)) following a references check.

Practice AND	Domain AND	Participants AND	Activity
multidisciplinary OR transdisciplinary OR interdisciplinary OR cross-functional OR	design	team	collaboration OR teamwork

Table 2.1: Structure of search terms

Inclusion and exclusion criteria

The evaluation of articles against the six established inclusion criteria (see Table 2.2) resulted in the selection of the 17 publications published between 1992 and 2021 (see Table 2.3).

No.	Inclusion criteria
1	Article must be published in English.
2	Article must report findings on meso-scale (team-level) collaboration.
3	Article must provide an overview of the empirical study
4	Study participants must work in teams.
5	Study participants must carry out a design task (including engineering design, product design engineering, or architectural design).
6	Authors must identify characteristics of participants in the context of disciplinary - functional/professional/educational - background (task-oriented diversity).

Table 2.2: Inclusion criteria

Authors	Title	Year	Source title
Adams R., Mann L., Jordan S., Daly S.	Exploring the boundaries: Language, roles and structures in cross-disciplinary design teams	2009	About: Designing - Analysing Design Meetings
Austin S., Steele J., MacMillan S., Kirby P., Spence R.	Mapping the conceptual design activity of interdisciplinary teams	2001	Design Studies
Awomolo O., Jabbariarfaei J., Singh N., Akin Ö.	Communication and design decisions in cross-functional teams	2017	Analysing Design Thinking: Studies of Cross-Cultural Co-Creation
D'Souza N., Dastmalchi M.R.	"Comfy" cars for the "awesomely humble": Exploring slang and jargons in a cross-cultural design process	2017	Analysing Design Thinking: Studies of Cross-Cultural Co-Creation
D'souza N., Dastmal-chi M.R.	Creativity on the move: Exploring lit-tle-c (p) and big-C (p) creative events within a multidisciplinary design team process	2016	Design Studies
Feast L.	Professional perspectives on collabora-tive design work	2012	CoDesign
Haines-Gadd M., Hasegawa A., Hooper R., Huck Q., Pabian M., Portillo C., Zheng L., Williams L., McBride A.	Cut the crap; Design brief to pre-production in eight weeks: Rapid de-velopment of an urban emergency low-tech toilet for Oxfam	2015	Design Studies
Hu Y., Li Y., Du X.	Thinking in interdisciplinary design teams based on workshop	2017	Design, User Experience, and Usability: Theory, Methodolo-gy, and Management
Jutraz A., Zupanic T.	The Role of Architect in Interdiscipli-nary Collaborative Design Studios	2014	Igra ustvarjalnosti - Creativity Game
Kasali A., Nersessian N.J.	Architects in interdisciplinary contexts: Representational practices in healthcare design	2015	Design Studies
Kleinsmann M., Valkenburg R.	Barriers and enablers for creating shared understanding in co-design projects	2008	Design Studies
Kleinsmann M., Deken F., Dong A., Lauche K.	Development of design collaboration skills	2012	Journal of Engineering Design
Kokotovich V., Dorst K.	The art of 'stepping back': Studying levels of abstraction in a diverse design team	2016	Design Studies

McDonnell J.	Collaborative negotiation in design: A study of design conversations between architect and building users	2009	About: Designing - Analysing Design Meetings
Sonnenwald D.H.	Communication roles that support col-laboration during the design process	1996	Design Studies
Wang J.K., Roy S.K., Barry M., Chang R.T., Bhatt A.S.	Institutionalizing healthcare hackathons to promote diversity in collaboration in medicine	2018	BMC Medical Education
Zolin R., Hinds P.J., Fruchter R., Levitt R.E.	Interpersonal trust in cross-functional, geographically distributed work : A longitudinal study	2004	Information and organization

Table 2.3: List of core literature

Excluded papers (see examples in Table 1 in the Appendix) are publications that did not fulfil the disciplinary diversity criterion – against the inclusion criteria no. 6 (Table 2.2). For example, in Badke-Schaub et al. (2010, p.123) where the examined team, defined as multidisciplinary, was in fact "composed as diversely as possible (male and female designers, of different nationalities with a different amount of expertise)". Or studies that do not sufficiently demonstrate the multidisciplinarity of the team, as in Gruenther et al. (2009, p.725) where the team is "composed of engineering students from several majors". Or studies that are lacking operationalised variables to empirically investigate team collaboration, as in Kuusk et al. (2020) in a recent CoDesign Special Issue on cross-functional collaboration, where the authors noted that their work "lacked prior hypotheses or were not aligned with the traditional structure of an empirical research paper" (Kuusk et al., 2020, p. 323–324). Four DTRS meetings on teamwork were identified by Christensen and Ball (2019) - DTRS2, DTRS7, DTRS10 and DTRS11 - but using the selection criteria, we included publications from two of these meetings, and excluded the other two, based on inclusion criteria 2 and 6 (see Table 1 in the Appendix).

2.2.2 Co-occurrence analysis

For the analysis of the selected literature, we collected bibliometric data of the 17 selected papers from Scopus – the world's largest abstract and citation database. The co-occurrence analysis method enables to construct and visualise a network of emerging themes, i.e. connections within a body of text using linguistic analysis of relationships between words for pattern recognition Godwin (2016) and nodes – representations of important terms, their weights and their location within the network Van Eck and Waltman (2014). We employ co-occurrence networks as a supportive tool to reveal patterns that are then further discussed. To perform the text mining functionality and create the term map (see Figure 2.3), we use VOSViewer applying natural language processing (NLP) algorithms Van Eck and Waltman (2011). The co-occurrence network has been created with the following steps:

1. tagging the body of text content through Apache OpenNLP toolkit (identification of verbs, nouns, adjectives, etc.),
2. identification of noun phrases, and converting plural noun phrases into single ones (Linguistic filter: e.g. team, visualisation, design communication, and disciplinary expertise, but not degrees of freedom and highly cited publication),
3. selection of the most important noun phrases - the larger the difference between the two distributions (measured using the Kullback-Leibler distance), the higher the relevance of a noun phrase (e.g. low relevance noun phrases: team, paper, results; high relevance noun phrases: expert designer, knowledge, domain),
4. grouping of noun phrases with a high relevance into clusters (themes).

In order to unclutter the representation, only the co-occurrences with a high frequency were included in this analysis. For each theme, the size of the label circle and its font size mirror the theme's importance, and the varying colours represent classification clusters. These clusters led to five identified theme relationships that are used to guide the qualitative analysis of the core literature.

2.2.3 Meta-analysis

In addition, we conducted a meta-analysis of the design and variables of each study, using an adapted version of the Collaborative Design taxonomy from Ostergaard and Summers (2009). Table 2.4 presents the taxonomy classification adopted by the authors, with factors included in the meta-analysis. To address the second part of our research question which focuses on the methodological analysis of design and implementation of the studies, we extended the taxonomy with additional variables (the design approach and research methodologies).

Factor of the taxonomy	Sublevel	Adapted
Team composition	Group (size and culture)	included
	Individual (expertise)	included
	Leadership styles (type)	included
Distribution	Personnel	included
	Information	included
Nature of Problem	Abstraction	included
	Complexity	included
Design approach	Duration	added
	Stage	included
Research methodology	Study setting	added
	Sample	added
	Type	added
	Industry	added

Table 2.4: Collaborative design taxonomy (adapted from Ostergaard and Summers, 2009)

2.3 Findings: 'Communication' and other emerging sub-themes

In this section, we address the question of what has been studied and found. The co-occurrence analysis of the selected literature shows that these studies address five main

themes: Communication, Knowledge and diversity, Trust and context, Barrier and design communication, Jargon and roles. As shown on the co-occurrence network map (Figure 2.3) constructed from the text mining functionality (see Section 2.2.2), communication is a key component of all the subthemes. Here, we investigate four theme pairs identified through the co-occurrence network map (hence being guided by the terms from the linguistic analysis output), synthesise each of them in the qualitative analysis, and discuss the role of communication within these.

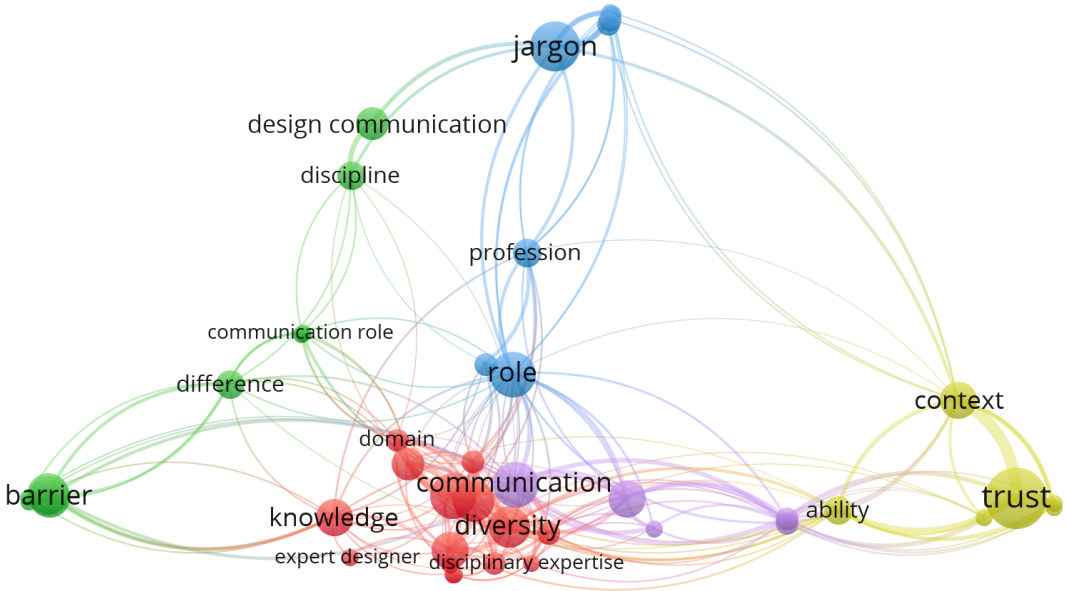

Figure 2.3: Co-occurrence map of emerging themes

2.3.1 Communication

The analysis of papers reveals that all studies show communication and social interactions as key elements of multidisciplinary design collaboration, as reported below.

Firstly, the co-occurrence analysis highlights that communication is a core theme in the selected literature, being linked to and embedded in all other theme clusters. Design is a social process (see Bucciarelli and Bucciarelli (1994)) and social interactions are a critical component of design activity, as they account for 21% of the conceptual design activity time (Austin et al., 2001). Sonnenwald (1996) even suggests that interpersonal

talks may facilitate the discovery of other participants' perspectives, which can lead to establishing personal bonds. This suggests that shared ownership over design outcomes within a multidisciplinary team can be created through communication and social interactions. In fact, the dynamics of interpersonal relations in design meetings, involving the mutual regulation of tensions and affects, has a significant effect on the efficiency of the collaboration and on the quality of the design outcomes (Détienne et al., 2012).

Secondly, scholars looking at design communication find cultural diversity often as critical as disciplinary diversity. Jutraz and Zupancic (2017) explored the differences in communication styles between team members from Asia or from Europe and identify participants' national-specific characteristics as a common communication obstacle. In their study, respondents pointed out that the most challenging part of communication relates to cultural diversity or individual differences, not to disciplinary diversity. A study on design collaboration within teams with East-Asian value orientation (see Taoka et al. (2018)) showed that the cultural orientation of the team members, in particular their 'Power Distance' score, affected the quality of collaboration and the level of engagement of the team members. Within our core literature, Zolin et al. (2004) find that such cultural differences result in varying expectations, lower predictability, and following decrease of the trust level. They suggest that the underlying rationale for this can be cultural misunderstandings instead of potential prejudices. In a similar study including Asian - European meetings, D'Souza and Dastmalchi (2017) take on the investigation of language within the cross-cultural design process. Their analysis of slangs used by Eastern and Western participants reveals the different characteristics between these two groups (individual vs. collective, expressive vs. restrained). They also discover the presence of the cultural brokers in the meetings which raises a question on how the design process can overcome barriers from cross-cultural jargon.

Nevertheless, communication challenges appear beyond cultural differences; the following sections will discuss the subtheme pairs revealed in the co-occurrence analysis that oscillate around the central notion of communication in multidisciplinary design collaboration.

2.3.2 Knowledge and diversity

Another important theme of the literature highlighted by the co-occurrence analysis is knowledge and diversity, which relates to the diversity of knowledge and experience associated with one's disciplinary background. In all studies, authors define teams involved as multidisciplinary or interdisciplinary. We find that none of the common classification taxonomies was used to differentiate the disciplinary distinctiveness.

As a result, many of the participants were derived homogeneously from creative backgrounds; they were often arranged with or simulated by designers and design-related professionals. In order to tangibly disseminate the specific disciplines, we analysed the disciplinary background of individual team members in the studies following the Classification of Instructional Programs (CIP)[1] (50.04 Design and Applied Arts; 11.01 Computer and information sciences; 04.02 Architecture; 14.01 Engineering; 52.01 Business/Commerce) and defining industrial experts as consulting professionals (such as doctors, nurses) and end users such as users of the designed outcome.

While all studies define teams involved as multidisciplinary, we found that the level of disciplinary diversity is very heterogeneous across the selected literature, two studies even involving one single discipline (Table 2.5), other studies assigning artificial roles to simulate multidisciplinarity. The details of the disciplinary profile of the teams involved in these studies is discussed below.

[1]The Classification of Instructional Programs (CIP) provides a taxonomic scheme to track and report about fields of study and program completions activity. CIP was developed by the U.S. Department of Education's National Center for Education Statistics (NCES) in 1980, with the latest revision in 2020.

First author, year	Disciplinary background (as in CIP classification)					Industrial expert	End user
	Designer	Architect	Engineering / Construction	Business	Computer Science		
Adams et al., 2009			X	X			
Austin et al., 2001		X	X	X			
Awomolo et al., 2017	X					X	
D'souza and Dastmalchi, 2017	X					X	
D'souza and Dastmalchi, 2016	X	X				X	
Feast, 2012	X	X			X	X	X
Haines-Gadd et al., 2015	X		X				
Hu, Li and Du, 2017	X				X		
Jutraz and Zupancic, 2017		X	X	X			
Kasali and Nersessian, 2015	X		X			X	X
Kleinsmann and Valkenburg, 2008	X			X	X	X	
Kleinsmann et al., 2012		X				X	
Kokotovich and Dorst, 2016	X	X				X	
Mcdonnell, 2009		X					X
Sonnenwald, 1996	X		X				X
Wang et al., 2018	X		X	X		X	
Zolin et al., 2004		X	X				

Table 2.5: Multidisciplinarity of the design team

In the study of Awomolo et al. (2017) with cross-functional teams, 5 out of 8 team members belong to the design team, and 3 other external consultants include: a market researcher, design researcher, and a design thinking expert; meaning that 7 out of 8 participants are from the same design background. In another study by Kleinsmann et al. (2012) specific roles (energy expert, culture expert, health expert and landscape architect) were assigned to the participants, however all participants were students recruited from design courses and professionals with design backgrounds. Similarly, the sample from the study of Hu et al. (2017), defined as multidisciplinary, involves graduate students from various design specialties. Overall, most participants in the core literature come from design, architecture, and engineering (Table 2.5), which, when mapped onto the epistemologically framed Becher–Biglan knowledge disciplinary typology (see Becher (1989); Coughlan and Perryman (2011)), all belong to the category Hard Applied. Similarly, participants in the research of Kokotovich and Dorst (2016) and D'souza and Dastmalchi (2016) come from art, architecture, psychology, journalism and english – all of which belong to the Soft Pure category in Becher's classification. Specifically, while Kokotovich and Dorst (2016) note that design teams consisting solely of designers have very similar perspectives and heuristics, all participants in their study had a background in art, as defined by the American National Endowment for the Arts [2], and were considered creative (see Amabile et al. (1996)). A truly multidisciplinary team has been employed in a study on design team boundaries (Adams et al., 2009), where participants were from mechanical engineering, industrial design, ergonomics and business. The study revealed significant challenges related to differences in disciplinary-related languages and world views, and further suggested that cross-boundary practices are less related to synthesising participants' areas of expertise, but refer more to crossing their perspectives, broadening the disciplinary knowledge with language, roles, or social interactions. Multidisciplinary collaboration also happens when end-users are involved, as in many codesign studies (see Sanders and Stappers (2008)), and take part in design meetings as experts of their dis-

[2](United States Code: Support and Scholarship in Humanities and Arts; Museum Services, 20 U.S.C. §§ 951-968, U.S. Congress, 1988): "music (instrumental and vocal), dance, drama, folk art, creative writing, architecture and allied fields, painting, sculpture, photography, graphic and craft arts, industrial design, costume and fashion design, motion pictures, television, radio, film, video, tape and sound recording, the arts related to the presentation, performance, execution, and exhibition of such major art forms, all those traditional arts practised by the diverse peoples of this country. (sic) and the study and application of the arts to the human environment..."

ciplines (Adams et al., 2009; McDonnell, 2009; Feast, 2012; Sonnenwald, 1996). Adams et al. (2009) involve experts with a minimum of fifteen years of experience, including architects and designers and end-user professionals such as doctors, nurses, engineers, or hospital managers. In Sonnenwald (1996), the communication between software engineers, software designers and end-users - who are salespeople and client's office staff – is analysed. The study identified communication roles that enabled the team to collectively integrate multidisciplinary knowledge and to form boundary-spanning activities. Mcdonnell (2009) investigates the conversations between architects and building users, in which she discovers blurred boundaries be-tween the participants' argumentations. Similarly, Jutraz and Zupancic (2017) suggest that the roles for users (expert practitioners in healthcare, in their study) and design experts overlap, therefore they argue to consider user participants as additional domain experts.

2.3.3 Trust and context

The analysis of the trust-context theme shows that knowledge sharing behaviour and trust creation appear to be established in the face-to-face context. Our theoretical analysis of the thematic pair of trust and context raises further questions about future communication challenges that can emerge, not only due to diverse disciplinary background, but also due to cultural differences and geographical distribution of the design teams. Details of the analysis are provided below. A study of Haines-Gadd et al. (2015) highlights the importance of trust in multidisciplinary collaboration. In fact, trust is found to be a critical component in cross-functional teamwork (Zolin et al., 2004). In terms of disciplinary backgrounds, respondents claim that they would trust professionals from the same domain and expertise more than from other professions. Even without the respect of one's disciplinary background, Feast (2012) reveals that bringing an outsider to an existing group, where participants' roles have been established, creates distrust and further misunderstanding of the group's motivations. An aspect affecting multidisciplinary teams' trust is the contextual knowledge convergence that enables mutual agreements between participants to take place and create shared understanding. Feast (2012) highlights that collaboration is needed to capitalise on the strengths of different stakeholders to develop shared knowledge

and to better deal with the complex combinations of interacting activities, behaviours and relationships that affect design work. This has also been emphasised in the study of Hu et al. (2017), who suggest that more frequent knowledge sharing behaviour, together with the complex sharing network, led to faster mindset shifting from one discipline to another. McDonnell (2009) defines shared understanding to be created through conversation during the design negotiations. Such exchange allows experts to express their non-expert knowledge, which in turn invites the end user to draw on their expert knowledge and thus gain a better understanding of the design context. Apart from varying domain-related perspectives and regional/national cultures, geographical distribution (and resulting lack of face-to-face interaction) plays a great role in decreasing the level of trustworthiness between participants. Direct, in-person meetings increase the trust between participating members, which results in higher creativity and quality of the work (see Aurisicchio et al. (2010); Gloor et al. (2012)). Consistent with this, Klein (2008) find that shared understanding is dependent on the face-to-face team communication, project management and project organisation, and geographical dispersion considerably influences the level of team trustworthiness (Zolin et al., 2004).

2.3.4 Barrier and design communication

The analysis of the thematic pair barrier and design communication reveals a crucial role of visual representation in bridging communication boundaries. However, some studies provide evidence that these can still be misunderstood by team members from different disciplinary backgrounds. Apart from expertise, intrinsic motivations and personalities are other components affecting creativity (see Amabile (1988)). Personality characteristics provide independence, idea-generating skills and enable taking new perspectives on the problem. Group cohesion is thus affected by motivations, world views, egos and clashing personalities (see Goldschmidt (1995)). Similarly, the lack of group cohesion and confrontational attitudes are challenged with differing personalities (Austin et al., 2001). Feast (2012) highlights that such conflicts influence teamwork so much, as they can lead to one-sided collaboration, when a participant's ego is being intimidated or when she/he receives less responsibility than expected. Several research papers suggest visual represen-

tations as a bridging medium between team communication barriers (see Badke-Schaub and Frankenberger (2004)). Schön (1983, p.80) notices that design collaboration occurs on the foundation of verbal and non-verbal components, where "drawing and talking are parallel ways of designing and together make up" the language of designing.

In our core literature, design communication with visual representations emerges as both a facilitating and bridging medium between disciplinary barriers. Adams et al. (2009) state that non-verbal activities, including gestures and drawings, act as communication between the group members, supporting multidisciplinary collaboration. They manage to build on each other's ideas in the forms of such visual representational practices. Consistent with this, Kasali and Nersessian (2015) suggest that design drawings are critical in developing cross-domain expertise. Such drawings are thus defined as a synthesis of multidisciplinary knowledge. They suggest that beyond the verbal interaction, these visual representations act as key roles in translating and blending differing professional expertise. This enables multidisciplinary assessment in the group, leading to later consensus among the participants. McDonnell (2009) highlights that the visual representations play an important role in defining the routine for internal interactions, helping to organise the discussions' themes to comply with interests of all the participants. These sketches become a common reference point for organising the conversation order, importantly without imposing a rigorous structure for such discussions. Notwithstanding, one might claim that quick sketches acting as a bridging medium, require a pre-established shared understanding in the collaboration (Feast, 2012). Similarly, a study from Klein (2008) supports this finding, when an electrical engineer created an explanatory drawing for the ergonomist however they were still not able to productively negotiate with one another a solution for the problem.

2.3.5 Jargon and roles

As shown earlier, multidisciplinary design collaborators often face communication challenges. This section shows that the use of different jargons – or disciplinary languages – is a source of difficulties in communication and that the allocation of specific roles may help overcome these difficulties. Klein (2008) suggests that on the team communication level,

the difficulties emerge due to differences of the jargon used by the participants, different design representations and responsibilities. Similarly, the importance of design jargon issues was highlighted by D'Souza and Dastmalchi (2017). Hu et al. (2017) define different jargon as unique, specialised work languages together with different past experiences, work patterns, quality and success perception, organisational priorities, and technical constraints. High constructive interactions foster productive creation of good ideas and promote idea integration and co-building. One person contributes from his/her discipline expertise, inviting the other to respond and supply information with the provoked expert response (McDonnell, 2009). This, however, requires the recognition of others' expertise and appropriately timed assertion of such expertise, in order to reach consensus.

Considering these aspects, the differing jargon used in multidisciplinary design meetings relates to their disciplinary and cultural background diversity. Social interaction and frequent constructive interactions can facilitate resolving possible communication tensions. To overcome jargon conflicts through encouraging discussion, stimulating imaginations and negotiating ideas, team roles act as a collaboration facilitator. Renegotiation of the earlier defined roles emerges as a feature of social integration during the design talks (McDonnell, 2009). Feast (2012) defines collaboration as a social activity that is affected by the participants' responsibilities and roles (that do not represent their domain-related expertise). As responsibilities relate to one's role in a team, many research articles attempted to classify these roles for multidisciplinary collaboration (see Lloyd (2000); Moore (2006); Stempfle and Badke-schaub (2002)).

We reviewed two classifications of roles and reported their findings in Table 2.6. Sonnenwald (1996) suggests 13 communication roles for multidisciplinary teams, that are categorised ac-cording to the boundary type they resolve. These boundary-spanning roles are supposed to support knowledge integration and collaboration, together with negotiating differences across discipline and personal boundaries. Adams et al. (2009) define eight emerging roles that work as triggers in shifting cross-disciplinary conversations. Their research also finds that frequent switching of roles correlates with the non-hierarchical nature of the meetings. In the instance where there is no end-user involved in the group, the role of the 'Storyteller' suggests that understanding the user becomes a meeting point, where team members can build a shared under-standing of the problem. They highlight

how people mediate cross-disciplinary practices by bridging and synthesising multiple perspectives. These two classifications of roles overlap for two major functions: Intergroup star ¡¿ Facilitator, as managerial and planning functions, and Interdisciplinary star Intradisciplinary star/Environmental scanner ¡¿ Informer, as domain-specific knowledge transmission functions. Sonnenwald (1996) findings lack many roles specifically designed for the ideation process facilitation, whereas Adams et al.'s (2009) investigation looks mainly at the ideation process of the teamwork. It is thus unclear what the best practices are regarding the suggested roles for the teamwork in design. Moreover, there is a requirement of time needed to clarify and establish such roles, as they are unclear in the early stages of collaboration. When the roles are not agreed and defined, later problems may occur (Jutraz and Zupancic, 2017). In their study, such lack of mutual agreement on roles led to unbalanced decision-making responsibilities. As a result, the team spent 1 or 2 weeks working additionally before reaching the joint decision. Similarly, McDonnell (2009) points out in her findings, the importance of appointing one's role a priori, and later renegotiating it during the design meetings.

	Sonnenwald, 1996		Adams et al., 2009	
Boundary type	Role	Description	Role	Description
Organisational boundaries	Sponsor	secures acceptance and funding in the larger organisational unit and external unit.	-	
	Interorganisational star	interacts with others in a larger organisational unit(s) and external unit(s) to ensure a match with the design project goals and strategies.	-	
	Intergroup star	plans and co-ordinates activities across groups and represents their group in planning discussions.	Facilitator	directs and manages the meeting, which is observed to be playing a crucial role in multidisciplinary environments.
	Intraorganisational star	filters and transmits organisational project information across hierarchical organisational levels within the design project.	-	
	Intragroup star	facilitates interaction among group members.	-	
Task boundaries	Intertask star	facilitates interaction and negotiates conflicts between people doing different design tasks.	-	
	Intratask star	facilitates interaction, and co-ordinates activities, within a task.	-	
Discipline boundaries	Interdisciplinary star	integrates knowledge from different disciplines and domains to create solutions to design problems.	Informer	brings external information to the meeting. Interestingly, this is the only role observed to be domain-specific.
	Intradisciplinary star	transmits information about new developments within a discipline.		

	Sonnenwald, 1996		Adams et al., 2009	
Multiple span boundaries	Environmental scanner	transmits information from outside the design context, but relevant to the design context, to design participants.		
	-		User Contextualiser	integrates the knowledge about the users internally and externally.
	Mentor	filters and transmits career information to individuals.	-	
	Agent	facilitates interactions and arbitrates conflicts among all design participants.	-	
Personal boundaries	Interpersonal star	facilitates interaction among individuals.	-	
	-		Evaluator	judges the ideas discussed and identifies a need to conduct an evaluation.
Ideation boundaries	-		Idea Generator	presents new ideas.
	-		Interpreter	clarifies a concept or idea presented.
	-		Questioner	raises questions not brought up in the conversation.
	-		Storyteller	contextualises an idea or clarifies an idea by telling a story and enables including knowledge about the use and users.

Table 2.6: Mapping of group roles from (Sonnenwald, 1996) and (Adams, 2009)

Although there have been several attempts to identify specific roles within design meetings, there is still a lack of consensus in this area. Further meta-analysis of the studies design will support our endeavour in understanding such differences.

2.3.6 Summary of findings

As a conclusion, our analysis has revealed heterogeneity and, at times, conflicts in findings on multidisciplinary collaboration around communication in design teams:

- Knowledge and diversity: not all studies employed multidisciplinary teams, where often disciplinary backgrounds were artificially simulated by participants from the same university degree,
- Trust and context: establishing trust requires face-to-face meetings, that can be hindered in geographically distributed teams,
- Barriers and design communication: visual representation and drawings act as a bridging medium in design communication, but can still be misunderstood by team members from other disciplinary backgrounds,
- Jargon and roles: assigning specific roles may improve communication challenges related to jargon differences, yet studies have no clear classification of such roles due to different study designs.

2.4 Meta-analysis: variables manipulated in the studies

To better understand how previous studies have been designed and why such diversity in the findings occurred, we further analysed the selected literature and reviewed the designs and variables of these studies by using a taxonomic classification of factors that influence collaborative design (Ostergaard and Summers, 2009): team composition (size, culture, expertise level, leadership), distribution, nature of problem, design approach and research methodologies). We present in the following summary tables, methodological details of these research articles, with each row

corresponding to one publication ("X" indicates where a variable was assigned a particular value. "?" indicates where it was not feasible to identify the value assigned to a variable).

2.4.1 Team composition

On an individual level, team composition characteristics are commonly manipulated variables in the study designs. Table 2.7 depicts the characteristics of the team composition in terms of size and culture in the core literature.

Authors, year	Size			Total study size	Culture	
	small	medium	large		cross-culture	homogenous
Adams et al., 2009		X		9	?	?
Austin et al., 2001	X			15	?	?
Awomolo et al., 2017		X		8	X	
D'souza and Dastmalchi, 2017		X		8	X	
D'souza and Dastmalchi, 2016		X		7		X
Feast, 2012	?	?	?	23	?	?
Haines-Gadd et al., 2015	?	?	?	?	X	
Hu, Li and Du, 2017		X		17	?	?
Jutraz and Zupancic, 2017		X		?	X	
Kasali and Nersessian, 2015			?	16	?	?
Kleinsmann and Valkenburg, 2008		X		50	?	?
Kleinsmann et al., 2012	X			9 teams		X
Kokotovich and Dorst, 2016		X		?	?	?
Mcdonnell, 2009	X			4	?	?
Sonnenwald, 1996			X	15	?	?
Wang et al., 2018		X		257	?	?
Zolin et al., 2004	X			108	X	

Table 2.7: Team composition: size and culture (adopted from Ostergaard and Summers, 2009)

The investigation on the heterogeneity of teams involved brings into light the potential cultural differences among team members, where many studies consist of culturally heterogeneous groups (Awomolo et al., 2017; D'Souza and Dastmalchi, 2017; Jutraz and Zupancic, 2017; Zolin et al., 2004). Research has shown that such cultural diversity increases the risk of communication is-sues and cultural barriers. Zolin et al. (2004) find that cultural diversity has a strong impact on decreasing trustworthiness between the group participants. In another study, respondents admit that cultural barriers are more challenging than discipline-related differences (Jutraz and Zupancic, 2017). One of the issues reported by D'Souza and Dastmalchi (2017) was the varying jargon that is used by members from different cultures. Additionally, Feast (2012) argues that the number of participants is another valid contributor. Group size plays an important component in the scientific research of teamwork (see earlier investigations by Shaw (1932)). For the purpose of this review, we use the group Size parameter with 3 levels defined originally in the team research theory (Klein et al., 2009):

- small with less than 5 members
- medium with 5 to 10 members
- large with more than 10 members

Most studies in the core literature consist of studies employing small and medium groups with only one study related to a group greater than 10 members. Feast (2012) emphasises that team size will considerably affect the collaborative level of the group. One person can easier influence the small team, whereas in larger teams, the more distributed workload results in lesser ownership from an individual. Wang et al. (2018) suggest limiting the team to 6 participants, in order to evenly distribute the expertise within a multidisciplinary team. However, findings based on one small sample size risk external invalidity (Yin, 1984). Explicitly, Kleinsmann et al. (2012, p.503) address this limitation in their article, and point out that "therefore, the findings cannot be empirically generalised". We can therefore investigate the total study size as a more holistic parameter to understand the feasibility of the papers' findings. The optimal size of research groups for art and design studies is 25±8 (Kenna and Berche, 2011). They suggest that, above this size, the quality of the study does not increase significantly. More than half of the papers in our review belong to the recommended study size. Overall, team characteristics, including its size and cultural diversity, play a great role in multidisciplinary collaboration, making a considerable impact on communication between the group members. While group size

may influence its cohesion, it also seems to impact the validity of the findings from conducted experiments themselves. We follow our meta-analysis of team composition with the comparison of knowledge experience and leadership factors in the core literature (see Table 2.8).

First author, year	Expertise level				Leadership	
	novice student	senior student	novice professional	senior professional	Yes	No
Adams et al., 2009			?	?	?	?
Austin et al., 2001			X	X	X	
Awomolo et al., 2017				X	X	
D'souza and Dastmalchi, 2017				X	X	
D'souza and Dastmalchi, 2016	X	X				X
Feast, 2012			X	X	X	
Haines-Gadd et al., 2015			X		X	
Hu, Li and Du, 2017		X				X
Jutraz and Zupancic, 2017		X			?	?
Kasali and Nersessian, 2015				X		X
Kleinsmann and Valkenburg, 2008			X	X	X	
Kleinsmann et al., 2012	X	X	X		X	
Kokotovich and Dorst, 2016	X	X			X	
Mcdonnell, 2009			?	?	X	
Sonnenwald, 1996				X	?	?
Wang et al., 2018		X				X
Zolin et al., 2004		X			X	

Table 2.8: Team composition: expertise and leadership

(adopted from Ostergaard and Summers, 2009)

Although many studies emphasise the importance of leadership in group work, the role of a project leader tends to be interpreted differently in the literature. Sonnenwald (1996) suggests that one of the responsibilities of a leader is to provide filtering and sharing information about the project's goals, plans, tasks, and detailed budget information. Consistent with this point, Kleinsmann et al. (2012) describe the project leader's tasks to be planning and monitoring the design process and costs. An important aspect of leadership is that while guiding the group through the design activity, there is a risk of the team leader progressing without agreeing the project's direction with the remaining participants (Austin et al., 2001). Therefore, the leader often takes another role and makes the most of the design decisions concerning not only the methodology used in the meeting but also its content (Awomolo et al., 2017). Also, through having multidisciplinary participants, such dominance of the team leader can be reduced. Haines-Gadd et al. (2015) present the idea of the leadership role rotation that becomes an enabler for new collaboration energies to take place at various project stages. The level of knowledge (experience) might also influence the design process, its outcome and team collaboration. D'souza and Dastmalchi (2016) find that undergraduate juniors can make a significant impact on the design process with an increased number of creative events within it. Contrary to this, the novice team in the study of Kokotovich and Dorst (2016), who did not use any design methodologies or tools, were later unable to both enrich the design solutions space, and did not manage to cross domains nor develop new higher levels of abstractions. The sample of the least experienced participants was represented by students from the undergraduate academic level. In 56% of the observed instances, the team was not operating on the competent level (Dreyfus, 2004), where problem-solving is accompanied with high design situation involvement, emotional involvement, learning and reflection. A lower experience level, described as limited expertise contributed, may lead to inefficient use of time and resources (Haines-Gadd et al., 2015). In most studies, teams are being formed in laboratory experiments using students from the same academic year or early-career, which is rarely the case in a real-world situation (Wang et al., 2018). An interesting perspective is presented by Sonnenwald (1996), where she suggests that the number of years of professional experience reflects the participant's role within the group. For example, participants with minimal professional experience can take on the roles of interaction facilitators between project members. Participants managing cross-organisational information require more than 8 years of professional experience, whilst those coordinating activities need more than 14 years. It is worth highlighting that the interdisciplinary star who integrates knowledge from different disciplines and domains has a minimum of 10 years of professional experience.

2.4.2 Distribution

Design process can be significantly affected by the dispersion of the team members. For ease of the analysis, we combine the distribution metrics of both personnel and information distribution and use an overarching category "distribution" for all variety of distribution boundaries, including geographic, organisational, and temporal dispersion (see Table 2.9).

First author, year	Distribution	
	Collocated	Distributed
Adams et al., 2009	X	
Austin et al., 2001	X	
Awomolo et al., 2017	X	
D'souza and Dastmalchi, 2017	X	
D'souza and Dastmalchi, 2016	X	
Feast, 2012	X	
Haines-Gadd et al., 2015	X	
Hu, Li and Du, 2017	X	
Jutraz and Zupancic, 2017		X
Kasali and Nersessian, 2015	X	
Kleinsmann and Valkenburg, 2008	X	
Kleinsmann et al., 2012	X	
Kokotovich and Dorst, 2016	X	
Mcdonnell, 2009	X	
Sonnenwald, 1996	X	
Wang et al., 2018	X	
Zolin et al., 2004		X

Table 2.9: Team distribution (adopted from Ostergaard and Summers, 2009)

As Ostergaard and Summers (2009) suggest, distributed design teams would require exceptional support compared to collocated teams. For example, in the study of Jutraz and Zupanic (2017) there was a significant variety of additional computer supportive tools used to facilitate the design collaboration, including SketchUp, Revit, Skype, GoToMeeting, Brainmerge, Box, Dropbox, GoogleDocs, Terf, and others. The authors raised the importance of implementing distributed work in educational courses, in order to improve designers' computer skills and learn about digital programs. Since geographical dispersion influences significantly the level of trustworthiness

between team members (Zolin et al., 2004), it may in turn challenge the whole design process (for example, Garner (2001) shows that distributed designers spent 51% more time creating graphic acts than those in collocated teams). However, only 2 studies in the core literature are looking at the distributed design teams. We can hence conclude that, there is still a big gap in previous empirical research in understanding differences and consequences of the geographical distribution of the design meetings.

2.4.3 Nature of problem

Some aspects of the design problem may also affect the collaborative design. Following our adopted taxonomic classification, we present in Table 2.10 variables based on the nature of the problem used in the selected empirical studies.

First author, year	Abstraction			Complexity (adapted to design objective)		
	concrete (physical)	abstract	intermediate (digital)	low (product)	medium (industrial)	high (service)
Adams et al., 2009	X				X	
Austin et al., 2001	X					
Awomolo et al., 2017	X				X	
D'souza and Dastmalchi, 2017	X				X	
D'souza and Dastmalchi, 2016			X	X		
Feast, 2012	?	?	?		X	
Haines-Gadd et al., 2015	X			X		
Hu, Li and Du, 2017		X				X
Jutraz and Zupancic, 2017	X				X	
Kasali and Nersessian, 2015	X				X	
Kleinsmann and Valkenburg, 2008	X				X	
Kleinsmann et al., 2012		X			X	
Kokotovich and Dorst, 2016			X	X		
Mcdonnell, 2009	X				X	
Sonnenwald, 1996	X				X	X
Wang et al., 2018			X	X		X
Zolin et al., 2004	X				X	

Table 2.10: Nature of design problem (adopted from Ostergaard and Summers, 2009)

In most of the studies, the participants are being instructed to focus on developing a physical product (adapted as concrete), e.g. buildings, backpack, car accessory for industrial or product design objectives. In one study, Hu et al. (2017) investigate how the mindset of participants switches from industrial thinking to service thinking. They find that the mindset shifting process is significantly influenced by communication and interactions between the participants. In order to successfully cope with service thinking without previous experience in this domain, participants are required to present frequent knowledge sharing. In a similar fashion, Kokotovich and Dorst (2016) study how designers can move from traditional concepts towards a higher level of abstraction. Their investigation of the project, that resulted in a website for the cards industry (digital product), suggests that multidisciplinary teams have difficulties in crossing domains and could not develop higher levels of abstractions. Bearing that in mind, 65% of the design outcomes are physical products, and in only 3 scenarios the resulting product is digital (D'souza and Dastmalchi, 2016; Kokotovich and Dorst, 2016; Wang et al., 2018). Considering these studies, the discourse of multidisciplinary collaboration raises limited understanding of issues related to the nature of digital outcomes and those with high levels of abstraction and complexity.

2.4.4 Design approach

As with the disciplinary background of the participants, the literature body varies in the examination of the participants' work type and the design process itself. Table 2.11 shows variables for design approaches investigated in the core literature.

First author, year	Stage		Project duration		
	conceptual design	prototype	short (day)	medium (<month)	long (>month)
Adams et al., 2009	X		X		
Austin et al., 2001	X			X	
Awomolo et al., 2017	X				X
D'souza and Dastmalchi, 2017	X				X
D'souza and Dastmalchi, 2016	X			X	
Feast, 2012	?	?			X
Haines-Gadd et al., 2015	x	X			X
Hu, Li and Du, 2017	X			X	
Jutraz and Zupancic, 2017	X				X
Kasali and Nersessian, 2015	X	X			X
Kleinsmann and Valkenburg, 2008	X				X
Kleinsmann et al., 2012	X		X		
Kokotovich and Dorst, 2016	X	X		X	
Mcdonnell, 2009			?	?	?
Sonnenwald, 1996	X				X
Wang et al., 2018	X		X		
Zolin et al., 2004	X				X

Table 2.11: Design approach (adopted from Ostergaard and Summers, 2009)

The majority of the selected studies refer to conceptual work, and only 3 studies describe the prototyping phase. Notwithstanding, it was found by Haines-Gadd et al. (2015) that prototyping is instrumental in the design process by decreasing mistakes and improving the design. They suggest that prototyping can be utilised as tools for communication and integration between the participants. The idea is supported by the research of Kasali and Nersessian (2015), who find that prototypes are critical in bringing together the differentiated expertise within the multidisciplinary teams. Additionally, an interesting aspect of the design process is the duration of the projects. We note that most empirical cases are spread across a longer period of the design collaboration (over a month), and only 3 refer to one-day projects.

2.4.5 Research methodology

With an increasing need for domain-crossing collaboration, the issue of multidisciplinary teamwork has generated appeal among academic work. Nevertheless, we note that there are differences in methodologies applied by the authors across the empirical studies in this review. We present in table 2.12 identified characteristics of the design of selected studies.

First author, year	Setting		Sample		Data source				
	natural	laboratory	university	industry	Case study	Protocol analysis	Field observation	Interviews	Questionnaire
Adams et al., 2009	X			X		X			
Austin et al., 2001		X	X						X
Awomolo et al., 2017	X			X		X			
D'souza and Dastmalchi, 2017	X			X		X			
D'souza and Dastmalchi, 2016		X	X			X			
Feast, 2012		X		X				X	
Haines-Gadd et al., 2015		X		X				X	
Hu, Li and Du, 2017		X	X				X	X	
Jutraz and Zupancic, 2017		X	X		X				X
Kasali and Nersessian, 2015		X		X			X	X	
Kleinsmann and Valkenburg, 2008	X			X	X				
Kleinsmann et al., 2012		X	X	X		X		X	X
Kokotovich and Dorst, 2016		X	X			X			
Mcdonnell, 2009		X		X		X			
Sonnenwald, 1996	X			X			X	X	X
Wang et al., 2018		X	X						X
Zolin et al., 2004		X	X						X

Table 2.12: Research methodology across the core literature

As presented in Table 2.12, out of the 17 core research articles, 8 studies were employing samples of university students. As Kasali and Nersessian (2015) notice, there has been little research into how interdisciplinary teams operate in the real world and how the multitude of professionals communicate and integrate their expertise. Only 5 studies in the core literature were carried out in a natural setting (conducted in a non-experimental nature), meaning over 70% of the research articles involve experiments in a laboratory setting, highly correlated with the employment of student participants (60% of them with university samples). In design studies, protocol analysis has been gaining much attention in the last quarter of the century (Dorst, 1995). The design research community widely employs this approach in order to measure not only the quantitative metrics but also to capture the thinking processes of the examined participants. It enables the researchers to analyse the design process as a sequence of events in time. This holistic approach is reached by involving protocol coding of video recordings and the following verbatim transcripts. Additional information from notes, sketches or screen captures are also included in the later synthesis to analyse the creative processes in the meetings. Unsurprisingly, protocol analysis is the most popular method within the core literature, with over 40% of studies applying this method for their investigations (Adams et al., 2009; Awomolo et al., 2017; D'Souza and Dastmalchi, 2017; D'souza and Dastmalchi, 2016; Kleinsmann et al., 2012; Klein, 2008; Kokotovich and Dorst, 2016; McDonnell, 2009). Notwithstanding, Feast (2012) observes that protocol analysis still has limitations for examining the collaborative design activity. They argue that it relies too heavily on the problem matter to be solved in a laboratory environment within hours of the session. Apart from protocol analysis, researchers in the core literature also employ case studies (Jutraz and Zupancic, 2017; Klein, 2008). We use the case study as an umbrella term for investigations of a particular phenomenon - *sauté* – in uncontrolled environments. Kleinsmann and Valkenburg (2008) use, more specifically, the learning history method based on storytelling. Since storytelling supports the process of relating events to each other, it is considered to be beneficial for design research. Another method used in the core literature is field observation (Hu et al., 2017; Kasali Nersessian, 2015; Sonnenwald, 1996), that requires going out into the field (Robson McCartan, 2016) and performing ongoing behavioural observation of the sample. It is worth highlighting a wholesome approach taken by Hu et al. (2017), as they combine spot observation and interviews to gather the data involving all original sketches and documents, real-time dynamic observation, and self-reflective opinions. Interviews have also been used by other authors (Feast, 2012; Haines-Gadd et al., 2015; Hu et al., 2017; Kasali Nersessian, 2015; Sonnenwald, 1996) with a similar number of studies using questionnaires (Austin et al., 2001; Jutraz Zupancic, 2017; Sonnenwald, 1996; Wang et al., 2018;

Zolin et al., 2004). Where the latter one has a considerably lower cost to perform, interviews provide a lower bias from the respondent (Robson and McCartan, 2016), which can be more fruitful when studying design processes and related team dynamics. Most studies in the core literature have been performed within the construction industry (see Table 2.13). We classify under this industry conjointly: architecture, construction, and engineering; studies within such efforts engage over 70% of the analysed literature body.

First author, year	Area of industrial application			
	construction	manufacturing	healthcare	software
Adams et al., 2009	X			
Austin et al., 2001	X			
Awomolo et al., 2017	X			
D'souza and Dastmalchi, 2017	X			
D'souza and Dastmalchi, 2016		X		
Feast, 2012	X			
Haines-Gadd et al., 2015			X	
Hu, Li and Du, 2017	?	?	?	
Jutraz and Zupancic, 2017	X			
Kasali and Nersessian, 2015	X		X	
Kleinsmann and Valkenburg, 2008		X		
Kleinsmann et al., 2012	X			
Kokotovich and Dorst, 2016		X		
Mcdonnell, 2009	X			
Sonnenwald, 1996	X			X
Wang et al., 2018		X	X	X
Zolin et al., 2004	X			

Table 2.13: Industrial mapping of the core literature

Specifically, most of the research papers focus on architectural practices (Adams et al., 2009; Austin et al., 2001; D'souza Dastmalchi, 2016; Feast, 2012; Jutraz Zupancic, 2017; Kasali Nersessian, 2015; McDonnell, 2009; Sonnenwald, 1996; Zolin et al., 2004). Healthcare and manufacturing constitute 17% each of the literature body. Only two studies include investigations within software development (Sonnenwald, 1996; Wang et al., 2018). Overall, the studies indicate the increasing need to employ design practices into industries, previously considered as non-design practices. According to the literature, participants from the software department or any mechanical-oriented divisions create barriers in the multidisciplinary collaboration, as they

employ different development processes while using different jargon and different representations of the design (see Klein (2008)). On the contrary, architects can draw on their experiences from design nature, and act as mediators between varying professionals (Jutraz and Zupancic, 2017), as well as enablers for efficient collaboration, by setting out the right processes. As a result, the disciplinary background of participants seems to directly impact the results of the experiments, and research has been equivocal in terms of the generalisation of findings on multidisciplinary collaboration. A synthesis of all variables used in the meta-analysis (Table 13) shows that most studies in the reviewed literature examined design activities which lead to physical outcomes ("Design outcome") and on collocated teamwork ("Distribution"); also, most studies are conducted in laboratories ("Setting") and nearly half of them rely on student sample participation ("Participants"). These results are discussed in section 2.5.2.

Variable	Parameter	% total*	Variable	Parameter	% total*
Participants involved in studies			**Studied design activity**		
Participants	Industry	53	Distribution	Collocated	82
	University	47		Distributed	18
Background	Industrial expert	19	Duration	Short (day)	19
	Engineering	17		Medium (<month)	25
	End user	9		Long (>month)	56
	Designer	23	Objective	Industrial	61
	Computer Science	6		Product	22
	Business	11		Service	17
	Architect	15	Industry	Construction	57
Expertise level	Senior student	32		Manufacturing	14
	Senior professional	37		Healthcare	14
	Novice student	11		Software	14
	Novice professional	21	Design phase	Conceptual design	83
Leadership	Yes	69		Prototype	17
	No	31	Outcomes	Physical product	69
Cultural Distribution	Heterogeneous	71		Digital product	19
	Homogenous	29		Abstract concept	13
Group size (people)	Medium (5-10)	64	**Research methodology**		
	Small (<5)	29	Setting	Laboratory	82
	Large (>10)	7		Natural	18
			Methodology	Protocol analysis	32
				Questionnaire	23
				Interview	23
				Field observation	13

Table 2.14 continued from previous page

		Case study	9

Table 2.14: Synthesis of variables presented in the meta-analysis of the selected literature (*example: 82% of the reviewed papers present a study of 'collocated' multidisciplinary design collaboration)

2.5 Discussion

This section presents the main findings from the review: the identification of the importance of 'shared understanding' in multidisciplinary design collaboration (2.5.1), the limited generalisability of reviewed studies (2.5.2), their limited methodological rigour (2.5.3) and their low industrial relevance (2.5.4).

2.5.1 Importance of shared understanding (from the theoretical synthesis)

Amongst the emerged theme relationships, we can identify prominent areas worth taking a closer look at. Conflicts regarding these aspects are related to disciplinary and perspective variation of the participants, and jargons used by them. Misunderstandings are common in multidisciplinary teams, which is also accentuated by the differences in cultural background, and geographical distribution of the team members. Visual representations appear to be a good bridging medium and facilitator for potential conflicts. However, there is a requirement of an established shared understanding between participants, where knowledge sharing actions are key to over-come design communication barriers (see Section 2.3).

Our theoretical synthesis, supported initially by the co-occurrence analysis, unearthed specific theme relationships related to the knowledge diversity and communication, trust and context, barrier and design communication, jargon, and roles. All the emerged themes present challenges of team collaboration, known in extant literature within the research of group cognition. Group level phenomena in an organisational context were studied by scholars using "group-mind" constructs linked to group cognition or team mental models (Klimoski and Mohammed, 1994).

Previous literature presents a resurgence of interest in the group cognition across many fields, including human resources (Cannon-Bowers et al., 1993), business policy and strategy (Floyd and Wooldridge, 1992; Reger and Huff, 1993), and organisational behaviour (Cannon-Bowers and Salas, 2001; Mohammed and Dumville, 2001; Walsh et al., 1988; Weick and Roberts, 1993). The notion of mental models was first proposed by Craik (1952) in an attempt to explain human behaviour coping within a complex world, as mental models are used by human beings as internal representations to react to the changing environment. Such dynamic requirements are prevalent in ill-defined design tasks that require non-routine behaviour (Goel, 1995; Simon, 1984). The greater the overlap or commonality in team members' mental models, the higher the team's capacity to develop common expectations of the task, predict team behaviours, and better adapt to the changing demands, whilst improving taskwork coordination.

It is unclear how that affects the notion of shared cognition in the design team, by which reaching too much consensus may cause individuals in the team to hinder creativity. The construct of shared mental models hypothesised hitherto from a perspective of team performance and effectiveness inhibits theorising for team creativity and innovation. Within design studies, we recognise an increasing body of research on shared cognition in design teams, with the construct being introduced in CoDesign in 2007 (Badke-Schaub et al., 2007; Casakin and Badke-Schaub, 2017/ed; Cash et al., 2017, 2020) that therefore sets the path for future research work. To further enrich our understanding of multidisciplinary design collaboration, we may take on the direction of studying the notion of shared cognition in a creative context in reference to the emerged themes and group aspects that have been identified in this presented literature review.

2.5.2 Low generalisability (from study designs and variables meta-analysis)

By revealing prevalent themes in multidisciplinary design collaboration, we challenge important scholarly assumptions regarding the relationship between them. And due to variation in variables used in the empirical studies, findings include both commonalities and contradictions in some aspects. As shown in Table 2.12, most studies were conducted in laboratory settings, nearly half of them rely on student focused on design activities which lead to physical outcomes and on collocated teamwork; also, most studies are conducted in laboratories ("Setting"). Lastly, more than 40% of the reviewed studies rely on student sample participation ("Participants"). The scientific community draws attention to taking extra caution with experiments on student

samples compared to non-student adult populations (Peterson, 2001), and while some consider student-based research externally invalid (Gordon et al., 1986), almost half of the investigated papers in this review are studies of university participants. Additionally, many of the works are laboratory experiments, where the authors have manipulated study variables. This can become a limitation for the external validity of the emerged findings (Robson and McCartan, 2016). Scientific experts do acknowledge this limitation and explain the choice of laboratory student teams plausible for the sake of methodological strictness (Stempfle and Badke-schaub, 2002). They suggest that laboratory experiments can provide some insight into basic thinking processes without being contaminated by unpredictable factors prone to take place in research with an industry context. This, however, must be considered with the highest caution for team collaboration research; though laboratory studies with student participants may be important for work behaviour research at the individual level (Dobbins et al., 1988), Chapanis (1967, p.564) observed that most laboratory experiments have very limited relevance for practical situation, where "unsuspected interactions in real life may nullify or even reverse conclusions reached in the laboratory".

2.5.3 Limited methodological rigour (from study designs and variables meta-analysis)

We follow our discussion on the limitation concerning the danger of low generalisability not only due to the laboratory setting/student participants, but also due to usage of secondary data in design studies. In a panel debate at DTRS11 in 2017, Gabriela Goldschmidt (in B. Christen-sen et al., 2017, p. 7) expressed concerns on the lack of the methodological rigour in design research: "When you use a shared database, you have to have very good reasons to do so. You have to make sure that the particular dataset that you have chosen is really the most suitable way to probe the kind of question that you are interested in, and that is not always what has happened here", which is supported by the points raised in our review of literature. Much of the published work and following this, some publications in our core literature, are de facto employing the same data subsets:

- DTRS 11 (Awomolo et al., 2017; D'Souza Dastmalchi, 2017).
- D'souza and Dastmalchi, 2016; Kokotovich and Dorst, 2016.
- Adams et al., 2009; Mcdonnell, 2009.

In line with our previous commentary on the lack of agreed methodological rigour in the design area, this limitation emphasises the issue of the methodological quality of the obtained findings. Traditionally, in order to ensure reliability of measures, each data set is designed for a specific research project, and to answer a specific set of research questions. Employing secondary data, in turn, would affect the process of data collection and sampling, and the risk unfolds when the meta-information is insufficient, which in turn increases the risk of lower reliability and validity (Hox and Boeije, 2005) of the used procedures.

2.5.4 Low industrial relevance (from study designs and variables meta-analysis)

This literature review is an important starting point in defining how to develop tools for collaboration in the realms of the current innovation-led economy. A report from McKinsey Co (Sheppard et al., 2018), shows that the use of design practices and business performance is positively correlated across a wide range of industries, and that design practices are beneficial for the development of physical goods, digital products and services, or a combination of these. Moreover, team collaboration discourse is undergoing a remarkable revolution, as its virtual factor has become a widespread common practice in companies of all industries. At Alpha-bet, one of the top 5 most innovative companies from the BCG 2019 annual report (Boston Consulting Group, 2019), 100 000 employees are spread out over 150 cities across more than 50 countries. According to industrial surveys, remote work will continue to be one of the main challenges in the post COVID-19 public realm (see IBM Institute for Business Value and Economics (2021)). Another aspect is the increase of service and digital product design over the last decades. Companies producing hardware products are alongside developing innovative digital applications. The companies on the referred most innovative list (Ringel, 2019) — especially those in the top ten — offer digital products including operational systems (iOS), cloud platform products and solutions (AWS), or digital advertising (Google Ads). However, our meta-analysis reveals that there is limited evidence for theorising specifically in the context of distributed collaboration, as well as abstract design outputs (see 2.14). In addition to design practices, leaders from these most innovative companies have extensively referred to the importance of team collaboration in the innovation design processes: "[...] software innovation, like almost every other kind of innovation, requires the ability to collaborate and share ideas with other people" explained Microsoft co-founder Bill Gates (BBC, 2007) or "My model for business is The Beatles. [...] That's how

I see business: great things in business are never done by one person, they're done by a team of people" - Apple co-founder Steve Jobs (Isaacson, 2011). Nevertheless, there are little efforts from the management academia to include design as part of their portfolio (Cash, 2018). Our meta-analysis of design studies accentuates and makes salient the need for higher rigour and standardisation of design research methodologies. Such discrepancies in the employed research designs and chosen empirical study settings may result in low generalisability of design research to a wider literature, inhibiting further theorising on design collaboration.

2.5.5 Study limitations

We acknowledge that traditional analysis tends to be performed with a single unit of analysis. However, to consider the methodological differences and explore team composition variables used by the authors in team-related works, we followed a multilevel approach (Gong et al., 2013) by crossing the levels of analysis. Namely, this type of analysis, widely discussed by Hackman (2003) enabled us to look at how teams are affected by their multidisciplinary design and how, on the micro-level, individuals' background affects such collaboration. Hackman (2003, p.907) suggests that social and organisational dynamics require attention to both lower and higher level of analysis through the process of bracketing that can: "(1) enrich understanding of one's focal phenomena, (2) help one discover non-obvious forces that drive those phenomena, (3) surface unanticipated interactions that shape an outcome of special interest, and (4) inform the choice of constructs in the development of actionable theory". Moreover, co-occurrence analysis is a unique method for literature reviews, gaining interest in recent years (Godwin, 2016). Due to the text mining nature of the process, conventional analysis would require more data points. The network analysis has complementarily supported us in unearthing the weights and relationships of the themes, not possible to visualise in the traditional review methodology. We adopted the co-occurrence network on our small base of the select-ed literature and hence, treat this solely as a preliminary guide and prerequisite to the following in-depth interpretative theoretical synthesis.

2.6 CSCW and current technology enablement

The identified themes from the literature review, highlight two critical, socio-cognitive team dynamics aspects: shared understanding and trust. In the attempt to determine the direction

for future work, we plot the collaborative systems defined by Saad and Maher (1996) versus the two criteria in the proposed matrix (see Figure 2.4), where:

1. High trust / High shared understanding – characterised in face-to-face meetings.
2. Low trust / High shared understanding – found in Asynchronous Interaction, including shared databases and thus current file management systems such as Google Drive (Saad and Maher, 1996).
3. High trust / Low shared understanding – found in Synchronous Distributed systems, including video conferencing (Bos et al., 2002; Nguyen and Canny, 2007).
4. Low trust / Low shared understanding – found in Asynchronous Distributed, defined as different time / different space (Saad and Maher, 1996), to which we categorised email and communication chat apps.

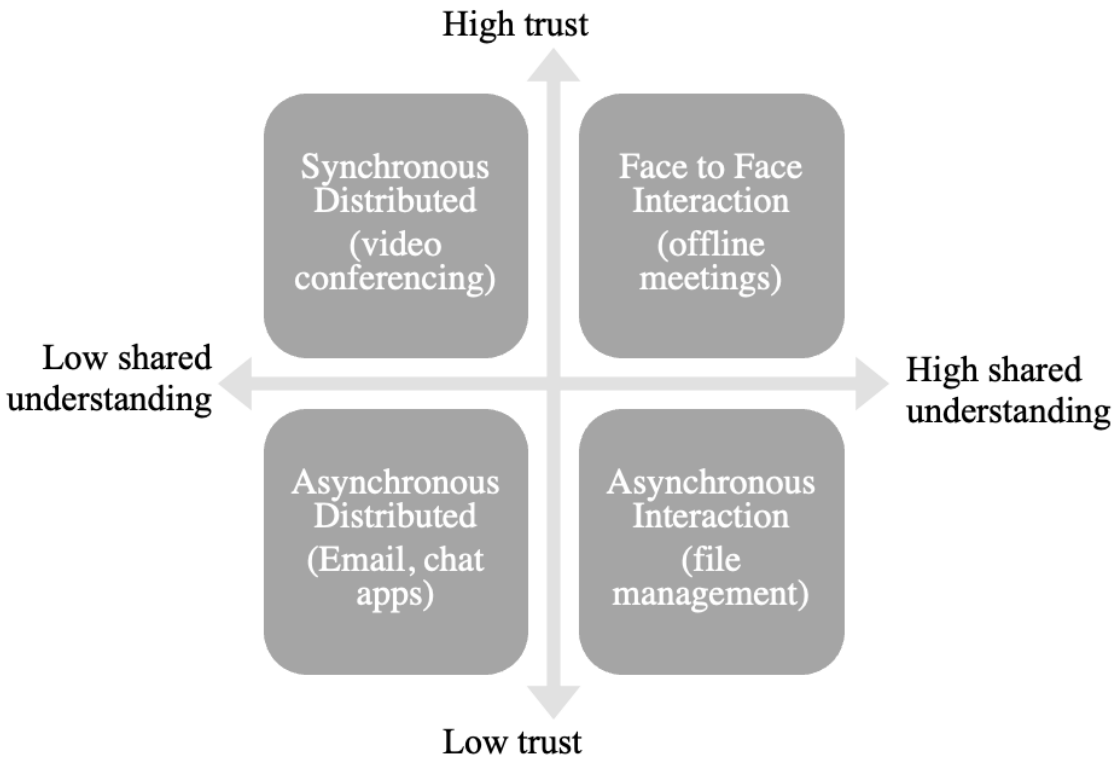

Figure 2.4: Mapping of collaborative systems (based on the systems from Saad and Maher (1996)) with the emerged themes of trust and shared understanding

We suggest that the most vulnerable system is the asynchronous distributed one, including email and communication chat apps; and this should be the direction for future research on facilitating

team dynamics aspects in multidisciplinary collaboration. Moreover, they both are speech-only communication channels, defined by Ostergaard et al. (2005) to be correlating with the lowest perceived effectiveness of teamwork. Interestingly, the two most vulnerable communication channels identified in the previous section – with the lowest indicator of trust and shared understanding – represent the top two collaboration tools used in the industry (Spiceworks, 2017*a*,*b*): Email (98%) and Collaborative chat apps (44%). To illustrate the industrial relevance, we map the functionalities offered from vendors against the tools suggested in academia in Table 2.15.

CSCW	Role detection	Video conference		Sketching	Communication	
		Traditional	Spatial faithful		Jargon translator	Auto translator
Email						
Skype for Business		X				
Google Hangouts		X				
Slack						
Microsoft Teams		X		X		
Atlassian HipChat						
Workplace by Facebook		X				X

Table 2.15: Analysis of current communication tools

As shown in Table 2.15, the majority of suggested tools from CSCW studies are not available in the leading communication channels used in the industry. Only traditional video conferencing systems, sketching and auto-translation are present in the vendors offer. However, it is worth noticing that the two latter ones has been available for commercial use since Q2 2019. This brings the promise of potential implementation for state-of-the-art tools recommended from academia into employment in the real-world context. Research in other areas can bring good inspiration for future studies on applying such approaches in multidisciplinary collaboration on a broader scale. An attempt in the analysis of speech-only communication meetings by Wasiak et al. (2010) refers to the use of content analysis of participants' email conversations. We can also identify one of the methodologies, already used in (homogeneous) design collaboration research – latent semantic analysis – of intra-group communication proposed by Dong (2005). Another promising approach involves NLP. The most recent research effort from Yang et al. (2019) present attempts to create a rapid, NLP-powered tool to enhance writing experience

during design activities. They present yet challenges that still need to be addressed in further investigations and raise questions on how their findings can be generalised to other design situations. Finally, research into multidisciplinary collaboration from design studies has excellent potential to provide insights into teamwork. However, due to variation in variables used by the experiments' authors, findings include both common similarities and contradictions in some aspects. We analysed such differentiation and identified emerging key themes, which can become a foundation for future research. Reviewing current literature body on multidisciplinary collaboration with a critical review in respect to the CSCW discourse is an important starting point in defining how to examine teamwork and develop tools for collaboration in the realms of the future innovation-led economy.

Chapter 3

Qualitative study of distributed design collaboration

3.1 Introduction

Much scholars in recent years have focused on studying human-computer interaction (HCI) and CSCW through empirical evaluation of a particular technological solution from the perspectives of cross-cultural barriers (Kayan et al., 2006), including language support (Tausczik and Pennebaker, 2013) and cross-gender barriers (Yuan et al., 2019). The findings highlight the importance of developing recommended functionalities to support ever-growing population of remote workers. However, few researchers have addressed the problem of the socio-cognitive aspects challenges related to the shared cognition of virtual teams (Arias et al., 2000; Qu and Hansen, 2008). Previous work has been primarily empirical and focuses on the process of team cognition development in distributed work and the ecology of tools used in such context. Building on an inductive, qualitative study of expert professionals working remotely in multidisciplinary teams, this paper explores the ecosystem of tools designed for computer-supported cooperative work (CSCW) and how it influences the way creative virtual teams develop shared understanding. Together, yet apart - we have asked ourselves "how do we build a shared cognition with our teammates in distributed design collaboration?" and looking through the lenses of systems psycho-dynamics, which focuses on the interplay between work tasks and emotions using individual reflections as our central accounts. In order to investigate how virtual collaboration tools serve the development of the shared understanding for distributed teams, and hence contribute

to the understanding of collaborative behaviours in the interactional context of distributed teamwork, this study presents a qualitative research of how virtual teams experience remote working using online collaboration tools and how they develop shared cognition in a given environment. We focus on socio-cognitive aspects of the development of shared understanding to contribute to the future design requirements of CSCW tools.

3.2 Theoretical Background

3.2.1 Shared cognition in design teams

Group level phenomena in organisational context are studied by scholars using "group-mind" like constructs linking to group cognition or team mental models (Klimoski and Mohammed, 1994). Extant literature presents resurgence of interest in the group cognition across many fields, including human resources (Cannon-Bowers et al., 1993), business policy and strategy (Floyd and Wooldridge, 1992), and organisational behaviour (Cannon-Bowers and Salas, 2001; Walsh and Fahey, 1986; Weick and Roberts, 1993). The notion of shared cognition in teamwork has been brought into the growing interest of scholars through evidence showing its influence on team processes, team performance (Kim et al., 2017) and team behaviours (Cannon-Bowers et al., 1993; Klimoski and Mohammed, 1994). Scholars have studied the development of shared cognition from the perspectives of psychology (Mathieu et al., 2000), and expanding further to design teams in engineering (Cash et al., 2017), codesign (Badke-Schaub et al., 2007) or management (Stigliani and Ravasi, 2012). Albeit, the discourse of shared cognition has been around for 30 years - there are many variations of its labelling: shared understanding, collective cognition, team mental models, shared knowledge, shared mental models, sensemaking, and more (Klimoski and Mohammed, 1994). For this study, we refer to the shared cognition and shared understanding construct defined by (Cannon-Bowers et al., 1993, p. 228), as "knowledge structures held by members of a team that enable them to form accurate explanations and expectations for the task, and in turn, to coordinate their actions and adapt their behaviour to demands of the task and other team members". Within this notion, scholars suggest the construct of two separate types of shared knowledge: task-related mental models and team-related mental models (Badke-Schaub et al., 2007; Cannon-Bowers et al., 1993; Cash et al., 2017). A recent reflective literature raises a further question of what do the team members share, focusing on the content of shared understanding. Cannon-Bowers and Salas (2001) suggest that

what is shared can be classified within four categories:

- task-specific knowledge
- task-related knowledge
- knowledge of teammates
- attitudes/beliefs

3.2.2 Creativity and team diversity

Heterogenous group work is a popular tool for fostering creativity through cross-fertilisation and a combination of different perspectives to catalyse novel knowledge. Following this, creativity requires political resources, emotional support and gaining buy-in of the ideas in a socio-political context of an organisation (Shalley and Perry-Smith, 2008). Research in the area of team diversity has grown significantly in the last five decades. Nevertheless, many comprehensive reviews have yielded mixed findings and a lack of consensus on the effects of performance on team diversity. Some scholars suggest that more diverse teams leverage a greater range of perspectives and hence have a greater potential to generate more high-quality solutions than homogenous teams (Hoffman and Maier, 1961; Watson et al., 1993). Contrastingly, higher diversity in the team results in less integration, higher team dissatisfaction and turnover (Jackson, 1996; Milliken and Martins, 1996). These mixed findings within the current theoretical perspectives on diversity research focus in the majority on the relationship between diverse teams and performance outcomes (Milliken and Martins, 1996; van Knippenberg et al., 2004) or even market shares and profits (Hambrick and Cho, 2020). We position our study of shared cognition, contrary to prior research not on performance outcomes, but rather on how shared cognition affects team working on creative outcomes, which defines the sample choice.

3.3 Methods

When looking at human behaviour and human cognition within the human-computer interaction discourse, we take the stand of qualitative research related to a phenomenological, hermeneutic research school originated in social science (Mills, 1959). Two weeks into our study, the world

has been announced into a lockdown due to the COVID-19 pandemic, hence the discourse of distributed working has been shifted to a new paradigm for many of the participants. Our study explored this phenomenon embracing personal perspectives as reflections of social issues. This focus on the understanding of the psychological nature and human behaviour within systems, follows systems psycho-dynamics as a lens looking at participants' management of emotions and tasks (Hirschhorn and Barnett, 1993).

3.3.1 Data Collection

Our sample focuses on professionals working in multidisciplinary virtual teams on creative projects with projects outputs that are novel and useful (Amabile et al., 2005). We have recruited the participants through LinkedIn job advertisements and snowball sampling from our professional network expanding our reach to passive candidates. Following the theoretical logic for the sampling strategy, we have reached the theoretical saturation (Glaser and Strauss, 1967) with a sample of 21 participants, where 10 were male and 11 female. Participants came from design teams from a rich variety of sectors including design consulting, fast-moving consumer goods (FMCG), research and development (RD), publishing, fashion, marketing agencies, academia, and technology development with a professional experience levels ranging from 1 year to 15 years. Two of the interview accounts recollect projects within Fortune 50 companies, other participants included professionals, such as self-employed font-end engineer, freelance designer, UI designer, design engineers - newcomers and partners from startups and established organisations. As the recruitment process of the participants started a month before the COVID-19 lockdown, 5 of the registered interviewees were working fully remote on a day-to-day basis, 7 were working in remote teams occasionally, and for 9 remote working was an imposed new normal. We have collected the study data through semi-structured open interviews. All the interviews were conducted through online video-conferencing tools, including zoom and Microsoft Teams. The interviews took place between 35 min to 75 min, were recorded with participants' permission and transcribed verbatim. The questions included inquiries about the participants' remote teamwork, how their teams develop shared mental models on equipment/ technology, processes, roles and goals (Cannon-Bowers et al., 1993; Casakin et al., 2013) and what challenges are they encountering in virtual collaboration both on a daily basis and in general.

3.3.2 Data Analysis

We follow the multilevel approach (Gong et al., 2013) by crossing the levels of analysis, widely discussed by Hackman (2003). He emphasises that social and organisational dynamics require attention to both lower and higher levels of analysis through: "bracketing can (1) enrich understanding of one's focal phenomena, (2) help one discover non-obvious forces that drive those phenomena, (3) surface unanticipated interactions that shape an outcome of special interest, and (4) inform the choice of constructs in the development of actionable theory" Hackman (2003, p.907). As our coding process evolved from using in-vivo coding for first-order codes taken from participants' own experiences and descriptions, we noticed after our first iteration of the preliminary coding scheme that when talking about virtual collaboration and the development of shared understanding, participants always refer to a specific mode of online communication separately. This led us to the revision of the coding scheme and the notion of the ecosystem of virtual collaboration tools emerged from the first wave of the data collection (see table 3.1 and table **??** for data structure with exemplary quotations). Our successive iterations of the coding schemes, iterated later, back and forth between the interview accounts and literature, presented the model of the shared understanding development within the ecosystem of computer-mediated teamwork.

3.4 Findings

The development of shared understanding in virtual collaboration rested on the utilisation of the whole ecosystem of HCI-supported online communication tools. Participants, when asked about their experience of distributed teamwork refer to each of the communication modes separately and were very detailed in describing the way they use each tool to serve a particular purpose. Table 1 presents our data structure from the coding scheme. Figure 3.1 presents the ecosystem of virtual collaboration tools rendered through participants' development of shared cognition in their virtual design collaboration.

Themes (from literature)	Second order codes (from literature)	Second order codes	First order codes
Task-related knowledge sharing	Task-specific knowledge	Email	Dry facts Formal communication Sending updates

Themes (from literature)	Second order codes (from literature)	Second order codes	First order codes
Team-related knowledge sharing	Task-related knowledge	Video conferencing	Group discussion on project Resolving work issues Group-level size
	Knowledge of teammates	Instant messaging	Getting to know colleagues Informal communication Open communication
	Attitudes and beliefs	Attitudes to work and personality clashes	Engagement discrepancy Lack of small talks Personality and interpretation clashes Unknown attitude to work Unknown mood and mannerism

Table 3.1: Data structure

Our model, theorised based on the qualitative data of the interview accounts, shows that in the shared cognition construct, remote workers can support three out of four categories: task-specific knowledge, task-related knowledge, and knowledge of teammates. Nevertheless, the reflections on the remote working revealed many emotions related to anxiety and frustrations related to the lack of shared attitudes and beliefs.

3.4.1 Overview of the study

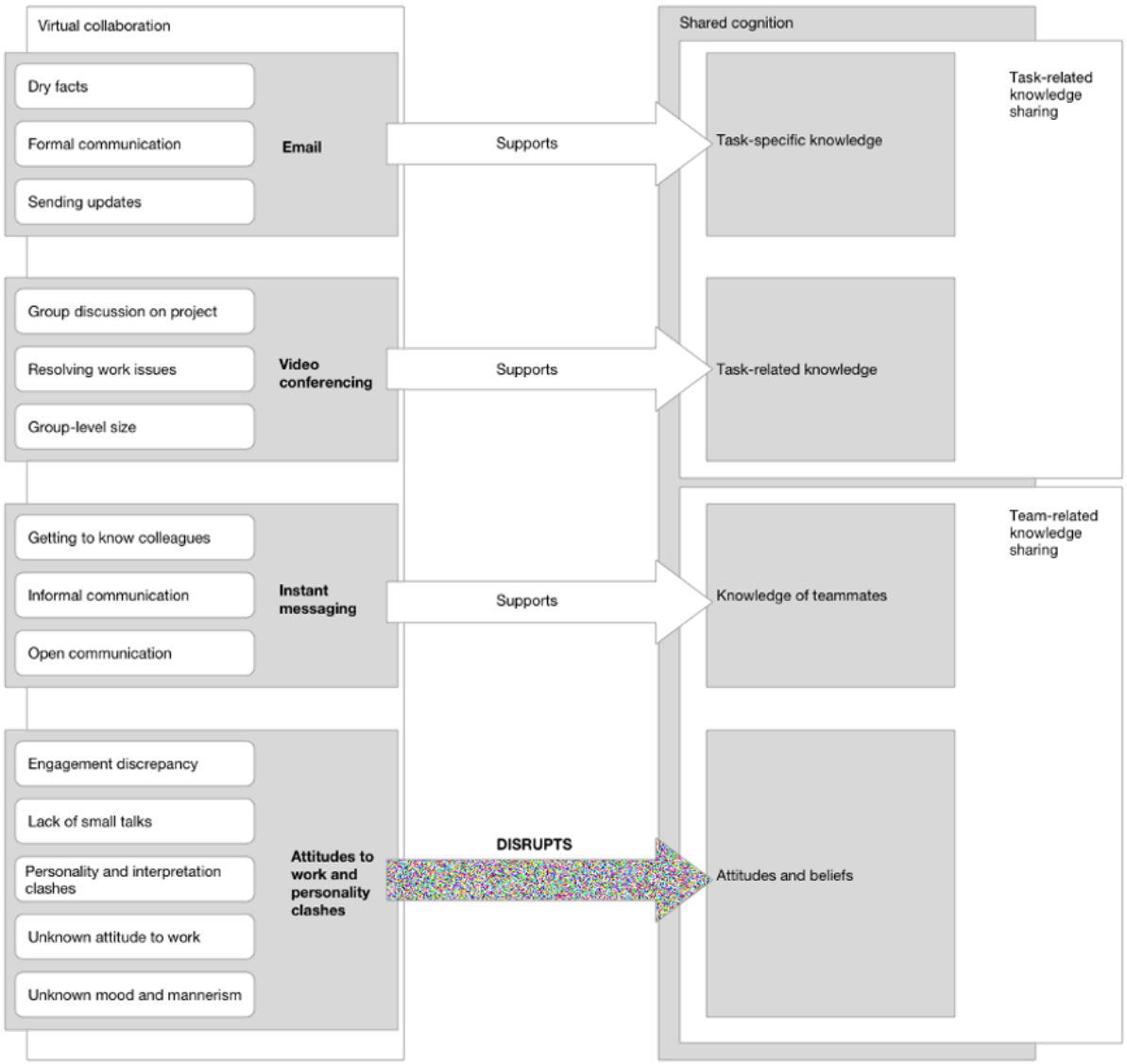

Figure 3.1: The ecosystem of the virtual communication tools within the shared cognition construct

3.4.2 Task-specific knowledge

Task-specific knowledge is argued by (Cannon-Bowers et al., 1993) to allow team members to take action in a coordinated manner without the need to communicate excessively, which leads to a compatible level of expectations for performance. Participants noted that the nature, in which they use emails is very specific in terms of both the communication purpose and style. Email communicates dry facts, as one interviewee mentioned that he sends emails only when he

needs "very precise, formal response". Another person reminisces that she treats emails with higher cautious as they seem to be more important: "So, so e-mails are maybe more formal, like if somebody is sending an email - probably important. And on Slack, you're not sure because you have so many group chats". Importance of emails strongly relates to the fact, that almost everyone describes emails as formal form of communication. For one participant, emails were not used for urgent queries, however the email still acts as formal communicator: But for ad hoc queries or things that aren't, of a serious or urgent nature, we would communicate via email which is probably the more formal communication channel. As participants consider emails as a tool to communicate precisely defined information, they tend to send updates on tasks, including setting up meetings or meetings follow up. "So we use Teams and it's for meetings, online meetings mostly, of course email to probably set up the meetings". They would use emails to deliver a specific message, send over a file to support communication in other channels. "It's kind of a lot of describing a lot of like imagining and sometimes while we're on the phone, we would ping each other an email with a mood board or an image if we prepared something in advance". Another participant would also refer to the nature of the email content as "dry facts" and hence a different style of language used by the senders: "There is, you know, it's harder to interpret the, the dry facts of the email, just because you're talking about things in slightly different language". Scientific study in HCI shows evidence that longer daily time spent on email, the lower was the perceived productivity and the higher the measured stress of study participants (Mark et al., 2016). One marketing interviewee had shared an interesting story, when her team stopped using emails at all, as the amount to communication through various tools has made the collaboration "messy". So it was, and we were also exchanging emails, so it was a little bit messy and was difficult to, organise. (...) since we started using that program, our communication was over there on the program. And then, but also we were exchanging a chat still on the Google Hangouts, but, we mostly like, we stopped exchanging emails Interestingly, in previous studies of distributed team communication, email was one of the main channel of communication in the virtual collaboration (Sonnenwald, 1996). However, in our study data, all participants referred to email only when describing a specific tasks requirement with the delivery of formal, precise information. Email has become a tool to address the development of task-specific knowledge sharing process in the distributed teamwork and acts as one of the components in the ecosystem of virtual collaboration.

3.4.3 Task-related knowledge

Additionally to the task-specific knowledge sharing (see Section 3.4.2), team members need similar knowledge (Rentsch and Hall, 1994) about teamwork in the nature of task-related processes. That includes a knowledge about teamwork "what it is, how it operates, it's importance" holding "across a variety of (albeit similar) task" (Cannon-Bowers and Salas, 2001, p.197). When describing group discussions on the project group level or resolving project issues, participants in our study refer to video conferencing. For example, one participant explains when his team is using WebEx - a professional video conferencing tool: "WebEx, that we'll be using more for the professional use, (...) setting up the meeting with four or five, seven people where we want to brainstorm what we want to have the weekly content to review some plans for the future or on the center where we, where we are." These discussions also help for some to sort any issues that would be stressful in the day and hence lower her performance. We haven't got any other calls in, and it's just through Google Hangout and that's kind of, the morning is probably the most important one because it helps you, I suppose, sets up your day in a good way. Almost all participants raise an observation that the task-related knowledge sharing on the video conferencing tools should only be discussed in smaller, project-level team sizes. "So I don't feel as though you're really utilizing the whole experience by having a large number of people and getting the most out of the tasks and what you're looking to achieve. So yeah, I think that's why I feel as though getting those work instructions across and being able to bounce off of each other. I think it's quite important to keep those numbers to one-on-one or maybe three people within, within a group." However, even in this case, the quality of the conversation is perceived by some as lower than face-to-face meeting, due to the smaller size of the discussant group: "if you have more than two people, maybe more than three people sometimes so I think three probably is, I see, as the limit maybe. I think the conversation moves very fast and it doesn't really give many people the ability to think and respond to certain comments and are moving up the conversation." This is in line with the suggestion of Egido (1988) that video conferencing still risks overall failure resulting from the misrepresentation as a substitute for face-to-face meetings. What seems to happen, as we report in the following sections, is that there is an additional layer of the knowledge-sharing construct required, that would support better shared cognition.

3.4.4 Knowledge of teammates

Within the theme of team-related knowledge sharing, scholars point to a theoretical attention of team mental models (Mathieu et al., 2000) or transactive memory (Dastmalchi et al., 2021; Moreland and Myaskovsky, 2000). Cannon-Bowers and Salas (2001, p. 197) explain, that this construct is required as "team members need to understand each other, their preferences, strengths, weaknesses, and tendencies" in order to increase performance. This is due to the fact that such shared cognition drives an understanding of how other team members behave through creating expectations or predictions of each other's actions. It exists when team members become more familiar with other and understand well the nature of the team interactions in their projects. One junior consultant talks about Slack - an instant messaging tool as a mean for her to get to know her new colleagues: "the direct messages with individual colleagues, which enables you to have quick, fast conversations and conversations, of course, that can be outside of work, talk or everything else, which has been quite helpful, especially joining as, as a new member and getting the chance to speak to individual members of the team separately, to, to get to know each other slightly more, that's helped." Instant messaging is perceived as for open communication, in contrast to emails. Many participants value the fast nature of the message turnaround and possibility to talk anything but the task-specific inquiries. "It also allows us to have lots of different channels of communication within it. So we can have, different group chats, different points of reference within it. "So like, we have one that is general, which is general news to the team, which we share like news articles or things relevant or pertinent for the business and the area that we work within." The conversations tend to be more relaxed and informal: "Slack's quite nice to have that interaction cause you're, it's, I suppose it's not Facebook, but if you're speaking to people as if, I suppose in a Facebook tone", encouraging workers to bridge teams, build relationships or simply have a laugh together: "For example, you're just, cause obviously we've got a section which says random, you just have a laugh with people. It's quite nice to just, it might not be face to face stuff, but it's just, it's quite nice having the team there when you need them cause you do interact with them still." "That's why I believe that the Teams can help as well to bridge these teams. To me, it's really allowing me to establish a bit closer relationship, even though we are not close together, but it could be, it's more personal one." Team knowledge within multidisciplinary teams (with a distributed nature of task-work knowledge) is necessary for the adequate team coordination and uninterrupted performance "as a collective entity" (Mohammed and Dumville, 2001). Low team knowledge sharing would impasse the development team members' behaviour expectations and hence hamper effective

team coordination.

3.4.5 Shared attitudes/beliefs

The last category in the shared cognition construct, interestingly not task-specific nor task-related, is related to a broader sense of shared belief structures and cognitive consensus (Cannon-Bowers and Salas, 2001; Mohammed and Dumville, 2001). This encompasses shared attitudes and beliefs of compatible perceptions about the task/environment, and is suggested in organisational behaviour to contribute to effective performance in decision making group (Walsh et al., 1988). The required sense of collectivism is to be found to increase satisfaction among teammates through offsetting the negative perceptions of resulted from team diversity (Ye and Robert, 2017).This cognitive consensus is however not being supported in distributed teamwork through virtual collaboration tools. Many of participants point out the lack of small talks and engagement discrepancy in remote working that relates to many clashes personality and interpretations. For example, one interviewee recollects: "because you're not seeing their face, you're not reacting. It's just like a bunch of words that is sent here and a bunch of words that is sent there. Their interpretations might be completely different. It opens up two different interpretations." These clashes are accentuated with the lack of understanding and possibility share knowledge about one's attitude to work, mood or mannerism: I think that's actually another big gap is, is the fact that you vicariously learning through other people, you know, when you're next to each other and looking at the types of conversations they're having. Our study revealed reflective opinions of the participants on the way they teams collaborate and, in the meantime, evoked the participants working self. Distributed teamwork caused stress for many of the interviewees, as they reported intense emotions, for example one marketing manager recalls: "My team was sort of stressed out, oh, why are they you know, calling me every five seconds on the guys, you just have to put yourself in your shoes, because you have to understand they have a lot of pressure from our board as well to sell." As one of the participant, when reminiscing the tensions in the project highlighted: "I think in general, [I miss] some of those informal meetings, coffees, whatever are helpful, just that people know there is still a person working on something, or she, he, she is part of my team and can have a worst or best day ever, but we're still people and not only emails that we're sending." This raises an alarm in the discussion about HCI and digital working environment not serving the last element of team shared cognition about attitudes and beliefs.

3.5 Discussion

Our data show that the cognitive consensus is disrupted in the distributed teamwork and such support is lacking in the virtual collaboration tools. Mohammed and Dumville (2001, p. 100) highlights that "Not only is it important that team members share an adequate knowledge of taskwork and teamwork, but that they also have a common conception of the assumptions underlying issues of significance." As more people are planning to work remotely even after the COVID-19 lockdown in 2020, we aimed to interview people from across various sectors, years of experience and previous experience with remote working. This richness of diverse accounts enabled our data to be triangulated and increase the generasibility of the findings. However, the study does share some limitations common in studies with theoretical findings within an inductive qualitative methodology research. Our sample, albeit included candidates from snowball sampling and internal networking (which expands to passive interviewees who do not normally seek to participate in academic studies), draw on workers substantially privileged in professional services. Nevertheless, almost half of the participants were already working either fully remotely or occasionally and for 9 participants, remote working was an enforced, unknown condition. This gives us diverse profiles of the interview accounts lowering the sample bias. Future research efforts would be ancillary to sharpen our findings, possibly with quantitative methods to expand the sample diversity and examine more in details the consequences of the lack of shared attitudes and beliefs. Further exploration with, for example, longitudinal study would normalise the strong emotions related to the COVID-19 lockdown enforcement.

3.6 Conclusion And Implications For Communication Systems

We studied multidisciplinary teams working on creative projects using virtual collaboration tools across different sectors to understand how shared cognition is being developed in a digital environment. Our interviews with 21 professionals lasting on average around one hour, revealed that remote team members utilise the whole ecosystem of virtual collaboration tools depending on the communication and knowledge-sharing purpose they want to achieve. Our insights cast light on a growing population of remote workers, as the COVID-19 lockdown has triggered many companies to the decision of the hybrid / fully remote working nature, saving on office

rent and travel costs. However, our data show that creative virtual collaboration tools cannot fully support the notion of shared understanding in remote design teams. Within the construct of shared cognition only task-specific knowledge, task-related knowledge and knowledge of teammates are supported with the current tools. Shared attitudes and beliefs are however disrupted in the digital ecosystem of collaborative tools and hence opens up a discourse about the value and importance of having a strong culture in teams. Our findings might be relevant for designers and engineers of future virtual collaboration tools, who want to increase effectiveness and better HCI. Extant literature on shared cognition focuses on tangible performance outcomes, and thus our research contributes to the understanding of this construct in terms of creative distributed teams. While previous work on CSCW focused either on chosen specific communication channels, or the ecology of tools with the perspective of workflow and team conflict, our study contributes to the work on the ecology of tools with a holistic view on the notion of shared cognition aspects. Through crossing the levels of analysis, our research highlighted challenges faced by distributed teams, namely the lack of support on attitudes/beliefs (one of the elements of the shared cognition construct) in the existing ecology, which informs the design of future CSCW tools.

Chapter 4

Moody Man: Affective Recognition Feedback System

4.1 Introduction

As innovation became a critical notion for competitive advantage for firms to survive in uncertain environments, and creativity being its pre-requisite (Amabile, 1988; Witt and Beorkrem, 1989), the growing interest in creative collaboration has been vivid during the past three decades. With the turbulent changes brought by the COVID-19 pandemic, technology-enabled remote work has emerged as a new norm for many professional workers (Statista, 2020*b*; Gibson et al., 2021), and is predicted to at least partly be remained (Ozimek, 2020). However, computing professionals have been focusing mainly on developing tools that support productivity for users to work faster, more efficient, and to reduce errors (Shneiderman, 2009). It has been raised in prior works (Frich et al., 2018; Shneiderman, 2009) that there are still challenges and "untapped potential" for creativity-oriented tools among HCI researchers. A study by Ocker (2005) highlights further obstacles for creativity in virtual work including the lack of shared understanding, domain knowledge, and social influences. Commonly, previous attempts for augmenting HCI environments in prototype-driven research included visualisations of group dis/agreements or contribution level (Janssen et al., 2007; Leshed et al., 2009). However, Samrose et al. (2021) conducted a medium-scale survey showing that virtual meetings suffer also from the negative tone and lack of social cues among other obstacles. A small body of literature addresses this through experimenting and testing emotion management systems in education (Wambsganss et al., 2021; Ez-Zaouia et al.,

2020), video meetings (Samrose et al., 2021; Ez-Zaouia et al., 2020; Samrose et al., 2018), or through chatbots (Benke et al., 2020; Peng et al., 2019). Given pre-COVID-19, chat apps were the number one collaboration tool for teams (Spiceworks, 2017*b*), recent post-COVID-19 industry surveys reveals that semi-synchronous instant messaging are becoming even more important for teams, reported with 35% dramatically increase of use, and 54% beginning to use (Statista, 2020*a*). To date, no interactive systems exists that explicitly provides dynamic affective recognition feedback (including both sentiment and emotions), and specifically there has not been conducted empirical studies targeting this concept in terms of virtual teams' creativity.

This paper seeks to address our interest in how affective recognition (including sentiment and emotion) affect shared understanding and creativity in text-based communication. To do so, we developed a solution for dynamic affective recognition feedback system seamlessly integrated into a market-leading team communication tool (Slack) with the leading AI system (IBM Watson), and examined how it can affect user's shared understanding and creativity through a quasi-experiment with online surveys, in-depth post-workshop interviews, and linguistic analysis of chat transcripts.

4.2 Affective Recognition Feedback System: Rationale And Design

Findings from prior work informed the design of the emotion recognition dashboard. The app included behavioural features related to the notion of team shared mental model: sentiment and emotions of text messages supported by emojis through a modal view (see Fig. 4.2), as emojis can facilitate conversational functions (Cramer et al., 2016). In text-based affective computing, emotions are represented through two predominant models: a categorical approach that assigns emotions discrete labels (e.g. anger, joy), and dimensional models that emphasise valence and arousal as fundamental dimensions in understanding emotional experience. Whilst studies show that emotions are better represented in with a dimensional model (Calvo and Mac Kim, 2013), the design of the Moody Man app was built on IBM Watson API, where the dimensional model was not available, and hence the study tool was based on categorical representation with a defined and restricted set of labels. We designed the dashboard with an infrastructure (see Fig. 4.1) that is seamlessly integrated with existent Slack chat messenger (as chatbot-based emotion management systems are found to be intrusive to participants (Benke et al., 2020)) due

to technical feasibility, the ability to add own software to the existing developer environment through API, and to reduce the Hawthorne effect[1].

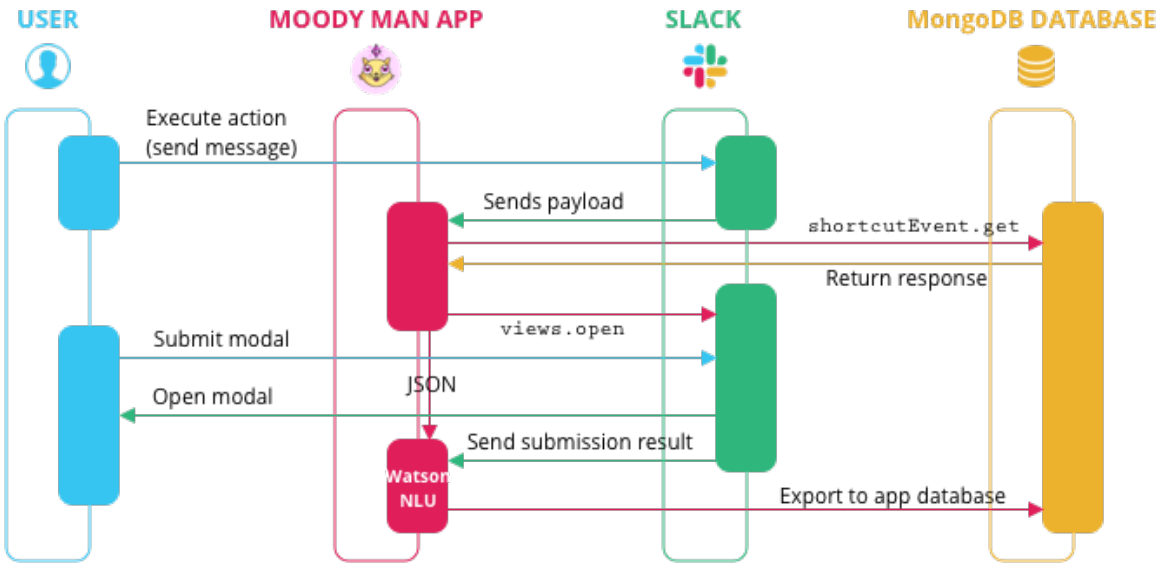

Figure 4.1: Flowchart of the app design

The basic design of Moody Man in Figure 4.1 followed design specifications from Slack documentation[2], and consists of a Slack Bot presenting a Modal View[3]). Afterwards, the app will query within the MongoDB database and find the sentiment and emotion values for the text. The app will then put the values into a JSON so that the Slack modal view in which participants can check the sentiment and emotion of a message. The front-end consists of a JSON object payload that Slack would understand and present feedback to the participant. The Python server, run in the background, manages processing the text and inputting the text into IBM Watson Natural Language Understanding (Watson NLU) to provide the relevant information. The results were then saved on a MongoDB database, better suited for query data into a data structure native to Python, which allowed the participant to review the information without any delay.

[1]The Hawthorne effect is a term used to describe the phenomenon where individuals modify their behaviour in response to the awareness that they are being observed (Adair, 1984).

[2]https://api.slack.com/surfaces/modals/using

[3]When the participant clicks on the shortcut, it will send a request to the app server to notify the shortcut has been clicked. The app will then retrieve the message the participant wants to view and understand the message's sentiment and emotion.

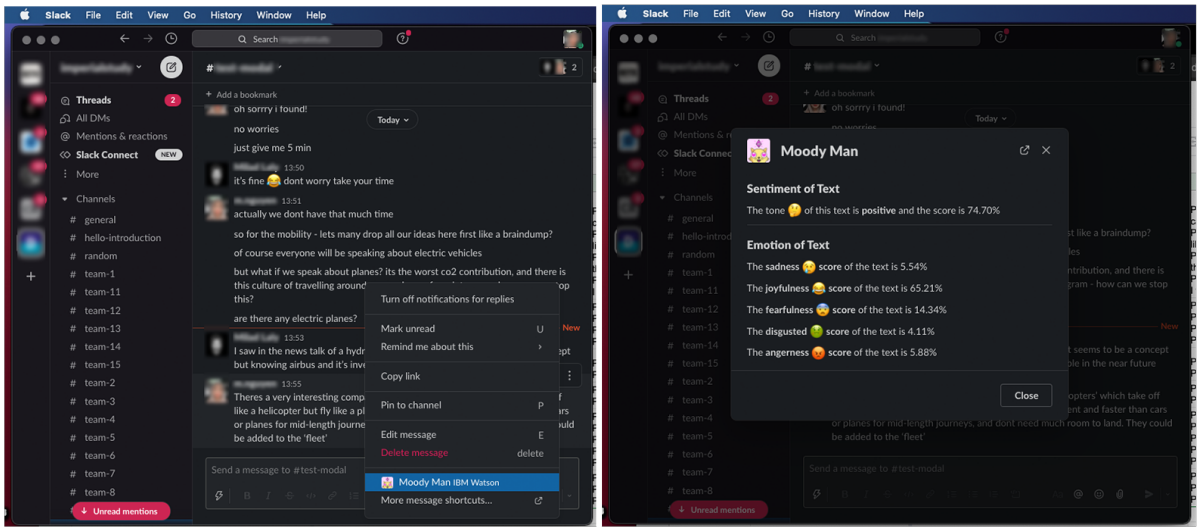

Figure 4.2: The Moody Man dashboard and it's components.

4.3 Methodological Approach

The objective is to assess how affective feedback (i.e. sentiment and emotions) in text-based communication affects online meeting creativity and team shared mental models. In this study, affective feedback is provided by the affective recognition feedback system that we developed - Moody Man - and tested through a series of quasi-experiments at design workshops with online pre-test (T1) post-test (T2) surveys. We followed the investigation with in-depth post-workshop interviews for qualitative analysis and performed linguistic analysis of post-workshop chat transcripts to study real affect development. The affective recognition feedback system was leveraging the *natural language processing* (NLP) for advanced text analysis through Watson NLU technology that analyses the content sentiment and emotion through numerical likelihood scores (*ToneScore — ibm-watson — watson-developer-cloud.github.io*, 2016):

> The score that is returned lies in the range of 0 to 1. A score less than 0.5 indicates that the tone is unlikely to be perceived in the content; a score greater than 0.75 indicates a high likelihood that the [analysed] tone is perceived.

It is identified as the leader in the Garner's Magic Quadrant for data science and machine learning (Gartner, 2021) and also the highest-rated NLP platform in Software Engineering considering the aspects (intents classification, confidence scores, and entity extraction) investigated by Abdellatif et al. (2021) with the highest accuracy (79.2%) according to Ermakova et al. (2021).

4.3.1 Participants

A total of 30 participants took part in the study, in line with similar studies listed in Table 4.1.

	Publication body	Article	Survey participants	Interview participants	Linguistic analysis of chat transcripts	Sample
Real-time language-based feedback	CHI '09: CHI Conference on Human Factors in Computing Systems	Leshed et al. (2009)	25	-		undergraduate students
Explainable AI	CHI '20: CHI Conference on Human Factors in Computing Systems	Liao et al. (2020)	-	20		UX and design practitioners
Affect Detection in Collaborative Chat	CSCW '13: Proceedings of the 2013 conference on Computer supported cooperative work	Brooks et al. (2013)			32	astrophysics scientists
Taxonomy of Affect in Collaborative Online Chat	SIGDOC '12: Proceedings of the 30th ACM international conference on Design of communication	Scott et al. (2012)			30	astrophysics scientists
Chat activity and chat sentiment	ICSEW'20: Proceedings of the IEEE/ACM 42nd International Conference on Software Engineering Workshops	Kuutila et al. (2020)			8	software developers
Real-time meeting feedback dashboard	CHI '21: CHI Conference on Human Factors in Computing Systems	Samrose et al. (2021)	23	9		employees of a large tech company

Table 4.1: Prior relevant studies' sample sizes

Participants were recruited among students from five universities in the United Kingdom. They were required to have a prior experience in (1) virtual communication channels and (2) multidisciplinary and creative teamwork. The participants' ages ranged from 20 to 36, and 63% were women. To control the factor of potential existing shared mental models, the matching of the dyads was based on the fact that the team members had not previously worked with each other. The study was approved by the Science Engineering Technology Research Ethics Committee under the SETREC reference 21IC6717. The participants were compensated 50 GBP for their participation.

4.3.2 Protocol

To explore how the affective recognition system affects virtual teams shared understanding the creativity, we adopted a quasi-experimental research design with within-subject users under a given intervention, using *one-group pre-test post-test* method informed by literature (Liu et al., 2021; Allen, 2017). For each group, the team was given an hour to ideate, envision and discuss a solution for future mobility[4]. First, participants were invited to work on a given design brief through a text-based communicator (Slack) and to complete an interim online survey (T1). In the second stage of the study (i.e. after 30 min of the workshop), the participants were introduced

[4]During the design workshops the participants were asked to discuss and brainstorm in their dedicated Slack channel a given design brief on the future of mobility. This concept is one of the challenges identified in ARUP Drivers of Changes (ARUP, n.d.). We selected this brief due to the following reasons: it requires creative thinking, multidisciplinary collaboration, is challenging enough, and can be completed in an experimental duration of the workshop.

to the Moody Man app and explained how they could utilise the tool to learn about affective (sentiment and emotion) feedback on the messages within Slack. Post-intervention phase, and at the end of the workshop, all participants were asked to fill out an exit online survey (T2). Following the design workshops, all participants were asked for 60-min in-depth post-workshop interviews to share their reflections and feedback on the collaboration process and the solution app.

4.3.3 Survey Measures

Our measures were each adapted from prior research for the context and consisted of multi-item statements with Likert-scale response formats. Table 4.2 presents used measurement scales and source works.

ID	Measurement	Scale	Source
Q1_1 - Q1_4	Shared understanding	Likert Scale 1-7 (1 = strongly disagree, 7 = strongly agree)	Cannon-Bowers et al. (1993)
Q3_1 - Q3_4	Attitude (Team Relationship)	Likert Scale 1-5 (1 = far too much, 5 = far too little)	Jehn (1995)
Q5_1 - Q5_4	Attitude (Task Conflict)	Likert Scale 1-5 (1 = far too much, 5 = far too little)	Jehn (1995)
Q9_1 - Q9_2	Attitude (Climate for Creative Productivity)	Likert Scale 1-5 (1 = strongly disagree, 5 = strongly agree)	Witt and Beorkrem (1989)
Q6_1_Q6_5	Self-perceived creativity	Likert Scale 1-5 (1 = strongly disagree, 5 = strongly agree)	DiLiello et al. (2011 May-Jun)
Q7_1 - Q7_6	Creative self-efficacy	Likert Scale 1-5 (1 = strongly disagree, 5 = strongly agree)	DiLiello et al. (2011 May-Jun)
Q4_1 - Q4_7	Team Satisfaction	Likert Scale 1-5 (1 = extremely dissatisfied, 5 = extremely satisfied)	Spector (1997)
Q8_1 - Q8_10	App evaluation	Likert Scale 1-5 (1 = strongly disagree, 5 = strongly agree)	Samrose et al. (2021)

Table 4.2: Survey measurement scales and source works

Table 3 in the Appendix provides the texts of the statements items for our primary measures.

Results of the quasi-experiment assessing creativity and shared understanding were obtained pre-intervention (T1) with the interim online survey after 30 min of the design workshop, and post-intervention (T2) with exit online survey using the same multi-item statements. The exit questionnaire included additionally a scale evaluating the feedback system dashboard. For all measures, we confirmed the statistical appropriateness of aggregation by computing the Cronbach α coefficients for the various measures. Items were averaged into an overall scale score.

4.3.4 Post-workshop interviews

Following the experimental workshops, we conducted in-depth semi-structured self-reflective interviews, with one participant leaving the study (N=29). Previous empirical works in HCI includes studies on Slack chat usage (Easley et al., 2018) with 8 interviews, meetings sentiment analyser (Samrose et al., 2021) with 9 interviews, or AI explainability (Liao et al., 2020) with 20 informants. The interviews ranged from 30-60 minutes. A total of 1122 minutes of interviews were recorded and transcribed verbatim. We performed axial coding (Charmaz, 2006), and followed grounded theory for our thematic analysis (Corbin and Strauss, 2014; Glaser and Strauss, 1967), widely used to study societal interactions in social science research disciplines. Our coding process has been conducted by the two first authors, where detailed annotation instructions were collaboratively pre-developed and intercoder reliability was performed (% of agreement: 85.7, Cohen's k: 0.695) based on extracted 1300 transcription lines. Both kappa and percent agreement has been performed and reported. The researchers frequently discussed between each other on an everyday basis and the iterative coding process resulted in 22 axial codes.

4.4 Results: Quantitative analysis of creative workshop surveys and linguistic analysis

Overall, the results from the exit survey (T2) showed that all measures have increased compared to the interim survey (T1). Since the quasi-experiment included within-subjects participants, we used Paired Wilcoxon test for the nonparametric independence test (Related-Samples Wilcoxon

Signed Rank Test) to validate the statistical significance of the changes between the exit and interim surveys. All scales are statistically significant in terms of the increases after the intervention. We discuss these improvements in this section.

Shared Understanding To measure shared understanding within teams, we asked the participants to rate four statements at both the pre-intervention (T1) and post-intervention (T2) periods, to see if there was a difference after using Moody Man. Shared Understanding has increased with statistical significance (p-*value*<0.001) between T1 (Mean = 5.38, S.D = 0.94, α = 0.71) and T2 (Mean = 6.10, S.D = 1.00, and $\alpha = 0.89$).

Attitude To assess if attitude has increased within participants, we asked participants to answer ten questions that would present if there is a difference between participant's attitude after Moody Man being available or not. Attitude has increased with statistical significance (p-*value*<0.05) between T1 (Mean = 3.59, S.D = 0.51, and $\alpha = 0.80$) and T2 (Mean = 3.66, S.D = 0.48, and $\alpha = 0.85$).

Creativity To evaluate whether creativity within participants has increased, we looked at two dimensions: a five-item Self-Perceived Creativity (DiLiello et al., 2011 May-Jun) and a six-item Creative Self-Efficacy (DiLiello et al., 2011 May-Jun). We reported a statistically significant increase in the exit surveys with a p-*value*$=0.012$, between T1 (Mean = 4.19 and S.D = 0.39) and T2 (Mean = 4.28 and S.D = 0.43).

Team Satisfaction After the experiment, we asked participants to answer seven questions to evaluate whether team satisfaction (Spector, 1997) has increased during the experiment within participants. Exit surveys T2 resulted in with the minimum and maximum on the 5-point scale ranging between 4.31 to 4.69 (Mean = 4.54, S.D. = 0.59, $\alpha = 0.906$), higher as compared to reports at T1 (Mean = 4.29, S.D. = 0.64, $\alpha = 0.859$). Team satisfaction has reported a statistically significant increase from T1 to T2 with a p-*value*<0.001.

App evaluation The 11-item scale adopted from Samrose et al. (2021) was only measured after the intervention with the app at T2. The responses on the evaluation of the prototype app showed the ambiguous and uncertain perception of the participants of the system. On the 5-level Likert scale, participants at the exit survey revealed uncertainty about the app (M = 2.831, S.D =0.818, $\alpha = 0.897$). We use this as guidance to garner further substantially valuable feedback and opinions from interview accounts following an in-depth inquiry post-workshop.

4.5 Results: Computational linguistic analysis

In order to triangulate our findings, we conducted a linguistic analysis of all chat entries from the quasi-experiments exported from the MongoDB database. We collected in total 1574 plain-text inputs, posted by workshops participants as text messages (overall 21 008 words). We classified them according to the timestamps to messages before and after the intervention, i.e. at T1 and T2. Watson NLU affective recognition analysis has been applied to both batches in order to measure the change in sentiment and emotion in these two study periods.

The results have further strengthened our confidence that the affect during T2 has improved as compared to T1 through:

- higher scores (likelihood of perceived tone) of:
  - sentiment: 0.57 (T1) to 0.68 (T2)
  - joy: 0.56 to (T1) to 0.64 (T2)
- lower scores (likelihood of perceived tone) of:
  - sadness: 0.18 (T1) to 0.14 (T2)
  - fear: 0.14 (T1) to 0.10 (T2)
  - disgust: 0.08 (T1) to 0.05 (T2)
  - anger: 0.12 (T1) to 0.08 (T2)

Statistical significance of the improvement has been analysed by using the Related-Samples Wilcoxon Signed Rank Test with results for each variable at $p\text{-}value<0.001$.

Improvements in sentiment (higher score in T2) affect further group dynamics in terms of participation and identity, as George (1990) suggests that positive group affective tone is negatively related to absenteeism. Additionally positive emotions, including joy (higher score in T2), combined with a decrease in negative emotions scores, including sadness, fear, and anger (all with lower scores in T2) allow the group for greater cooperation and reduced conflict in the group (Barsade, 2002).

4.6 Findings: Qualitative analysis of interviews

Going back and forth to the literature, and following grounded theory we grouped the axial codes into categories from literature and identified two overarching themes that emerged from this iterative process.

4.6.1 Motivations for affective recognition

Unclear results from the surveys about the app evaluation triggered our interest to understand better and more in-depth how and when the app would be found useful for the study participants. Our interviews revealed specific environments that would motivate informants to use affective recognition dashboards.

Usage points

We identified several usage points that echoed the argument of Clore and Palmer (2009) on specificity of the collaboration constraints concerning **team size**, as the feedback tool *would have been more useful if the team was bigger* (P-17), because *when we there's a bigger group and you can't, you know, like, think about how everyone's feeling.* (P-10). It is specifically crucial in creative collaboration phase of **ideation** *when you are doing design, but being critical in like a constructive way that you're not coming across as like, negative* (P-1). From the individual level, it helps team members for defining an online portrayal and **self-verification** is a *quick indication whether it's comes across as good or not* (P-5) which in turn may be *a solution to have a better relationship with colleagues* (P-20)

User type

Referring to the affective recognition, motivations for usage depend heavily on the user type, that is described by the characteristics of users including domain knowledge, **cultural background** and language barriers (Liao et al., 2020). Participants hint at use cases for the affective recognition tools being useful when *English is not (his) first language* (P-22) or when one is *trying to learn English* (P-26). Differences in **domain knowledge** can also be mitigated by

affective recognition, for example as reported by P-26, when the collaborator is *not a designer, it would definitely be a tool to try and say what is it you're trying to convey.*

Emojis

Previous research on emoticons has revealed several key applications for this feature: depicting emotion toward a subject (or recipient), helping to control emotion levels, representing emotions that are absent in the text, better expressing the writer's meaning, and either reinforcing or softening the writer's commentary. Cramer et al. (2016) suggest that emojis can fulfil similar emotion-oriented roles as emoticons. Our interview accounts' reveal how this took place in a work context in creative collaboration. In order to **enhance affective communication**, all participants reached out to emojis to improve the collaboration process, as they felt *it's necessary to, like create more of like, friendly vibe* (P-19) or *make the conversation a little less bureaucratic* (P-16). Emojis helped to **clarify the context**, for example by using *smiley face or a question mark or whatever, like, it just clarifies your thought, as if you're face to face a little bit better* (P-28). For Cramer et al. (2016), emojis are now often used to elaborate on contextual information or show how a situation has changed, for example providing or re-emphasising situational context. Emojis can be used for convenient conversation management for cases such as quickly **acknowledging** the last turn, ending a conversation when not knowing what to say or not wanting to say anything, or when saying nothing would be inappropriate. Participants found emojis as a way to show agreement (P-13, P-15), or complete the trail of thoughts, when they *don't need to add anything more to these ones, or, okay, this thread is done, like this job is done* (P-22).

Impression formation

In all aspects of communication, impression management is a one of the key considerations. Some authors has previously examined the notion of impression management in computer-mediated communication (CMC) from the perspective of casual social relationships (Bazarova et al., 2013) or romantic relationship (Zytko et al., 2014). In an online setting, the variety of nonverbal clues that typically help in the development of impressions is significantly reduced (Switzer, 2008). In line with this our participants highlighted the need to use Moody Man in **less familiar relationships**, for examples when they *don't know the person [their] talking to* (P-29). The affective and emotion recognition feedback system would be hence used *quite a lot, especially at*

start getting to know people (P-3). More specifically, such feedback system would be utilised by the study participants when speaking to a **figure of authority**, for example when *talking to my boss, or my boss's boss, for example, or a professor even at uni* (P-28), especially when one's *need to be more careful about the word I use* (P-3). Self-presentational concerns can be mitigated, by utilising emotion and affective recognition that can in turn support **positive self-portrayal**. Prior work reports that textual cues were more dominant in the process of impression formation (Pelled et al., 2016). For example, one of the participants recalled if *the feedback that is neutral, then like, that's okay to send, and you don't really have to worry about if you're coming across to* (P-1). The motivations to use affective feedback tools include moments when the user needs to be *be careful with the way you express yourself* (P-19) and when one wants to *make sure that [he is] coming across well* (P-5).

4.6.2 Design Goals for AI affective recognition adoption

Delivery timing

While previous work on the delivery timing of feedback systems with sentiment analyser suggests usefulness of reports on behaviour features **post-meeting** (Samrose et al., 2021), our study revealed that workshop participants, albeit would *find it interesting* (P-5), they would not *even review it* (P-20), as *damage has already been done* (P-30). This is due to the fact that in terms of building a shared understanding within online teamwork, it is *quite difficult sometimes to compensate afterwards* and hence participants would not have *any reason to reflect on that* (P-26). The in-depth interviews revealed further concerns about this and stronger preference towards a **pre-sentence delivery timing**. P-12 recalled that she does not *feel [that] there's any point in finding out [her] message is angry and might cause a bit of friction after [she] sent it.*

Usability

Specifically, we found a detailed suggestion on how this pre-sentence feedback could be designed: *as you're typing, there's like a little emoji that sort of changes color as your sentences are completing. And maybe like a really easy way, because I can also see that being kind of annoying after a long time, if you're just having a normal conversation, you don't need to see it, so maybe*

like a very quick toggle - then you can just toggle them on and off in the corner, and then it changes color, or it just becomes sort of transparent (P-28). Moreover, from our interviews, we have learnt about obstacles for the greater adoption of such feedback systems. User experiences and usability have been seen salient in multiple interview accounts, and the critique was often related to the **number of clicks** required to access the feedback information. Since the Moody Man app required *extra click* (P-24), as it *was hard to access [and] a bit of a pain to having to click on other stuff* (P-14). Another challenge for adoption was the **numeric data representation**. It seemed that sentiment and emotion measurement displayed as percentages were unclear to the workshop participants, where some reported that they were not aware if that was *noise or whatever that it is reading of that emotion* (P-21). This would also affect the speed of participants' comprehension, as they would prefer something *more visual, something more easy to understand; because percentages, you might understand that but if you just look at a chart or something, it's like quick one second* (P-14).

Trust

Trust in accuracy, algorithm, and the data source is one of the frequent themes that emerge in discussions regarding adoption hurdles for AI-based products, from the very end users of the systems created through utilising machine learning (ML) models. Our study participants reported concerns about **accuracy** that *there's a possibility it wouldn't be accurate* (P-30). This was affected by the perceived accuracy of one of the respondents recalled *didn't think it really reflected the message very accurately (...) I don't think I think I got it completely the wrong way. So I thought okay, I don't think this is really that helpful for me* (P-28). Prior work on AI explainability raises concerns about such models and the lack of trust in the **algorithm**, being considered as "black boxes" since they don't provide any information about how they arrive at their estimates. Determining how to visualise, explain and understand deep learning models is becoming more important in research (Liao et al., 2020). Our participants challenged the accuracy as they were *trying to understand how the what the algorithm was, or the code was behind* (P-22). According to a study from Kennedy et al. (2021), users pay more attention to the size of the training data set, the algorithm's source, and the stated accuracy, and less attention to the model's transparency or the relevance of the training data. However, the source of the **trained data** seems to be of interest for our participants, as they *would assume that the AI has been taught with Native users, so I wouldn't trust it to assume from non native uses* (P-10) as similar, questions arose, whether the model was *based on British slang, or normal English*

(P-22).

AI design (complexity of emotions detected)

"Labelled" emotions, for example, anger or happiness, have a special place in the affective computing world. However, some researchers are still debating the concept, value, and existence of such "labelled" states (Russ, 1993). Even while most AC applications seem to rely on such categorisations, some research in HCI suggests that alternative methods may better serve computer system development. There's a debate over what the right degree of representation should be for the applied use of affective computing (Calvo and D'Mello, 2010). Some of the participants mentioned that they did not continue to use Moody Man as the AI did not contain **emotional nuances** they deemed useful to their mannerism such as *irony and sarcasm* (P-11). This implies that participants wanted to have a wider range of emotions including various situational and contextual nuances. Additionally, P-1 mentioned that *you can't really judge some message based on if it's positive or negative.* This implies that further research is needed to display and present an extensive range of emotions of AI to be adopted by a wider audience.

4.7 Discussion And Future Work

This study was performed as a quasi-experiment, as opposed to a traditional experiment, because the random assignment of participants to conditions for between-subjects treatment was not feasible for the given total sample size. As noted in chapter 2, experimental research design presents various limitations: difficulty to generalise findings to a wider population, limitations from sample bias, or decreased empirical relevance. One of the most challenging issue for studies with limited resources, relates to the within-subjects design of the study, which on one hand, gains from increased control and efficiency; and at the same time, poses a risk of lower internal validity and of the carryover effect, where one condition can impact the behaviour on other conditions regardless of the intervention. Although every possible attempt was made to control many aspects, several factors remained that could not be controlled in the setting. We are aware that our research may have the following limitations, that are advised to be addressed in future work: (1) time passed, (2) cultural context, and (3) reflective bias. As our findings present how affective recognition facilitates online impression formation, and following studies on impression management being a predictor for long-term relationships, we present evidence for

how AI-based affective recognition can support virtual teams in building long-term relationships. The study also presents threefold directions for further research: (1) ethical, (2) social, and (3) technological implications.

The theme of concern over the transparency of Artificial Intelligence (AI) is a common one in applications that utilise AI, as highlighted in the work of the United Nations publication 'Resource Guide on Artificial Intelligence (A.I) Strategies' (Nations, 2021). This legitimate concern can stem from questions of trust, fairness, and particularly accuracy, as highlighted in this study. Concerns over transparency may seem to be particular to the implementation of AI, however, in reality, these same concerns have also historically been levied at technologies governing areas such as privacy and security. Artificial Intelligence, particularly in the form of neural networks is a younger technology, requiring time for best practices such as transparency to become embedded as a critical element of AI itself. Also, an area for consideration regarding this study is the topic of sentiment itself. There are few functions of intelligence that appear to be in the purview of the human experience quite so much as sentiment. The application of sentiment to language for communication can be considered core to what it is to be human, being a solely human behaviour. It is therefore difficult to disregard this perspective when analysing the reports of the participants in their perceptions of accuracy.

Whilst prior works on sentiment recognition in virtual teamwork focuses on team performance *in situ*, especially in respect to short-term real-time team behaviour, our study sheds light on how AI-based models for affective recognition can affect long-term relationships. Through post-workshop interviews, research participants shared multiple reflective accounts on how dynamic sentiment and emotion recognition feedback systems would motivate them to use for impression formation with strangers or figures of authority. Such technology may provide opportunities to self-evaluate their language, to change their behaviours, and to revise their text in real-time/during a meeting, reported as valuable for their online impression formation. As Human et al. (2013) suggested, initial impression formation is a significant predictor of longer-term relationship development, and establishing accurate impressions among new acquaintances has a positive impact on the development of their relationship. Our study, therefore, presents the potential of the affective recognition technology for building long-term relationships through facilitating impression formation.

The present findings suggest several courses of action to improve future designs of AI-based tools. With regard to the feedback systems and their delivery timings, in contrary to previous works

with tone analyser, our participants found pre-message feedback more useful than post-meeting. A further important implication for design guidelines refers to the usability of the developed systems, especially in terms of the UX and UI. Participants advocated the minimum required a number of clicks to access the feature, suggesting a potential toggle to active the affective recognition feedback on demand. They also raised an aversion to the numerical representations of the AI-generated feedback in terms of user readability and quick comprehension. Lastly, our findings suggest that designers of future AI-based communication support systems tailor the solution to specific usage points, concerning affect being crucial in more personal feedback and social collaboration including ideation, brainstorming, newcomer onboarding, or promotion opportunities.

Our results are encouraging and present promising insight into how dynamic affective recognition feedback systems can improve shared understanding and creativity in virtual teams. We hope that this study will serve as a base for future investigations in this limited, yet fascinating intersection of the two disciplines of creative research and HCI, and help inform future AI-based solution designers with guidelines for stronger adoption.

Chapter 5

Discussion and Conclusion

Much like the construction of the Tower of Babel, design collaboration between diverse teams is vulnerable to communication challenges. Where teams lack shared understanding – whether through language variation or jargon idiosyncrasy, prevalent in multidisciplinary collaboration – they can become as scrambled and uncoordinated as the men of Babel.

5.1 Discussion

This thesis investigated the challenges and opportunities of multidisciplinary design collaboration in distributed teams, with a focus on creativity and shared understanding. The study adopted a Design Research Methodology (DRM) structure and included a systematic literature review, in-depth qualitative research, a prototype proposal, and an evaluation of a machine learning-based dynamic affective recognition feedback system. Collectively, the studies addressed several research questions related to multidisciplinary collaboration. They identified and highlighted the importance of shared understanding as a crucial factor that impacts team dynamics and creativity in distributed multidisciplinary design collaboration. The studies also examined the impact of communication channels, virtual tools, and affective recognition in remote teamwork and provided recommendations for improving decentralised collaboration.

To answer the first research question, a systematic literature review identified the main patterns within previous research on the topic and highlighted the need for greater rigour in the study of multidisciplinary design collaboration. It also identified a gap in understanding how design

collaboration is affected in distributed work and how design teams create digital artefacts. This study identified shared understanding and trust as two important aspects of socio-cognitive team dynamics in multidisciplinary design collaboration. The second study mapped the findings of the literature review onto the field of CSCW and illustrated the industrial relevance of these findings. In order to guide future research, we analysed collaborative systems and found that asynchronous, distributed systems including email and communication chat apps are the most vulnerable in terms of shared understanding and trust. These systems are also speech-only communication channels, which have been shown to be associated with lower perceived effectiveness in teamwork. The top two collaboration tools used in the industry at the time of the study, email and chat apps have lowest levels of trust and shared understanding. This study suggests a need for research on how to facilitate team dynamics in multidisciplinary collaboration, particularly in these vulnerable systems.

The qualitative research presents findings from in-depth interviews with practitioners of design teams. It investigates the use of virtual collaboration tools in multidisciplinary design teams and their impact on distributed collaboration and shared cognition. The study identifies the key factors that influence collaboration in remote teams and provides recommendations for improving the use of virtual tools in multidisciplinary design. The last study proposes a prototype with a machine learning-based dynamic affective recognition feedback system and discusses the implications of the findings for the design of AI-based tools for multidisciplinary design collaboration. The findings of this study indicate that dynamic affective recognition feedback systems have the potential to enhance shared understanding and creativity in distributed multidisciplinary design teams. The paper highlights the importance of transparency in AI-based tools and the need to consider usability and user experience in their design. This research serves as a starting point for further exploration into the intersection of design and HCI, and can provide guidance to AI solution designers looking to augment decentralised teamwork. The use of these systems in virtual teamwork has not been extensively studied, making this a limited but interesting area of research. Our results suggest that these systems can be useful in improving communication and collaboration in multidisciplinary teams, and we hope that future research will continue to investigate this topic.

Eventfully, the COVID-19 pandemic and resulting lockdowns had a significant impact on this study's research design and implementation, as it was conducted entirely remotely from 2020. While the virtual format enabled greater flexibility and access to participants, it also presented new challenges in terms of potential distractions, technological limitations, and communication

barriers. The lockdowns were a time of heightened emotions and stress, and this could have had an impact on the sentiment of the data collected.

Despite these challenges, the study was able to adapt to the remote setting and produce valuable insights into multidisciplinary design collaboration in distributed teams. The virtual interviews provided an opportunity for participants to reflect on their experiences of enforced remote work and collaboration, offering a unique perspective that may not have been possible in a non-lockdown context. Conducting interviews remotely provided also an opportunity to leverage the intimacy of the meetings. Additionally, the use of virtual tools allowed the study to include participants who may have been geographically distant, providing a more diverse range of perspectives.

Overall, the study was able to adapt to the new working environment and produce valuable insights into multidisciplinary design collaboration in distributed teams, despite the limitations imposed by remote data collection.

5.2 Future Work

Based on our findings, there are several directions for future research. Future work in the field of multidisciplinary design collaboration should aim to address the identified gap in understanding the effects of distributed work on design teams and the creation of digital artefacts. This may involve conducting studies with a focus on non-physical or software design projects, as well as examining the underlying mechanisms of shared cognition in these contexts. Additionally, research should aim to address the need for greater rigour in the study of design collaboration, potentially through the use of more rigorous study designs and the inclusion of a wider range of non-laboratory contexts, variables, and non-student participatory simulations in analyses. Finally, future research should consider the changing requirements of design outcomes and settings, particularly as the use of remote work and digital technologies continues to grow.

Additionally, in future research, it would be beneficial to expand upon the co-occurrence analysis method by increasing the number of data points and possibly incorporating additional text-mining techniques. This would provide a more comprehensive and robust analysis of the themes and relationships within the literature. Additionally, it would be valuable to further explore the potential of multilevel analysis in studying multidisciplinary design collaboration, particularly

in regards to the micro-level impact of individual background on collaboration. This could involve exploring the effects of different combinations of disciplines and cultural backgrounds on team creativity and understanding how to facilitate the development of shared understanding in diverse teams.

In order to address some of the limitations of the second study, future research should focus on expanding the sample size and diversity in order to increase the generalisability of the findings. This could be achieved through the use of quantitative methods, such as surveys or experiments, which would allow for a larger and more diverse sample to be studied. Specifically, longitudinal studies could be conducted in order to track the development of shared cognition in distributed teams over time, and to better understand the consequences of the lack of shared attitudes and beliefs on team performance. By focusing on these areas, future research can provide more comprehensive and nuanced insights into the challenges and opportunities of multidisciplinary design collaboration in distributed teams.

Lastly, one key area for future research is the development of emotionally more complex virtual tools that more effectively support the development of shared understanding in reference to attitudes and moods. This could involve exploring the use of different communication channels or the incorporation of additional emotions, and functionalities, such as those suggested in the second study. Another important area for future research is the ethical, social, and technological implications of AI-based affective recognition. This could include exploring the potential for such technology to be used in a biased or manipulative way and developing guidelines for its ethical use in virtual team settings. Finally, future research on AI-based tools in virtual teamwork should focus on addressing the limitations identified in this study, such as the need for greater transparency, explainable AI, and the importance of considering the role of sentiment in impression formation. One potential course of action could be to design AI-based systems that provide pre-message feedback, with a focus on usability and user readability. It may also be valuable to tailor these systems to specific usage points, such as ideation and newcomer onboarding, in order to improve shared understanding and creativity. Additionally, further investigation into the long-term effects of these tools on relationships and impression formation could provide valuable insights for designers of AI-based communication support systems. Overall, there is a need for more research in the intersection of creative research and HCI, in order to inform the development of effective AI-based solutions for virtual teamwork.

5.3 Contributions

The four studies presented in this thesis contribute to the fields of design studies with design cognition and design collaboration, team-level organisational management of multidisciplinary members, and digital work supported by machine learning-based tools. The key takeaways from these reviews for the design research communities include a set of recommendations:

- Communication challenges, including language variation and jargon idiosyncrasy, can hinder design collaboration in diverse teams and lead to a lack of shared understanding.
- Shared understanding and trust are critical socio-cognitive team dynamics aspects in design collaboration.
- Asynchronous distributed systems, including email and chat apps, may be vulnerable to communication challenges and may be an important focus for future research on facilitating creativity and team dynamics in multidisciplinary collaboration.
- Previous studies on multidisciplinary design collaboration may present an unbalanced picture of the value of team diversity due to a lack of focus on distributed work and digital design outcomes.
- The majority of suggested tools from CSCW research are not currently available in the leading communication channels used in the industry, but there is potential for implementation of state-of-the-art tools recommended by academia in real-world contexts.
- Communication media can impact trust and shared understanding in design collaboration, and the choice of communication medium should be carefully considered in future research.

The third paper is a qualitative study of virtual teams working on creative projects using virtual collaboration tools in different sectors. The study aimed to understand how shared cognition is developed in a digital environment. Its findings showed that:

- Remote team members use a range of virtual collaboration tools for different communication and knowledge-sharing purposes.
- However, these tools do not fully support shared understanding in remote design teams, particularly in terms of shared attitudes and beliefs.

These findings may be useful for designers of future virtual collaboration tools who want to increase effectiveness and improve human-computer interaction. The study also contributes to the understanding of shared cognition in creative distributed teams by considering the holistic view of shared cognition aspects in the ecology of tools. The research highlights challenges faced by distributed teams, specifically the lack of support for shared attitudes and beliefs in the current ecology of tools.

The fourth study investigates the use of machine learning-based affective recognition technology in facilitating multidisciplinary design collaboration and online impression formation in virtual teams. The work discussed the ethical, social, and technological implications of natural language processing and machine learning-based affective recognition technology and provided design guidelines for future development. Through a quasi-experiment, we found that:

- Dynamic sentiment and emotion recognition feedback systems can motivate team members to use the technology for impression formation with strangers or figures of authority, and can potentially improve long-term relationships through facilitating accurate impression formation.
- Natural language processing-based affective recognition systems can increase creativity and shared understanding in virtual multidisciplinary teams.
- There's a need to focus on explainable AI that aims to help users understand and interpret predictions made by machine learning models.

These findings contribute to the research communities of design studies with design cognition, and computational studies by highlighting the potential of AI-based tools in supporting virtual team dynamics and facilitating successful multidisciplinary design collaboration in the digital age. Overall, this thesis contributes to a better understanding of the challenges and opportunities in multidisciplinary design collaboration and the use of AI-based technology in virtual team work to augment creativity in decentralised teams.

Chapter 6

Postscript

6.1 Reflections and Dissertation Postscript

Since the completion of our research and experiments, the field of affective computing has experienced ongoing development, resulting in both new opportunities for research and business, as well as growing ethical considerations. Recent research has explored the emotional analysis of online work, expanding the investigation beyond written communication to include collaborative video interactions. This postscript offers a current update on recent advancements and their consequences, highlighting the growing interest in emotional analysis in diverse distributed work environments.

Subsequent inquiries have expanded the range of emotional analysis to include collaborative video meetings, going beyond the limitations of text-based channels. The study conducted by Murali et al. (2021) presents a tool that aims to facilitate the communication of affective responses from listeners during virtual presentations. The bot utilised in video conferences examined the facial expressions and head movements of the participants, and dynamically highlighted those that were the most expressive.

Following that study, during Q3 2021, a commercial solution has been introduced for a real-time emotional analyser known as Microsoft Emotions Detection for Microsoft Teams, which was a video communication tool (Microsoft, 2021). The application employed facial analysis algorithms to detect emotions in video conferences using Microsoft's Face API. It had the ability to recognise a variety of emotions, such as anger, contempt, disgust, fear, happiness, neutrality, sadness,

and surprise. Microsoft's Face API primarily utilised facial expressions to detect emotions by capturing visual cues from images and videos. Compared to this, Moody Man (see chapter 4) is a Slack app specifically designed for text-based communication and relies only on textual content for emotional analysis. When examined alongside Moody Man, Microsoft Emotions Detection surpasses its ability to recognise emotions through additional visual cues. It also supports a wider range of emotions. Yet it is crucial to recognise the ethical aspects linked to the facial recognition technology. The employment of face data for emotional analysis rises concerns over privacy, individual consent, data security, and the potential of perpetuating biases in ethnicity, gender, or age. In 2022, Microsoft ceased the commercialisation of the technology that was developed for identifying individuals' emotions through face images (Reuters, 2022). Moreover, it pledged to limit the availability of facial recognition technologies.

With the progress of affective computing, ethical concerns have become progressively important. Emotional analysis has faced increasing criticism in recent years due to concerns regarding its ethical implications. The API of the Moody Man app, specifically the IBM Watson NLU, was deprecated in June 2023 (*IBM Cloud API Docs — cloud.ibm.com*, 2023). A pivotal advancement in this area is the EU AI Act (Reuters, 2023), that has made certain practices associated with affective computing unlawful. The significance of such ethical frameworks and regulatory measures in influencing the direction for further research in affective computing cannot be underestimated. As ethical considerations become more imperative, it is thus necessary for academics and practitioners to carefully engage with the complexities within this field, employing affective computing in such a way that is both contributing whilst respecting ethical and legal constraints.

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Chapter 7

Appendix

.1 Example of excluded publications - during the PRISMA process

Publication/ DTRS meeting	Authors, Year	Title	Exclusion evidence
Design Studies	Graff et al., 2020	Perceived analogical communication in design teams: Development and validation of a scale	Not meso-level, the study is on micro-level "This study focused solely on the recipients' perception that an analogy was used, and we are not able to say if the recipient interpreted the message correctly".
Design Studies	Cash et al., 2019	The dynamics of design: exploring heterogeneity in meso-scale team processes	Not multidisciplinary "Study on "meso-scale team processes in two engineering design cases (. . .) As such, while the teams comprised a mix of backgrounds, they both had a dis-tinct engineering focus and similar levels of experience overall".

CoDesign	Jordan & Adams, 2016	Perceptions of success in virtual cross-disciplinary design teams in large multinational corporations	Not meso-level, the study is on macro-level: "Results indicate that factors that contribute to success include the context in which teams work, the method by which teams do their work, and the media by which teams communicate".
CoDesign: Special issue: Experiential Knowledge and Collaboration	Kuusk et al., 2020	A transdisciplinary collaborative journey leading to sensorial clothing	The research was not empirically designed to study team-dynamics, team aspects were only reflected on in discussion section: "During the publication process of our results at some conferences and journals we were often criticised for at-tempting to combine in a single manuscript the findings from each field and, moreover, em-bedding the description of the collaboration process, which was an important part of the methodology, as reflected in this article. Criticisms included that we lacked a prior hypotheses or were not aligned with the traditional structure of an empirical research paper.".
DTRS2	Akin & Lin, 1995	Design protocol data and novel design decisions	Not multidisciplinary: "The objective is to study the behaviours of designers using techniques of cognitive psychology in general and protocol analysis in particular".
DTRS7	Mcdonnell, 2009 Adams et al., 2009	INCLUDED	
DTRS10	Hess & Fila, 2016	The Development and Manifestation of Empathy within Design: Findings from a Service-learning Course	Not meso-level, the study is on macro-level: "We provide a visual summary of student designers' empathic design techniques, the interrelation of these techniques, along with implications for how design educators might effectively embed empathy throughout design curricula."

DTRS11	Awomolo et al., 2017 D'souza & Dastmalchi, 2017	INCLUDED

Table 1: Example of excluded publications during the PRISMA process

.2 Predictive study: Data Structure

Table 2: Data structure with additional evidence

Second order codes	***First order codes***	***Examples***
Email	Dry facts	"There is, you know, it's harder to interpret the, the dry facts of the email, just because you're talking about things in slightly different language, just because of that, you might feel less receptive to an email because you understand the class and you might, you know, not want to make a fool out of yourself in a way."
		"But I'd say it's generally via email and updates that way so that things don't get lost because channels such as Slack sometimes, with everyone kind of collaborating on there, you could kind of lose the thread and you can lose what the original kind of point was because there's not many of them follow up comments and so email for more sort of formal work"
		"I think emails are good for certain things, you know when you need a very precise, formal response or stuff like that"
		"And literally I sketch some sketch to something. I took pictures and I emailed it to my team in London and that's what I said, listen, imagine this almost like books and go to the model room, get some models done and try to experiment with this."
	Formal communication	"So, so e-mails are maybe more formal, like if somebody is sending an email - probably important. And on Slack, you're not sure because you have so many group chats."

		"But for ad hoc queries or things that aren't, of a serious or urgent nature, we would communicate via email which is probably the more formal communication channel."
		"That those would be my main channels, I think, within the team, but generally email for more formal things and then follow up with face to face."
	Sending updates	"So we use Teams and it's for meetings, online meetings mostly, of course email to probably set up the meetings"
		"It's kind of a lot of describing a lot of like imagining and sometimes while we're on the phone, we would ping each other an email with a mood board or an image if we prepared something in advance"
		"when we have like team meetings, which ordinarily would be in the office space face to face all around the table and things will be communicated and then followed up with a, an email"
	Group discussion on project	"We were on, we were on a project together for candidates for this [role] that we had for checkout. And we would kind of, we worked on the same projects and then we just did a group call with [the manager]."
Video conferencing		"WebEx, that we'll be using more for the professional use, like the other resources for the professional reality, but more informal use, like here we'll be using more for the proper professional uses, setting up the meeting with four or five, seven people where we want to brainstorm what we want to have the weekly content to review some plans for the future or on the center where we, where we are. So whenever I'm sending the invitation, I tend to use WebEx."

	"we tend to operate a lot on the, on the minutes. So planning the agenda before the meeting for the proper meeting, again, there will be a lot of meetings are structured, unfortunately, but we are trying to go as much as we can need to structured one. So we should decide the agenda before even best, if we could be sending pre-reading, that would be the best case scenario. So when you can, write the one pager, let's say one page of document explaining exactly the background of the project, objective of the projects and kind of what we are trying to resolve, assessing the best, move with the agenda and then we go into the meeting. We can know exactly who is the owner of different sections, who should be, who is the contributor, so we should be both in the process and then we debate."
Resolving work issues	"We haven't got any other calls in, and it's just through Google Hangout and that's kind of, the morning is probably the most important one because it helps you, I suppose, sets up your day in a good way. And you've got any issues from the start off, you can disclose that straight away and sorts out in the morning and not let it hang there through the day. And I think they're quite handy just in case you do have an issue that you're, you're mulling on and if you've got any questions at your half and half on in terms of what to do throughout the day"
	"Calendars and agendas, which are very, very busy with a lot of calls and meetings online that you can't really, work in between the meetings with people. Cause you need to schedule everything. You have to do it in small parts to get to the right people and meet with them and talk to them about the issues."
	"It has annotation capabilities so we can, we can paint, we can, we can write on the screen so people can present you something and you can, you can, in the real life, people on the other side can, can type or paint some answers or some ideas that you can react"

Group-level size	"if you have more than two people, maybe more than three people sometimes so I think three probably is, I see, as the limit maybe. I think the conversation moves very fast and it doesn't really give many people the ability to think and respond to certain comments and are moving up the conversation. So perhaps it's, it's a bit more difficult to manage where usually you would have people in a face to face, you would have say a group of four, five, six people. Everyone would stop talking when one person is speaking. So you're able to all digest what everyone's saying. Think about response, respond back, whereas everyone's responding at the same time. It doesn't really, it can be a bit messy" "So I don't feel as though you're really utilizing the whole experience by having a large number of people and getting the most out of the tasks and what you're looking to achieve. So yeah, I think that's why I feel as though getting those work instructions across and being able to bounce off of each other. I think it's quite important to keep those numbers to one-on-one or maybe three people within, within a group." "I think that on a one-to-one instant messaging for, and then a one-to-one face to face, I feel as though the differences are just mitigated somewhat I feel in the larger group is a bigger gap there of the differences of quality between face-to-face and having those, those larger chats. I think when you're one to one, you can pretty much understand everything and pick up on all the points that someone wants to get across. It doesn't move up the conversation chain as quickly. It doesn't get lost as quickly. It's a bit more of a slower paced and direct information stream. So yeah, I would definitely still prefer face to face, but it's more efficient than having a larger group on, on technology."

Instant messaging	Getting to know colleagues	"the direct messages with individual colleagues, which enables you to have quick, fast conversations and conversations, of course, that can be outside of work, talk or everything else, which has been quite helpful, especially joining as, as a new member and getting the chance to speak to individual members of the team separately, to, to get to know each other slightly more, that's helped."
	Informal communication	"Slack's quite nice to have that interaction cause you're, it's, I suppose it's not Facebook, but if you're speaking to people as if, I suppose in a Facebook tone. For example, you're just, cause obviously we've got a section which says random, you just have a laugh with people. It's quite nice to just, it might not be face to face stuff, but it's just, it's quite nice having the team there when you need them cause you do interact with them still."
		"That's why I believe that the Teams can help as well to bridge these teams. To me, it's really allowing me to establish a bit closer relationship, even though we are not close together, but it could be, it's more personal one."
		"And if it's a more informal communication via Slack or on the telephone, in some instances, WhatsApp, if someone's at home and like on medical leave."
		"Teams for everyday communication, Microsoft Teams, where we can chat. And when we can have a bit more informal communication with one, two maximum three, four people, kind of like what we, what we do here."
		"I would say the Teams I almost use as a WhatsApp application when they're, I just want to talk one to one maximum one to three people, mostly chatting, maybe sending some gifts, like very informal formal setup, actually, mostly for chatting."
	Open communication	"the very quick time instant messaging platform on Slack allows for very quick communication, more open communication."

		"it's probably, it's probably isn't as many challenges in terms of that, because it's quite easy to communicate as a group and you want something pretty instant."
		"It also allows us to have lots of different channels of communication within it. So we can have, different group chats, different points of reference within it. So like, we have one that is general, which is general news to the team, which we share like news articles or things relevant or pertinent for the business and the area that we work within."
Attitudes to work and personality clashes	Engagement discrepancy	"I think that engagement, proper, proper engagement. I mean, we are having a one on one conversation. So it's super easy for us both to be engaged in this situation. And if I suddenly disappear out of you, and stop talking, it's kind of obvious. I'm not Yeah, yeah. If we have a group of five or six people, it's much more challenging to understand when someone is with us and when someone has kind of just glazed over, dropped out or, you know, pick their mobile up under them. They're away."
		"But I think the biggest one is the, the usual one, as long as the person is not facing and in the same place, it's really hard to get the same level of engagement. Usually it's much easier to disengage, to disconnect, especially in this setup of more people."
		"So although process wise or a step wise or task wise, I can see the progression, of each people, but, I don't have the sense of how much people are actually interested or engage or feeling a part of the, the whole project."
	Lack of small talks	"I would say having, you know, maybe video open or having an Hangouts open for maybe a slightly longer period, you know, watch you're working or something, you're you maybe, that might bridge the gap and seeing visually that person and having an opportunity to maybe talk a bit more that might, that might help."

	"We don't just just walk into a room and go right okay, so the agenda on the agenda item number one is this and everyone's barely sat down by his sheets shooting the breeze having a little chat. And that's missing, I think with remote work."
	"And like, everyone knows like that, like the value of like, you know, like being in an office and just having that small talk, small chat, like, and we need to find ways to be creative. I don't think we've got the perfect tools for it"
Personality and interpretation clashes	"because you're not seeing their face, you're not reacting. It's just like a bunch of words that is sent here and a bunch of words that is sent there. Their interpretations might be completely different. It opens up two different interpretations."
	"My team was sort of stressed out, oh, why are they you know, calling me every five seconds on the guys, you just have to put yourself in your shoes, because you have to understand they have a lot of pressure from our board as well to sell. So sometimes like I understand that might be frustrating for you. But sometimes you do have to sort of stand in their shoes to understand where they're coming from."
	"Like you have to take a phone, call this person or talk in the chat and be hopeful that the person have time right now to help you. That's is, this is very stressful. In terms of personality. I'm. I am, I'm meeting some, some of those tensions"
Unknown attitude to work	"I think that's actually another big gap is, is the fact that you vicariously learning through other people, you know, when you're next to each other and looking at the types of conversations they're having. How they phrase certain things when they're speaking to clients or candidates and just picking up on little sentences, little words or phrases to use subconsciously knowing that that's had success with that client or success with that candidate, you just take that for yourself and install that and maybe turn it into something else for yourself."

	"So being in the office has been, was, it was, it was a massive help obviously cause when I started, ask some questions, one of the last questions and no more."
Unknown mood and mannerism	"Even that tonality, the tonality on after, after conversation, after many conversations starting today, you can probably pick up on how they're feeling that day, whether they, they need, you know, they need a bit of a conversation, whether or not you can, you can build rapport with the team like that. If you, if you're seeing someone that's had a lot of success throughout the day, you could go over and congratulate them and speak to them about it and you know continue to make them feel good about that."
	"I think in general, some of those informal meetings, coffees, whatever are helpful, just that people know there is still a person working on something, or she, he, she is part of my team and can have a worst or best day ever, but we're still people and not only emails that we're sending."
	"But then, it's difficult to sense how much the other peoples are, are engaged or interested because I'm missing all the other surrounding information. Like what kind of a, how do they come into the meeting room and what kind of attitude do they have? What is there a, how did they look like capturing their emotions. I think I'm missing a lot of that parts. So although process wise or a step wise or task wise, I can see the progression, of each people, but, I don't have the sense of how much people are actually interested or engage or feeling a part of the, the whole project."

.3 Prescriptive study: Survey Measures

ID	Statements	Measurement	Scale	Source
Q1_1	In my team, the team members have a similar understanding about the procedures, strategies, and contingency plans involved in decision-making.	Shared understanding	Likert Scale 1-7 (1 = strongly disagree, 7 = strongly agree)	Cannon-Bowers et al. (1993)
Q1_2	In my team, the team members have a similar understanding of each other's responsibilities, interdependent roles and communication patterns.			
Q1_3	In my team, the team members have a similar understanding about the technology, resources and tools needed to make decisions.			
Q1_4	In my team, the team members are familiar with the preferences and abilities of each other.			
Q3_1	How much friction is there among members in your team?	Attitude (Team Relationship)	Likert Scale 1-5 (1 = far too much, 5 = far too little)	Jehn (1995)
Q3_2	How much are personality conflicts evident in your team?			
Q3_3	How much tension is there among members in your team?			
Q3_4	How much emotional conflict is there among members in your team?			
Q5_1	How often do people in your team disagree about opinions regarding the work being done?	Attitude (Task Conflict)	Likert Scale 1-5 (1 = far too much, 5 = far too little)	
Q5_2	How often are there conflicts about ideas in your team?			

Q5_3	How often are there differences of opinion in your team?			
Q5_4	How often are there disagreements within you team about the task you are working on?			
Q9_1	In my team, we are encouraged to develop new ways of doing things.	Attitude (Climate for Creative Productivity)	Likert Scale 1-5 (1 = strongly disagree, 5 = strongly agree)	Witt and Beorkrem (1989)
Q9_2	In my team, when team members come up with new ideas they receive appropriate praise.			
Q6_1	I feel that I am good at generating novel ideas.	Self-perceived creativity	Likert Scale 1-5 (1 = strongly disagree, 5 = strongly agree)	DiLiello et al. (2011 May-Jun)
Q6_2	I have confidence in my ability to solve problems creatively.			
Q6_3	I have a knack for developing the ideas of others further.			
Q6_4	I am good at finding creative ways to solve problems.			
Q6_5	I have the talent and skills to do well in my work.			
Q7_1	I feel comfortable trying out new ideas.	Creative self-efficacy	Likert Scale 1-5 (1 = strongly disagree, 5 = strongly agree)	
Q7_2	I have opportunities to use my creative skills and abilities at work.			
Q7_3	I am invited to submit ideas for improvements in the workplace.			
Q7_4	I have the opportunity to participate on team(s)			
Q7_5	I have the freedom to decide how my job tasks get done.			
Q7_6	My creative abilities are used to my full potential at work.			
Q4_1	How satisfied are you with your team?	Team Satisfaction	Likert Scale 1-5 (1 = extremely dissatisfied, 5 = extremely satisfied)	Spector (1997)

Q4_2	How satisfied are you with the functioning of your team?			
Q4_3	How satisfied are you with your participation in the workshop?			
Q4_4	How satisfied are you with the decisions made by your team?			
Q4_5	How satisfied are you with communication among your team members?			
Q4_6	How satisfied are you with the strategy of your team?			
Q4_7	How satisfied are you with the interpersonal relationships among the team members?			
Q8_1	The real-time feedback app improved my awareness of meeting behaviours.	App evaluation	Likert Scale 1-5 (1 = strongly disagree, 5 = strongly agree)	Samrose et al. (2021)
Q8_2	The real-time feedback app improved meeting effectiveness.			
Q8_3	The real-time feedback app improved meeting inclusivity.			
Q8_4	I think the app is important.			
Q8_5	I think the app is useful.			
Q8_6	I'm satisfied with the app.			
Q8_7	The app drew insights from my meeting.			
Q8_8	The app determined if sentiment in the meeting changed.			
Q8_9	The app determined the attitude of each attendee in the meeting.			
Q8_10	The app determined the emotions of each attendee in the meeting.			

Table 3: Statements used in measurement scales and source works

.4 Prescriptive study: Data Structure

Themes	Second order	First order	Quotes
Design goals	AI design	Complexity of emotions	P-11: like I use a lot of irony and sarcasm. And I cannot imagine that our computer would even remotely be able to. To identify that. P-23: if there was like, I don't know, an option to extend the range of emotions that you can detect, like, you know, you have your defaults. P-1: the dimension of the different motions, emotions was an important because I think you can't really judge some message based on if it's positive or negative P-16: ut pick it up on on nuances. Like when you ask a question and like a bit of a passive aggressive way, because you're trying to get a point across, I think it struggled with that maybe
	Delivery timing	Post-sentence	P-15: I think it would be nice if it was live and automatic. Like it's just like, as you're typing a message P-30: if it's after then, I mean, the damage has already been done if it's offensive P-20: If it's at the end, maybe I wouldn't even review it, you know

	Pre-sentence	P-12: I would say before you hit send because as I don't know, I personally don't feel like there's any point in finding out my message is angry and might cause a bit of friction after I've sent it because the damage is already done P-28: it would be very, very handy to like, as you're typing, there's like a little emoji minute sort of changes color as as your as your sentences are completing, and maybe like a really easy way, because I can also see that being kind of annoying after a long time, if you're just having a normal conversation, you don't need to see the so maybe like a very quick toggle, like shift slash or something, then you can just toggle them on and off the little emoji in the corner, and then it changes color, or it just becomes sort of transparent, I would definitely use something like that
	Post-meeting	P-7: I'd rather try and compensate. But I think it's quite difficult sometimes to compensate afterwards P-29: I guess it's better to have it in a sentence. Because if it's overall you don't want to change.
Trust	Accuracy	P-26: In general, like, I wouldn't have any reason to kind of, like, reflect on that. P-29: I don't know if I would be confident enough in this in this feature. P-30: it could maybe sometimes lead to certain misinformation. I'd say maybe. Maybe in the expression that's detected by the Moody Man, is that there's a possibility it wouldn't be accurate P-28: I didn't think it really reflected the message very accurately (...) I don't think I think I got it completely the wrong way. So I thought okay, I don't think this is really that helpful for me.

		P-22: but then I feel it all depends on the algorithm and you know, how accurate it is and how I think people need to be made aware of how it works a little bit more.
Trust	Algorithm	P-22: I was trying to understand how the what the algorithm was, or the code was behind how it's saying that something is like 22.23% aggressive rate. So something is like that. What is it? If I if you're telling me that it's based on British slang, or something like that, then I would say that maybe probably I would have, but I didn't know at that point. You know, if it was based on British slang, I just thought it was based on like, normal English, you know
		P-8: So I feel I doubt whether so I actually i don't i don't i feel this is not something related to this workshop, but I feel like humans, like how they perceive the emotion is very, sometimes it's very intuitive. Or we really need to, like use a very quantitative approach to try to get this done. So this is where I doubt Yeah.
Trust	Trained data source	P-10: I think it'd be the opposite. I would assume in my mind, I would assume that the AI has been taught with Native users, so I wouldn't trust it to assume from non native uses. P-10: I just wouldn't trust the ball, as I would have seen in my head, that I would be better at interpreting someone with a foreign way of talking, as opposed to a bot who was poorly trained with just English pieces. Yeah.

Usability	Data presentation	P-8: I don't know whether the percentage thing just makes sense to me. P-21: So, for me when I see numbers like this, yeah, when it gets to a single digit percentage that feels, I'm not aware of it that is noise or whatever it is slightly. It's like that reading of that emotion. P-29: I think that those two decimal points on unnecessary Yeah, it's too detailed. P-14: you'd want it more visual, something more easy to understand because percentages, you might understand that but if you just look at a chart or something, it's like quick like one second P-16: sometimes it would be like, minus percent of happiness. And I'd be like, is this supposed to be like, super sad, super unhappy, or P-24: because if the moody man requires extra click
Usability	UX	P-5: if it was like, easily, more easily accessible, that maybe I'd be more inclined to use it P-14: it was hard to access, it was a bit of a pain to having to click on other stuff.

Motivations	Emojis	Bridging role	P-15: that's why sometimes I will use the sort of symbols smiley face in my emails, because I still do want to come across as friendly. But usually emails seem as a more formal type of communication. Whereas emojis seem like quite a, like a colloquial, almost casual thing that like you use it when you are messaging your friends, as opposed to in a professional setting. P-19: I felt it's necessary to, like create more of like, friendly vibe, I guess P-26: there's Seems to be like this overlap or a bridge that allows both both or all all cultures to, like understand what people are saying and get the joke. P-28: So using a smiley face or a question mark or whatever, like, it just clarifies your thought, as if you're face to face a little bit better.
	Emojis	Revealing emotions	P-1: emoji is replacing that sort of feedback that you would get emotionally from your group members. P-16: I think are just easier to like, make the conversation a little less bureaucratic, it's just, it tries to attempt to put some motion in a conversation.

		P-24: as in as a method of kind of communicating things like a thumbs up, I guess it's a way to kind of convey emotion. So they're not used extensively before, or distracting things. But if there's a certain kind of sentiment to them, or just as a quick response to like
Emojis	To quickly react and acknowledge	P-15: So I think I might not use emojis, but reactions could be quite a good substitute. So you can see that Archie and I use reactions quite a lot. And partly also because I felt like that was another way to organize our reactions to each other's messages. So because we didn't really use the reply in thread, a good way to express that we agreed with each other was to react to each other's messages
		P-13: it's kind of like show some agreement almost instead of having to say, Oh, yeah, no, I agree with you. Like give him a thumbs up
		P-22: he tick mark one was pretty good. Just to show that, okay, this thread is complete, I don't need to add anything more to these ones, or, okay, this thread is done, like this job is done.
		P-8: Because for him for manager, I need to be more Be more careful about the word I use
Impression Formation	Figure of authority	P-28: If I was talking to my boss, or my boss's boss, for example, or a professor even at uni, than I probably, when I really needed to be careful about what I was saying.
		P-1: the feedback that is neutral, then like, that's okay to send, and you don't really have to worry about if you're coming across to, like a negative way.
	Positive self-portrayal	P-19: So it's probably useful. As far as you know, you have to be careful with the way you express yourself to not come across one way or another.
		P-5: Because you'd want to make sure that you're coming across Well, on the communication is as good as like other people's.

Usage Points	Speaking to strangers		P-29: I think if I don't know the person I'm talking to, I would probably use it. P-3: I think I'd use it quite a lot, especially at start getting to know people
	Useful for idea evalutaion		P-1: I think it wouldn't be particularly useful when you're ideating because content, but when you are making decisions and when you are discussing the ideas, so that evaluation, and from that evaluation, what you decide on, I think that is a really important aspect to know. If you mean, you can be critical and that's important when you are doing design, but being critical in like a constructive way that you're not coming across as like, negative. P-5: it's like a quick indication whether it's comes across as good or not.
	Self-verification		P-20: If someone realizes that, oh, people think I'm rude. Why is that? Or, you know, maybe it's all a matter of how they are communicating. And and this could be a solution to have a better relationship with colleagues.

User type	Useful for bigger teams than dyads	P-17: moody man as a whole would have been more useful if the team was bigger because like, they were just that would have been just so many other people you'd have to talk to and like, you know, you can't always like read everybody just from like the messages so like, then you could, you know, click on that and just and use it, but when the second When there's only two people, it's just like, you know, you sort of yourself get the vibe from them like you don't. You don't have to, like necessary use moody man.
		P-10: I believe when we there's a bigger group and you can't, you know, like, think about how everyone's feeling or like, everyone's interactions, because I could see it being released.
		P-1: sometimes the mood can be really tense, like in a group messenger chat. But then when you actually meet in person, it's like, everyone's like, cool. And like, I think it's easy for that tension to start in a group chat.
		P-13: I think that's probably a more useful tool, if you have like, a conversation between more people.
	Cultural difference	P-26: just looking at like those sort of cultural barriers between people. I could see it being mega useful for people trying to learn like there's the English language. Yeah. And then there's like, the, the underbelly of it, which every language has, which is like, the jokes the sarcasm.
	Not native speaker	P-22: I was trusting, moody man more so than questioning it, I would say, some degrees, like I was looking at what I was saying more than not taking bad as what the truth is. because English is not my first language.
		P-26: to certain native English speakers, I don't think it's particularly particularly useful. Yeah. But if it's an an English speaker to a non native, then I think it could, it could definitely help

Domain knowledge	P-8: So if you're a designer, someone else's designer, [..] I wouldn't use that as if I was speaking with an engineer P-26: in terms of understanding the other person who I don't know, and he's not a designer, it would definitely be a tool to try and say, like, what, what is it you're trying to convey to me in this project

Table 4: Data structure with exemplary quotes