Socio-technical Design Heuristics to Mediate Transdisciplinary Team Learning Activity

'An Activity Theory-Informed Design-Based Research Study'

Thesis submitted for the degree of Doctor of Philosophy (PhD)

2026

by

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Declaration

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Summary

This mixed-methods Design-Based Research (DBR) study, conducted over a six-year period (2018-2025), explores aspects of mixed reality (XR) systems that may support novice hybrid transdisciplinary teamwork. The study produced four categories of heuristic supports derived from landmark teamwork literature, distributed cognition (DCog) and distributed cognition of teams (DiCoT) research, as well as our own category of additions which were developed, refined and tested over three user centred design cycles. The final design cycle employed an exemplar instanton of the heuristics in a software 'Transdisciplinary Teamwork Tool' (TTT) to evaluate them in a real-world hybrid learning based educational setting with student teams on the CHARM-EU M.Sc. in Global Challenges for Sustainability.

Our literature review identified heuristic supports to scaffold technology-mediated hybrid team development. This includes general guidance on user experience, plus detailed supports for teamwork and distributed team cognition. Regarding teamwork, we emphasise the importance of team needs (Tuckman, 1965), feedback between members (LaFasto & Larson, 1989), team roles (Salas, et al., 2013), team communication (Katzenbach & Smith, 1993) and supports for team mental model building (Mohammad, et al., 2010). Our distributed team cognition heuristics emphasise DCog (Hutchins, 1965) and principles from DiCoT (Blandford and Furniss, 2006; Webb, 2008), representing each of the DiCoT models, i.e. physical organisation of work, information flow and mediating artefacts.

The research is rooted in the social constructivist interpretative paradigm and takes a socio-technical perspective to emphasises the social construction (Vygotsky, 1978) and distributed cognition of meaning making in hybrid transdisciplinary teamwork, with a focus on novice transdisciplinary team synthesis. While primarily qualitative dominant (QUAL + quan), the DBR format included scope for exploratory sequential aspects and limited triangulation as the research progressed over the design cycles.

Our analysis leverages Cultural Historical Activity Theory (CHAT) (Rubinstein, 1973; Vygotsky, ibid; Leontiev, 1981; Engeström, 1987, 2000) which we operationalize by applying Activity Oriented Design Method (AODM) (Mwanza, 2002) to address a recognised gap in methodological clarity when working with CHAT. Additionally, AODM is extended with methods selected from the Change Laboratory toolkit (Bligh & Flood, 2015) to explore third generation Activity Theory aspects that are overlooked by AODM. The identification of culturally historical systemic contradictions guided our analysis to refine and comment on the heuristics.

This study asked, how might we design XR systems that support novice hybrid transdisciplinary teamwork? Two sub-questions guided our inquiry: What design heuristics can be used for such applications, and how can the design heuristics be evaluated when implemented in a test artefact? Findings showed that the literature-based and our user-centred heuristics were well supported and considered to be useful scaffolds for team synthesis by our cohorts of novice hybrid transdisciplinary teams. The findings imply that our heuristics offer practical implications for educators forming and supporting distributed and hybrid teams and include targeted supports for novice transdisciplinary teams working in hybrid and related technology-mediated contexts such as XR.

The research additionally highlights two heuristics that emphasise the importance of ongoing development of practice and practitioners, which were not testable within the limited scope of our study. Our TTT exemplar artefact was designed to support a longitudinal Change Laboratory approach which could explore such themes, and future research should test these heuristics to advance the emerging corpus of XR teamwork literature.

Abstract

This mixed-methods Design-Based Research (DBR) project addresses challenges in the growing field of hybrid teamwork by developing, refining and evaluating a collection of heuristic supports that target novice hybrid transdisciplinary teams. The heuristics emerged from the dual foundations of the study with transdisciplinary teamwork underpinning each of three design cycles, and a focus on mixed-reality theory established in our initial design constraints. Together, these perspectives informed the structure and evolution of the heuristic set. While the full collection of heuristics may benefit any team, specific supports for transdisciplinary synthesis and team mental model building are included to scaffold novice transdisciplinary teamwork challenges in particular.

The aims of the study seek to address our first research question:

RQ1. How might we design XR systems that support novice hybrid transdisciplinary teamwork?

Our objectives address RQ1 via the following two sub-questions:

RQ1a. What design heuristics can be used for such applications?

RQ1b. How can the design heuristics be evaluated when implemented in a test artefact?

Three categories of heuristic support were drawn from landmark teamwork literature, Distributed Cognition theory (DCog), and Distributed Cognition of Teams (DiCoT), with an additional category of user-centred heuristic supports being produced during our research, and which focus on novice hybrid transdisciplinary team onboarding and orientation. Our final design cycle instantiated the collection of heuristics within an exemplar software artefact called the Transdisciplinary Teamwork Tool (TTT), to evaluate them in a real-world novice hybrid transdisciplinary team learning context with students of the CHARM-EU M.Sc. in Global Challenges for Sustainability.

The research adopts a social constructivist, socio-technical perspective, emphasizing meaning-making as a socially and cognitively distributed process that can be scaffolded with purposeful technology mediation via tools such as mixed reality. Data were produced over three design cycles and analysed by operationalizing Cultural Historical Activity Theory (CHAT) using the Activity-Oriented Design Method (AODM) to address CHAT's methodological challenges. AODM was enhanced with tools from the Change Laboratory toolkit to identify culturally historical third generation Activity Theory systemic contradictions in the evaluation of each heuristic.

Findings confirm the utility of our heuristics as effective scaffolds for novice transdisciplinary synthesis within hybrid team learning contexts. The study also identified two heuristics focused on team development that could not be fully tested but offer promising directions for future research.

This work contributes theoretical insights and practical design heuristics for educators and software developers supporting transdisciplinary team learning in hybrid, distributed and immersive environments.

Keywords

Design Based Research, Novice hybrid teamwork, Mixed Reality, XR, Distributed Cognition, Activity Theory, Transdisciplinarity, 21st Century skills, Educational Technology.

Acknowledgements

I would like to acknowledge and express my eternal thanks to my supervisor Dr. Jake Rowan Byrne for his unwavering and always thought-provoking support and excellent doctoral supervision throughout my Ph.D. journey. From our first meeting we connected in our excitement for the dynamically evolving field of distributed and hybrid teamwork and the potential for XR applications to scaffold such work. Sincere thanks also to Professor Dr. Brendan Tangney for co-supervising my work and his invaluable and insightful feedback. Thanks of course go to Dr. David Murphy from University College Cork and Professor Dr. Hamish McLeod from the University of Edinburgh for acting as referees on my initial research proposal, as well as my colleagues Mr. Gaurav Jain for programming assistance refactoring my TypeScript code to handle multiple concurrent connections, and Mr. Paul Dunne for encouraging and helping me to begin this research journey in the first place.

I would like to thank the students and staff of the CHARM-EU M.Sc. in Global Challenges for Sustainability, for their kindness and generosity with their time and inputs. Without you, this thesis would not exist.

Final thanks go to the Trinity College Dublin School of Education and CHARM-EU for their amazing support and encouragement.

Dedications

Unending thanks to my family, especially my amazingly kind and thoughtful daughter Chloe, my parents Bill and Louise and my brother and sister Thomas and Rebecca for their love and inexhaustible support and patience while I buried myself in this research. I cannot express in words my love you all and how lucky I am to have you in my life. This thesis is dedicated to you.

Agradeço à Capoeira por me ensinar resiliência em todas as coisas. Ao Mestrando Tatu e ao Mestre Peixe Cru da Comunidade de Estudios e Pesquisas da Capoeira, a força que você me deu tornou essa jornada possível.

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Definition of acronyms used

AODM. Activity-Oriented Design Method

AT. Activity Theory

CHARM-EU. Challenge-driven, Accessible, Research-Based, and Mobile European University Alliance

CHAT. Cultural-Historical Activity Theory

DB. Database

DBR. Design-Based Research

DCog. Distributed Cognition

DiCoT. Distributed Cognition of Teams

HCI. Human–Computer Interaction

ICT. Information and Communication Technology

MS. Microsoft

M.Sc. Master of Science

NVivo. NVivo Software

PLO. Programme Learning Outcome

TTT. Transdisciplinary Teamwork Tool

UI. User Interface

UX. User Experience

XR. Extended Reality (or Mixed Reality)

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Related Publications

The following related papers were published during the current research.

Griffin, D. & Byrne, J.R., (2023) Design Heuristics for XR Tools to Support Social Presence in Hybrid Teams, CSCW 2023: Emerging Telepresence. Journal Article.

Griffin, D. & Byrne, J.R., (2019). Mixed Reality (XR) Tools For Distributed Teamwork, The Irish Conference on Game-Based Learning, Cork, Ireland. Published Abstract.

The following papers were partially informed by, although not directly related to the research questions in the current research.

Griffin, D., Gallagher, S., Vigano, V., Mousa, D., Van Vugt, S., Lodder, A., & Rowan Byrne, J. (2022). Best practices for sustainable inter-institutional hybrid learning at CHARM European University. Education Sciences, 12(11).

Gallagher, S., Griffin, D., Vigano, V., Mousa, D., Van Vugt, S., Lodder, A., & Byrne, J. R. (2021). Inter-institutional hybrid classrooms: A CHARM European University perspective. CHARM-EU. https://www.charm-eu.eu/toolkit/inter-institutional-hybrid-classrooms-charm-european-university-perspective

Chapter 1. Introduction

1.1 Background and Context

This thesis investigates how novice transdisciplinary student teams may be supported to synthesise their diverse disciplinary perspectives in hybrid and distributed learning contexts. A design-based research approach (DBR) informed the development, refinement and evaluation of a set of heuristics that were designed to guide technology-mediated hybrid teamwork at the earliest stages of collaboration. The heuristics combine established supports for distributed teamwork, such as communication, structure and trust, with additional scaffolds grounded in distributed cognition to help students articulate, share and compare perspectives. Hybrid teamwork describes a work arrangement where team members may be partially co-located or at times fully distributed, although partial co-location is typically implied. Regarding the cohorts discussed in the current research, the term describes teams working across different university campuses with subgroups of members in each location. Our study recognises the critical need for transdisciplinary teams to tackle global scale 'wicked' problems. Wicked problems are complex, multifaceted issues lacking clear solutions. They typically occur in relation to an intersection of domains spanning issues such as social inequality, climate change, public health and similar multidimensional problem spaces. Addressing wicked problems depends on collaboration across disciplines to develop a holistic picture of the many issues and wide variety of stakeholders that are involved. For novice transdisciplinary team members beginning their transdisciplinary teamwork learning journeys, developing an awareness of multiple perspectives is a key first step in problem framing to identify relevant understandings of the problem situation and clarify the project goals from the perspectives of those involved, (Pohl, 2017). The development of a transdisciplinary team synthesis implies that members from diverse disciplinary backgrounds can work cohesively in a way that is consistent with academic rigour.

Distributed teams are more prone to lack cohesion than co-located teams due to the reduced capacity for communication when it is mediated via technology (Bubaš, 2001; McCool, 2023; Agarwal, 2024). This may frustrate the teams' efforts to work collaboratively and to reach consensus on shared decisions. Any distributed team must overcome these challenges to succeed, and the difficulty is amplified for novice transdisciplinary teams where members must each express and then integrate their disciplinary perspectives before synthesizing these into a coherent, shared conceptualization of their project goals (Jahn, et al., 2012). Mixed reality (XR) is a technology that can support the development of shared meaning (Witmer & Singer, 1998; Gee, 2004; Castranova,

2007) and has been termed “the ultimate empathy machine” (Bevin, 2019). Aspects of XR may therefore be helpful in resolving communication challenges by scaffolding the development of perspective taking skills and less immersive tools such as web-applications that offer similar communications affordances for team learning may be useful tools to explore this problem space. Empathy and perspective-taking are invaluable team skills and examples of what has been termed 21st century skills (Ravitz, 2012). Such skills are highly prized by today’s employers but are underrepresented in contemporary third level academic programmes (Herlinawati, et al., 2024). XR offers a technology to scaffold the development of these skills and may have applications in supporting transdisciplinary team cohesion.

Distributed teamwork is mediated by technology and such mediation has been theorized to modify the intelligibility of communications (McLuhan, 1964; Daft & Lengel, 1984). If XR is to be helpful for distributed teams’ development, then care should be taken to understand the impact of technology mediation on team communication so that we can best leverage its positive communication affordances. XR is a technology that merges physical and digital domains, and this presents an opportunity to extend the range of communication channels available in remote work. Many scholars have focused on this aspect of media to improve communications. McLuhan (1964) focused on the transformational interpretation of a message when received via different types of medium. Daft and Lengel’s (1984) media richness theory described media as being either ‘hot or cold’, to describe their capacity to transmit salient information. XR has the potential to move beyond such interpretations to develop conceptual or virtual spaces for learning that blend a variety of media and experiences. Such a vision is not new, as evidenced by the many universities that established projects in Linden Labs Second Life environment during the 2000’s (Swanson, 2007), or contemporary efforts such as the Decentraland University District (Decentraland, nd). But such projects focus on replicating real environments within virtual contexts, which fails to leverage the unique affordances of the medium. Inter-reality describes a type of mixed reality that blends real and virtual aspects to present real-world information within the virtual environment. Such innovations can scaffold the construction of shared team mental models by providing dashboards and other contextual information that teams can access in real-time. Empathy and perspective-taking are two 21st century skills that such real-time information may scaffold by prompting learners’ insights and reflections regarding their team peers. Despite its potential, the role of XR in supporting teamwork remains underexplored (Klimova, et al., 2018) and as educational institutions and professional organizations increasingly adopt hybrid and distributed teamwork models, it is pertinent for educational researchers to examine how technologies like XR may be helpful in supporting remote teams.

“Team cognition refers to a shared understanding among team members that may pertain to roles and responsibilities, team mission objectives and norms, and familiarity with teammate knowledge, skills and abilities”, (Cannon-Bowers, et al., 1993). Levine (2018) reports that research of team cognition has mostly focused on two aspects, namely shared mental models and transactive memory systems, and his own work on the topic has emphasized the importance of sharing information and team members preferences, for teams to reach consensus. Perspectives of team peers must be understood to avoid the situation Levine describes happening when “groups reach incorrect problem solutions because members share common (rather than unique) information”, (Levine, ibid). XR may give scope to purposefully mediate such sharing by highlighting the views of team members through the enriched medium. Opportunities exist therefore to scaffold team cognition by distributing the creation of team mental models across team members and tools, while regulating information flow with virtual artefacts that can act as transactive memory supports.

During this study we worked with several cohorts associated with the CHARM-EU M.Sc. programme in Global Challenges for Sustainability. CHARM-EU is an alliance of European universities with students located in each campus coming together to work as a single hybrid cohort during their studies. The M.Sc. programme places a focus on transdisciplinary teamwork and other techniques vital to tackling global scale wicked problems relating to sustainability. Five cohorts agreed to work with us overall during our research. Our first participants were part of the CHARM-EU Winter school in January 2019. These students were identified and invited by CHARM-EU as representative prospective M.Sc. students and their activities on the Winter school were part of the master’s programme preparations. Their involvement in our research was separate from the Winter school activities. Our remaining cohorts were enrolled CHARM-EU masters students over two years of the M.Sc. programme. These were drawn from two classes of newly arrived first semester students or ‘Phase 1’ in CHARM-EU parlance, and two classes of slightly more established students from the programme capstone project. Our interventions with these students were included as part of their unassessed coursework for the M.Sc programme.

1.2 Research Problem

The following research questions emerged as a response to examine the potential for XR to support novice transdisciplinary hybrid teamwork. To address the issue, we adopted an exploratory stance by asking how we might best approach the problem.

- **RQ1.** How might we design XR systems that support novice hybrid transdisciplinary teamwork?

To answer RQ1 it is necessary to know what can be designed, and using a heuristic approach may help inform a design that can be tested.

- **RQ1a.** What design heuristics can be used for such applications?

A prototype that instantiates our design heuristics serves as the focus for a learning intervention and source of test data.

- **RQ1b.** How can the design heuristics be evaluated when implemented in a test artefact?

The aims of the study are encapsulated in RQ1's investigation of the emerging field of hybrid transdisciplinary teamwork to identify the types of supports that may benefit novice teams. Our objective therefore relates to operationalizing an approach to RQ1 via our two research sub-questions by developing heuristics relating to the identified supports and to evaluate these by instantiating them and testing in an exemplar artefact.

1.3 Theoretical Framework and Methodological Approach

Leontiev's conceptualisation of Activity theory (AT) offers a lens to think about dynamic systems of human activity, and the current research applies AT to frame our analyses of team cognition with the team activity as our unit of analysis. This macro view of activity considers influencing factors to identify tensions arising from their interplay, including personal motivations, interpersonal interactions, cultural and historical conditions and most pertinent to our research, AT emphasises the role of tools or artefacts that mediate interactions. Mediation is obvious in immersive XR environments but can occur at many levels depending on the tools in use. For example, the additional of enriched media in a hybrid team meeting purposefully focuses attendees' attention on a tool, which consequently influences their meeting format. On aggregate AT articulates that the influencing factors form the context in which activities are carried out and they therefore refine the range of potential outcomes for any given activity. A social construction of reality requires alignment of a consensus reality, and Activity Theory can help to conceptualise the processes and influences that determine such an outcome by considering the role of mediating artefact such as an XR tool in mediating team cognition. In our study, consensus reality may be equated with the concept of a team mental model that describes the team's project goals and the expected modes of interaction and sub-activities (i.e. actions and operations) of the team's work. Engeström's (1987) work on third generation activity theory has been invaluable in helping to identify team tensions that stem from earlier or parallel activities, and we have found Mwanza's (Mwanza, 2002; Mwanza-Simwami, 2011) Activity Orientated Design Method (AODM) to be a useful approach to operationalising activity theory in our study. AODM proposes an 8-step model of reflective questioning to categorise third generation activity concepts. This facilitates the identification of tensions, which has been helpful in evaluating a set of heuristic supports designed to scaffold transdisciplinary team synthesis via team mental model building based on sharing of structured sentiment feedback (see Chapter 5 for complete details of this approach).

Each of our three design cycles included an intervention with students and their feedback helped to refine both the heuristics and the subsequent interventions in later cycles. We argue the benefits of DBR in our literature review for generating practical knowledge that can be immediately helpful in addressing local problems, while simultaneously contributing to the scope of theoretical knowledge. We term our literature review as design "cycle 0" in this thesis, and it formed the basis of a set of design heuristics that we present in the current work, with additional heuristics being introduced during our first and second design cycles working with students before the being refined between the second and final, third cycle.

Between cycle 2 and 3 we applied AODM to refine our heuristics set from twenty-nine to sixteen that could be explored in detail during a focus session. The refinement identified overlapping concepts that we had implemented in an exemplar mediating artefact using related design features, and therefore it represents a practical attempt to include as many themes as possible in the space of a short focus session rather than a rejection of any heuristics. We do not discount the remaining heuristics as our argument for using heuristics is that they can be applied in a variety of formats. During our analysis we produced related focus group questions to explore the heuristics and asked additional probing questions to explore students' attitudes of the themes during our focus group sessions. Feedback revealed a variety of tensions that helped to clarify implementation issues in our design, and we comment on the impact of these in chapter 4, The Design Process (see design review sections for cycle 1, sections 4.6.9 and cycle 2, section 4.7.6).

Our research contributes to the field of technology-mediated learning by developing and refining a set of heuristics that guide and support hybrid and distributed transdisciplinary teams in building shared understanding. By integrating XR, AT, and DCog, we provide a framework for addressing communication challenges in novice distributed and hybrid teams.

1.4 Significance of the Study

The current work furthers the field of transdisciplinary hybrid teamwork with our investigation of XR informed team supports. We present the following contributions.

- Our study proposes four categories of heuristic hybrid team supports including twenty-nine individual heuristics that were tested and refined to a set of sixteen. Three of these categories were developed during literature review, with a fourth being informed by student feedback and was developed over two design cycles before being refined in our third and final design cycle. The first category, composed of only one heuristic, relates to general user experience guidelines as best practice for supporting any technology-mediated work. The second category of heuristics relate to team supports and team mental model building, which covers the themes of team's needs (Tuckman, 1965), feedback between members (LaFasto & Larson, 1989), team roles (Salas, et al., 2013), team communication (Katzenbach & Smith, 1993) and supports for team mental model building (Mohammad, et al., 2010). The third category of heuristics relates to supporting distributed cognition (Hutchins, 1965) and distributed cognition of teams (Blandford and Furniss, 2006; Webb, 2008). Within our study we also developed our own, fourth category of heuristics that are informed by student feedback and which target novice transdisciplinary team onboarding. These relate to team member orientation, fostering social presence in hybrid teams and establishing team relationships. Sixteen of the twenty-nine were tested directly by analysing participant feedback through the lens of Activity Theory (AT), operationalised using Activity Orientated Design Method (AODM).

- Design and implementation of our Transdisciplinary Teamwork Tool (TTT) as an exemplar implementation of our heuristics within a real-world hybrid team learning context. This tool is an evolution of our paper prototype worksheet that we created for our second design cycle intervention and refined by contextualising student feedback through the application of Activity Oriented Design Method (Mwanza, 2002).

- A methodological contribution expanding the use of Activity Theory (Leontiev, 1981; Engeström, 1987) and the Activity Oriented Design Method (Mwanza, ibid), and extended with notation from Bligh and Flood's (2015) Change Laboratory Toolkit.

1.5 Thesis Structure

Design based research's use of on design cycles has influenced the format of this thesis. DBR cycles generate data during each iteration and analysis of such data produces design inputs which inform the design of the next cycle. It is convenient therefore to explain our approach as the study progressed, since inter-cycle data prompted design decisions that may be difficult to explain without context. DBR cycles involve stages of designing, testing, evaluation and reflection (Scott, 2020) and we therefore present our work in a similar fashion.

The study began with a literature review in chapter 2 where we outline the development of a conceptual framework (section 3.3) designed to address our research questions. We term this "cycle 0" to recognise that it formed the inputs into our first official design cycle. Following this, we present our methodological approach in chapter 3 to explain our design philosophy, methods and practice considerations.

Chapter 4 describes our design process, and the reader will note the repeating structure of the subsections in this chapter. Each cycle is described in terms of the persons and practicalities involved as well as the methods used, and data generated. Within each cycle we aimed to evaluate and refine heuristics using AODM, and our explanation of each cycles notes when updates were considered and/or actioned in a design review section. This pattern is repeated for each of our three design cycles.

In chapter 5, 'Final heuristics analysis and findings', we move to evaluate our heuristics with an in-depth AODM analysis for each based on cycle 3 participant feedback. With so many heuristics to discuss, a high-level analysis of the set would miss detail and we have instead opted to develop an analysis vignette for each heuristic that applies AODM to frame the focus session feedback. Using vignettes in this way supports a granular discussion for each heuristic and clarifies the overall interpretation of our results.

Chapter 6, 'Discussion and Conclusion' revisits our research questions by reviewing the findings and interpreting them through the lenses of technology-mediated teamwork and distributed cognition, and our application of AODM throughout the project.

2 Chapter 2. Literature Review

2.1 Introduction

Transdisciplinary teamwork requires an integration of diverse disciplinary perspectives however the growth of hybrid teamwork introduces technology-mediated communication constraints. To address this issue, the current research explores how aspects of mixed reality (XR) can support novice hybrid transdisciplinary teams by scaffolding shared meaning-making. The research positions social constructivism (Vygotsky, 1978) as the overarching epistemological perspective to emphasize the co-construction of knowledge through social interaction. Cultural Historical Activity Theory (Leontiev, 1981; Engeström, 1987) offers as a lens for analysing the dynamic nature of technology-mediated team collaboration, and Activity-Oriented Design Method (Mwanza, 2002) provides a method of operationalising CHAT for a systematic identification of tensions that shape team interactions. Our purpose in this thesis is to propose and test a set of guiding design heuristics that build on established theory relating to teamwork supports, while incorporating a distributed cognitive perspective to conceptualise the dynamics aspect of hybrid teamwork. Perspective taking, empathy and team mental model building are considered in terms of information flow, coordination mechanisms, and cognitive distribution across people and tools.

2.2 Framing Philosophy – Socio-technical Perspectives

Teamwork depends on both self-knowledge and awareness of others to build accurate shared mental models (Cannon-Bowers, et al., 1993; Mohammed, et al., 2010). Yet to understand ourselves it is necessary to recognize that we exist within a social system, and self-knowledge is deeply influenced by external factors that modify our view of reality (Vygotsky, 1928;1978). The influence of social protocols and cultural norms on the individual is apparent. At the team level, social protocols are well established, indeed, they are frequently documented. The use of a project management methodology is an obvious example that defines the norms and modes of interaction for the team. The rules of the methodology define how we can think about the work. At a cultural level, such protocols are more profound. They mediate our understanding of reality by defining the very rules of engagement with it. Recognizing these effects is a critical step that must be taken before we can hope to design solutions to social-technical problems, and we should therefore explore them now to help understand their impact.

Our knowledge and understanding of reality are filtered through the many layers of our unique, subjective consciousness (Bashkar, 1997) and we must recognize that the design of any tool offers both affordances and constraints (sometimes termed negative affordances) in how we can understand its purpose and usage (Gibson, 1979; Norman, 1988,1999; Dickey, 2003). Our subjective experience of reality is framed within a larger social and inter-subjective context where we need to employ heuristics and rules-of-thumb to navigate our social landscapes. Such tools are useful to us because they offer a flexible and pragmatic way to understand reality. But our existence is defined by more than a social system. We exist within a broader techno-social system, one that may have always been part of the human experience (Greenfield, 1991). The creation of any new tool is an expression of our cognition, manifest in the physical domain - our ideas realized physically.

Distributed teams work together as a techno-social system that can be viewed as a composite of the persons, tools and context of their work. This diverse environment includes a wide range of perspective and software designed to support teamwork should therefore be inclusive of all users and adaptable to as broad a set of perspectives as we can deliver (CAST, 2024). The process of teamwork is dependent on these elements working in unison. Distributed Cognition Theory offers a useful tool to think about the interplay of the various parts a system whose elements work as a single unified process. Hutchin's (1995) work on Distributed Cognition (DCog) framed cognition as a field, comprising of both the individual thinking a thought, and the influence of their external environment on the formation of that thought. Hutchins was describing static objects and instruments, but it is reasonable to expect that the same feedback phenomena which is at play in the DCog view of cognition also occurs inter-subjectively between individuals. Bronfenbrenner (1977) would describe this as the microsystem layer of his ecological systems theory, plus parts of the mesosystem (given that the elements of a distributed cogitative system can also share relationships amongst themselves). This is consistent with Vygotsky's (1962) view of social-historical determination which sees thought and language developing through social learning that first starts between an infant and parent. Teamwork and group decision making are nice examples of this occurring as a distributed process. Each group member simultaneously builds their own individual cogitative map of understanding that is influenced by the connections that they share with each of their teammates, and indeed to the very concept of the team itself. When viewed as a network, teams, groups and societies can be seen as self-pollinating, densely interconnected phenomena.

Viewed through the lens of Distributed Cognition, the development and adoption of any new tool is an auspicious moment. It represents an expansion of human consciousness, or an increase in conscious capacity if you will. We have added an extra layer of meaning to our collective experience of reality. The tool, the action of its users and the feedback loop of representational meaning that subsequently ensues between the tool, individual actors (and indeed groups of actors), creates a new thread of meaning that weaves itself into the fabric of human experience. The tool has become a part of the framework through which we define meaning. This aligns with Popper’s (1968) concept of world 3, wherein the development of an exosomatic artefact contributes to the evolution of the environment that it was developed in. The mass market adoption of the mobile phone and cheap data networks are obvious contemporary examples of this that have led to profound social and cultural changes. Entirely new experiences emerge that shape and reshape our view of ourselves and our place in the world as was highlighted in Putman’s (2000) analysis of the influence of technology on society. But we can see that tools and technology regularly influence thought and culture, shaping and guiding it throughout our evolution. Stone tool making both depended on, and reciprocally influenced the development of our motor skills, strategic thinking and countless other aspects of our nature. All technologies do this to varying degrees depending on how widely they are adopted. Language is a universally adopted technology and affects us greatly. Vygotsky (1962) believed that language and thought are independent but that they develop together. Variation in language requirements can produce remarkable cogitative regional differences across the globe, particularly in isolated regions. As independent human cultures developed, their people’s languages evolved and adapted to meet the needs of their particular environments. Words that defy attempts at translation are commonplace. Language constructs such as words and grammatical structures have an influence on the minds of the speaker. We can see this in action through regional differences in cognition (for example the capacity of some cultures to see or be unable to see certain colours, and the lack of any word for that colour in their native language (Lupyan, 2012). The claims of Whorfian (1956) linguistic determinism are excessive, and both Chomsky and Pinker have highlighted that Whorf's theory fails to sufficiently describe the nature of the relationship between thought and language (Den Ouden, 1975). It seems more likely that weak linguistic relativity more accurately describes the relationship between thought, language and cognition. That is to say, it influences it in a feedback loop of meaning and meaning making which becomes ever more complex as it continues to evolve. XR introduces a profound change in our relationship with technology. We are no longer required to interact with ICT from the view of an outsider and instead it is now possible to immerse oneself into a piece of media and experience it from an entirely new perspective. New modes of expression are enabled when comments can be shared both synchronously and asynchronously in the same conversation. Such media allow for the expression of sentiment literally and figuratively, often both simultaneously within the same media (for example in the case of memes) and their cultural historical impact can already be felt. This evolution in how we interact with our tools will undoubtedly bring new challenges that may in time reshape the human condition in unpredictable ways.

Communication is clearly an essential skill for any kind of teamwork. When communication is mediated via technology, new challenges arise for teams. Short, Williams, & Christie's (1976) foundational work on Social Presence theory showed that computer mediated communication reduces social context cues between individuals, which results in a reduced sense of social presence for those involved. Siegel, et al., (1983) applied Social Presence theory to a study of group communication, where they showed that remotely connected teams made fewer remarks and took longer to reach consensus than co-located teams. This impoverished sense of connection is apparent in the work of Walter & Bourgoon who used Social Information Processing theory to show differences in our trust for another due to whether we communicate synchronously or asynchronously (Walter & Bourgoon, 1992; Walther, 1994). Indeed, many heuristics that we subconsciously employ when forming impressions of others can be negatively influenced by technology, such as schema development, stereotyping and person memory (Hancock, 2001).

McLuhan (1969) posited that the influence of a communications medium modifies our ability to communicate and collaborate, which has consequences for the success of online group learning and teamwork. It should be noted however that this influence is not necessarily negative. Multimedia communication extends cognition by allowing us to consider things from different perspectives. Larkin and Simon (1987) showed this in their analysis of sentential representations and diagrammatic representations of the same problems, where they found considerable computational advantages for information processing and quicker understanding through the use of images. McLuhan would surely recognize the immense jump in information bandwidth that XR affords. In addition to the audio and visual information, there is the sense of depth and distance from being in the space, and obviously massive amounts of information (contextual or otherwise) that can be presented via a user interface. He might therefore conclude that XR offers us a chance to reach a more accurate transfer of meaning between individuals. We must consider here if any completely accurate transfer of meaning, with all of the subtleties and nuance that it entails, is even possible between two individual beings. I propose that if it is ever to be so then it will be with the help of tools that extend our current cogitative capabilities. As one of our participants remarked about having seen their peers live feedback in our final intervention and having insights about how team members see themselves, one rarely has the opportunity to “crawl around inside somebody else's head”. Inter-reality team dashboards and related tools offer such a future, and we envisage future teams benefiting from many such tools and insights into subjective team data. But the epistemological question of what is knowable and worth knowing focuses on the object of our knowledge and as educators, we should be more interested in how we construct it (or more accurately, how we co-construct it with others). Constructivist theory sees learning as the process of actively constructing knowledge through a sequence of refinements to an internal conceptual schema (Piaget, 1978) that develops through experience. A social constructivist perspective extends this concept to include the influence of others. Appreciating that knowledge creation is an intersubjective process shows us that any enquiry of that knowledge should also be considered intersubjectively. Indeed, as discussed earlier cognition itself is a socially entangled process and any individual persons understanding is coloured both by their personal experience and the ever present direct and indirect feedback of others. Both constructivist and social constructivist perspectives are useful ways to think about cognition and learning that depend on cycles of refinement to construct knowledge.

A mixed reality tool that can support distributed teamwork needs to consider the impact of these effects. Interpersonal communication within teams is already recognised as a challenge (Cohen and Levesque, 1990; Stevens & Campion, 1994; Salas, et al., 2005) which suggests the need for design considerations that can clarify and support meaning-making. Communication that is mediated via technology is modified subtilty by the influence of that technology McLuhan (1969), meaning that care must be taken to understand the role technology plays within the teamwork.

2.2.1 Constructivism

Piaget’s foundational constructivist ideas relate to how learners construct knowledge based on their prior experiences (McLeod, 2012). Knowledge is actively constructed in the mind of the learner in a process of examination and reflection which leverages prior concepts or understanding. Thus, Piaget believed that each learner constructs a personalized understanding of a topic. Most learners have similar prior experiences (for example, resulting from a school curriculum) and will generally arrive at a consensus understanding of a topic, however each learner brings their own subtlety and nuance to this understanding.

Vygotsky's work added a social component to constructivism by recognising that the learner is forever situated within a social context (Vygotsky, 1978). Social interaction and experience therefore add greatly to the understanding and knowledge that one can achieve. Social experiences modify the construction of learning, both positively and negatively, by acting as an extra layer of foundational knowledge. Applying this understanding to the study of teams, one might expect that the quality of the inter-relationships within the team should influence the quality of the learning. This is consistent with da Silva, et al., (2013) whose findings ''showed that the consistent use of team building criteria correlated significantly with project success, and the criteria related to human factors, such as personality and behaviour, presented the strongest correlations'', (da Silva, et al., 2013). This idea also supports Hinds and Bailey's (2003) views that because distributed teams are less connected to their peers, they take longer to form relationships and experience higher levels of team conflict than co-located teams. Distributed teams have fewer opportunities to interact than co-located teams do. This equates to fewer opportunities for meaning making or the co-creation of knowledge within any distributed team, but especially so in a distributed team of learners. Student teams typically have less extrinsic motivation to engage with their teammates beyond their course and project work. A remote student team takes longer to establish what the renowned inventor of the constructivist-inspired 'Moodle' learning management system, Martin Dougiamas, has referred to as the ''reciprocal spiral relationship'' (Dougiamas, 1998) that exists between individuals engaging in any kind of socially co-constructive activity. Dougiamas employs this understanding of co-construction in the design of Moodle, where constructivist learning activities can support didactic processes through series of interactions between instructors, students and peers.

Social Constructivism

Lev Vygotsky's (1978) Sociocultural Theory of Cogitative Development views language as the basis for learning. He viewed language development and knowledge acquisition as inherently social phenomena. His concept of the Zone of Proximal Development (ZPD) explores the relationship between a learner and a More Knowledgeable Other (KMO), who can help the student reach beyond their current understanding. There is a set of MKOs in every transdisciplinary team and each supports a ZPD for their peers when it comes to their co-development of the team project. Vygotsky showed knowledge acquisition to be an activity that is based in a process of dialogue and a gradual building of understanding with the help of the more knowledgeable other. Here we can see that the types of mental processes that are typically considered to be internal to the individual, arise out of wider social processes. In transdisciplinary teams this can initially appear to be a chaotic process where each member needs to acknowledge and attempt to reconcile the views and ontological stance or each of their peers before a synthesis can take place.

Cultural Historical Activity Theory (CHAT)

Activity Theory is not really a theory in the grand sense but rather a theoretical perspective and set of recommendations about how to think of human activities. The term has evolved since its inception amongst Russian scholars of the early Vygotsky circle and now includes a wider perspective of activities viewed within a culturally historical context. Activity theory's main arguments are summarised below, (with notes quoted from Kaptelinin, et al., 1999) and our supplementary notes following.

- Object-Orientedness ("activity is directed toward something that objectively exists in the world, that is, an object."). This is the goal state or objective of the activity.

- Hierarchical Structure of Activity. ("Actions are goal-directed processes that must be carried out to fulfil a motive"). To distinguish between activities and more granular component tasks, Vygotsky describes activities on three levels, i.e. activities, actions, and operations.

- Internalization and Externalization ("internal activities cannot be understood if they are analyzed separately, in isolation from external activities, because it is the constant transformation between external and internal that is the very basis of human cognition and activity."). The mind exists as part of a society. Social feedback and didactic process inform the creation of minds.

- Mediation ("tools shape the way human beings interact with reality. Shaping external activities results in shaping internal ones. Second, tools usually reflect the experience of other people who tried to solve similar problems before and invented or modified the tool to make it more efficient and useful. "). The modifications to the tool are culturally historical. They determine how it works and how we can think about its usage.

- Development ("Activity theory sees all practice as being reformed and shaped by historical development. It is important to understand how tools are used not in a single instant of trying them out in a laboratory (for example) but as usage unfolds over time"). Cultural historical development takes time and repeated effort to have any impact.

Activity theory has evolved through three main stages, loosely termed; Mediation, Action to Activity, and Activity Systems. Activity Systems includes both third and fourth generation Cultural Historical Activity Theory.

Mediation

Vygotsky's early work was foundational to that of Aleksei Leontiev (1981) whose refinements to Rubinstein's (1973) Activity Theory helped to popularise it and bring it to the attention of non-Soviet scholars. In this evolution of Activity Theory, influences from community, rules or the division of labour act to modify how the activity may progress. These influences are socially constructed due to culturally historical factors. Indeed, even the mediating instrument or tool that modifies the subject-object relationship may itself be viewed as the output of some prior activity and is therefore also a culturally historical construction with its own connections to the other elements in the model.

Vygotskian Activity Theory proposed mediation as an answer to psychological arguments based on stimulus-response (i.e. behaviouralist and early cognitivist views that dominated the discussions of the day). Vygotsky's Mind in Society is an effort to explain the link between human experience relating to internal and external worlds, or experiences of cognition. Vygotsky proposed the notion of mediation as the link that connects both perspectives to address dualistic conceptions of the individual in society and show that thinking is inter-related with context. Understanding that cognition is socially co-constructed between individuals, groups of individuals and the wider society has obvious implications for teamwork. Vygotsky's work recognises the influence of social processes on cognition by framing human activity in terms of a subject-object relationship where the subject engages in an activity to achieve their objective. Vygotsky viewed this relationship as always being mediated by some form of instrument, which in turn reciprocally influences the activity because of the mediation.

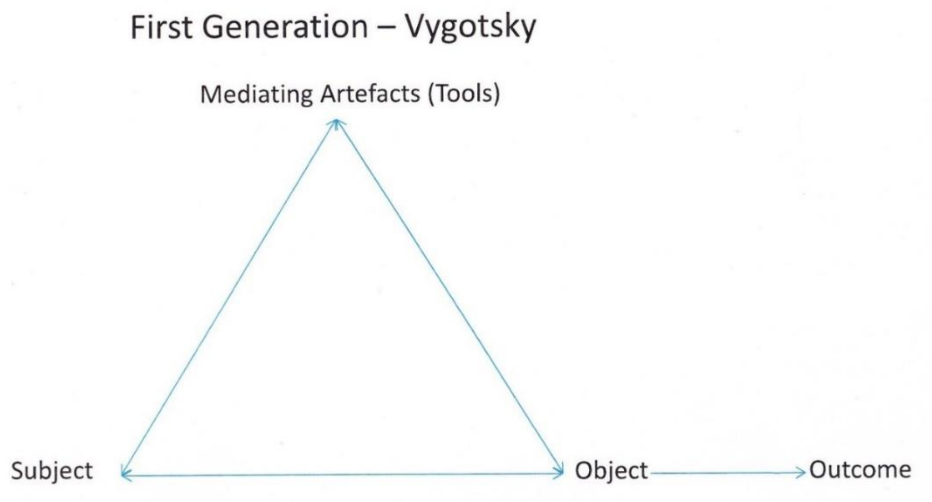


Figure 2-1. Vygotsky's model of mediated action, illustrating how tools mediate human activity. Adapted from "Vygotsky Basic Mediated Action" by Van der Veer, R. (n.d.)

Action to Activity

Vygotsky failed to sufficiently define the relationship between individual action and collective activity. His focus on action filters out much of the historical context that influences human culture. Leontiev's response was to look at the broader context of action as part of a larger activity and to consider the cultural and historical reasons that determine the context. He illustrated differences between action and activity in his famous example of the "primeval collective hunt". The example highlights apparent clashes in motives when limited solely to a view of actions of individuals within group activities. In the example of the hunt, Leontiev described a group of humans engaging in a hunt activity where individuals in the activity divide the labour such that some catch the animals when others drive them out of the undergrowth. These drivers appear to have an objective that is at odds with the purpose of the hunt activity if we fail to view their actions as part of a collective effort. Leontiev's contribution, which is now known as second generation Activity Theory, places greater emphasis on the idea of an action taking place as part of a system and the influence of the components of the system on its eventual outcome.

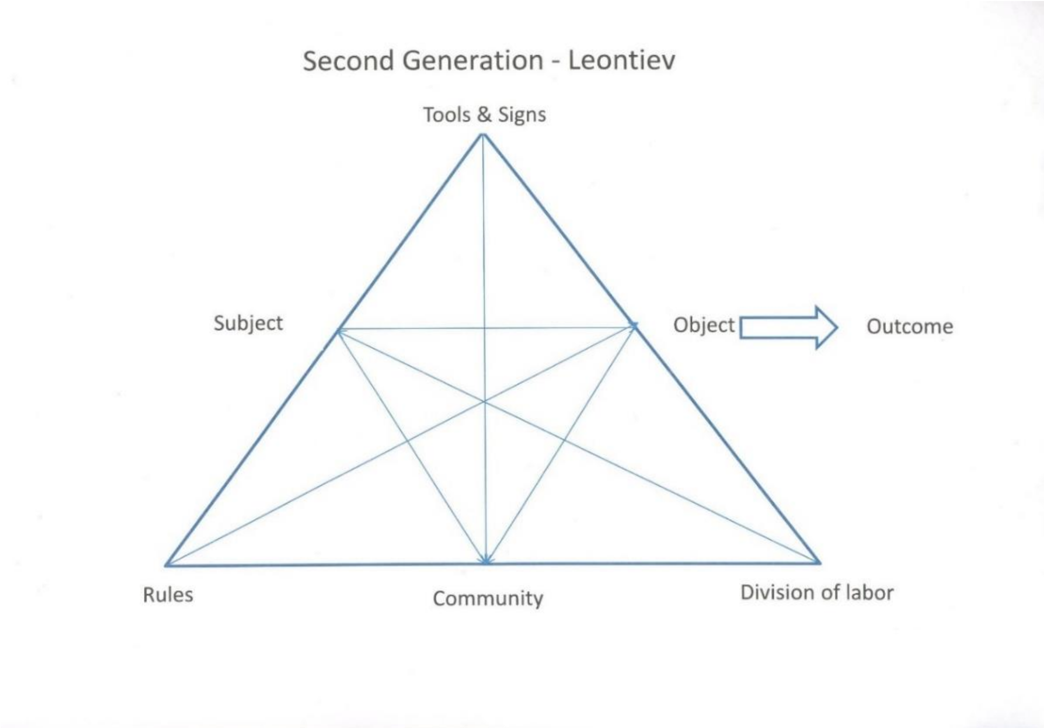


Figure 2-2. Second-generation Cultural-Historical Activity Theory (CHAT) model, illustrating the expansion of Vygotsky's mediated action framework. Adapted from "Second Generation CHAT" by Engeström, Y. (n.d.)

Activity Systems

Although Leontiev described his improvements to the model, he did not extend the triangle diagram that we now recognise as the second generation of the theory. Engeström's (1987) initial work on Activity Systems upgraded the diagrammatic representation of the model to include the extra factors of Rules, Community and Division of Labour. Engeström says of CHAT that is can "integrate agents, world and activity". His conceptualisation of Activity Systems emphasises the dynamic nature of activity and highlights the role of rules, community and division of labour and their effects on an activity. Activity Systems are a core concept of what Engeström terms Third Generation Activity Theory. This evolution considers that activities exist in a wider context of many concurrent or parallel activity systems, which may or may not share the same objective. Additionally, the third generation of the theory explores the cultural historical nature of activities more closely by considering the impact of tensions that arise from these other activities. Tensions can be described as contradictions in goals between neighbouring activity systems or between elements in the system itself, that manifest as problems relating to exchange, production, distribution and consumption (Engeström, 1987; Engeström 2000) depending on which sub-triangle they are focused. Conceptualising activity systems in these terms helps to identify tensions that may exist within elements, between elements, or with the impact of external parallel or historical earlier versions of the activity versus the current iteration.

Third generation activity theory is deeply connected with Engeström's concept of Expansive Learning, where tensions within or between systems can initiate a sudden expansion in learning for an individual tackling some challenge. Subjects crossing boundaries between different activity systems also introduce tensions, where one activity is adopted in favour of another, and these too are seen as opportunities for expansion of learning. The notion of expansions of learning that arise from crossing boundaries has obvious parallels in transdisciplinary team synthesis where individuals must evolve their unidisciplinary views to integrate the perspective of their peers if team growth is to occur.

In recent years Engeström has begun work on a fourth generation of the theory that considers the impact of networks on each of the elements in the model, although such developments are beyond the scope of the current study.

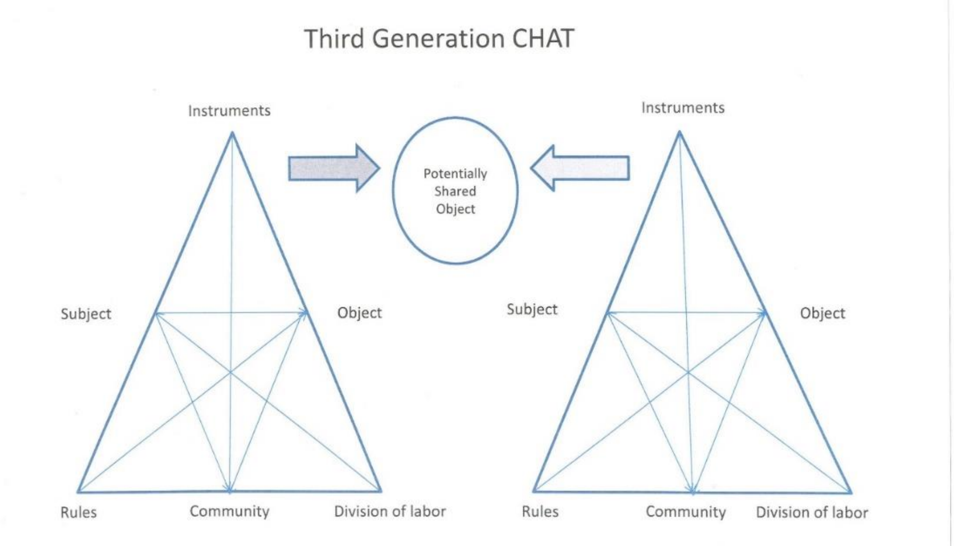


Figure 2-3. Third-generation Cultural-Historical Activity Theory (CHAT) model, illustrating interacting activity systems and contradictions. Adapted from "Third Generation CHAT" by Engeström, Y. (n.d.)

2.2.2 Socio-Technical Frameworks

Aligning with a socio-technical framework offers a structured way to view the blend of human and technology related issues that arise during computer mediated teamwork. The current study employs a set of complementary theories to frame the problem and support an analysis. Activity Theory is the primary lens through which we view the interactions of team members in the current research. This is a powerful tool that considers an activity with respect to the persons involved, their experience, and motivations, as well as the purpose of the activity and its social context. Activity theory looks at cognition of individuals, but it views the individual as an insufficient unit of analysis to understand cognition since the wider context of the activity is also considered to be a critical factor. We apply the theory at the level of team analysis to address this concern. Using CHAT in this way helped us to bridge the divide between social and technical components of our intervention.

Activity Orientated Design Method (AODM)

Daisey Mwanza's doctoral thesis introduced the Activity-Oriented Design Method (AODM) as a response to Activity Theory's lack of an established method (Mwanza, 2002), and AODM has been used successfully to characterise learner's experiences with technology (Mwanza-Simwami, 2011). AODM offers a toolkit of concepts and recommendations that help with its application in analysis and interpretation of variant factors by categorising them as belonging to elements of the activity system triangle. "When compared to existing Activity Theory informed method, for example, the 'Activity Checklist' introduced by Kaptelinin and others (2000), AODM offers a step forward by making the link or relationship between activity triangle components and generated research questions explicit", (Mwanza, ibid).

Tensions and systemic contradictions

Greenhow & Belbas, (2007) note that "three methodological traditions have emerged in the CSCL literature: experimental, descriptive, and iterative design" and they position AODM as a hybrid methodological approach which relies on both the descriptive and iterative traditions. The authors continue by saying that the purpose of AODM is to "facilitate design insights, but not to 'find or predict solutions' " (Greenhow & Belbas, ibid). Activity theory's descriptive power cannot be understated. Its potential to simplify complex and multi-dimensional activities by providing "perspectives on human activity and set of concepts for describing that activity", (Nardi, 1996), has been helpful in the current research. Yet there is still no widely accepted method for applying Activity Theory (Barab, et al., 2004; Bligh & Flood, 2015/2017; Colasante, 2024) and work needs to be done to establish these methods. We would concur with Greenhow & Belbas's view that AODM has the potential to add structure to the application of Engeström's evolution of the theory, although there are limits that must be addressed.

AODM can be a powerful method to identify contradictions between elements of an activity system however it struggles to describe the culturally historical context of certain types of activity system tensions. Concepts from third generation activity theory have yet to be integrated. Tensions that result from differences between earlier versions of an activity and some new implementation or approach such as a technology-mediated learning intervention in our study, are beyond the purview of AODM. Engeström's third generation CHAT frames these as tertiary contradictions. Similarly, AODM cannot fully describe tensions that result from parallel activity systems (perhaps with a shared objective), which Engeström refers to as quaternary contradictions. Our review has not uncovered research fully integrating AODM with Engeström's definition of tensions that stem from antecedent or parallel activity systems (i.e. "tertiary" or "quaternary" contradictions). When applied as a purely descriptive framework, AODM is often used to capture a moment in time that can be compared against earlier or later moments to explore the dynamic nature of an activity. However, in practice this comparison step is often ignored, which limits its ability to fully capture the cultural historical nature of the elements within the activity system being studied. An additional notation is required to assist in categorising tertiary and quaternary activity system tensions with AODM and the current research proposes and employs Bligh and Flood's (2015) icon set from their Change Laboratory Toolkit as a suitable solution.

2.2.3 Distributed Cognition

Vygotsky's view of knowledge creation and Hutchins (1995) view of meaning making share parallels in their reliance on external factors where we might not expect them, as well as a beautiful simplicity in their combined implication that cognition is socially co-constructed. Hutchins formed his theory of Distributed Cognition while working with US Navy bridge crews to analyse their interactions. His analysis stems from the perspective that the bridge crew officers mediated their cognitions through both the ship's instrumentation and the other bridge officers. DCog frames cognition as a field effect that extends from the mind and body out into the world. In this interpretation of cognition, experience is formed from the interaction of mind and world such that artefacts in the world are intrinsically bound to the thoughts they represent. Hutchins work was quickly follow by Clark and Chalmers' (1998) seminal article 'The extended mind', which has become the introductory text to the subject for many. The extended mind differs for DCog in its focus however by examining how external tools modify an individual's cognition, as opposed to

Hutchins understanding of cognition from a distributed perspective to see how it is spreads across individuals and artefacts within a system. This expansion of the unit of analysis to include a social dimension, mirrors that of Engeström's (1987) third generation activity theory expansion of Leontiev's (1981) work. DCog aims to explain mental processes by looking at groups and their tools. DCog theory focuses on four aspects of cognition. A DCog system contains embodied information that can be accessed by its members, akin to a transactive memory system. It requires coordination between agents (e.g. teammates in our study). It recognises that the set-and-setting or ecosystem that the activity take place, has an impact on its outcome. Finally, roles exist within the system that are defined by functional relationships between members or elements, and these can be mapped to distributed cognitive processes. We have used the principles within our collection of design heuristics, which we present at the end of this current chapter (see section 2.5).

Blandford and Furniss's (2006) Distributed Cognition of Teams (DiCoT) introduced a methodology for applying Distributed Cognition to the design of team working systems, informed by their study of the various interacting roles required in ambulance support teams. They offer a set of eighteen principles relating to the organisation of work within a team, how information flows within the team and the impact of artefacts on the team's work. The principles offer a frame for understanding a distributed team as a cognitive system, and a cookbook to support good team cognition in general. Our process of selecting the most relevant and testable of the DiCoT principles is described in the 'Heuristic Implementation Mappings' subsection of section 4.8.3.

2.3 Teamwork

Teamwork is recognised as a key transversal skill that is highly prized by employers (Ravitz, 2012; UNESCO 2014). "Teamwork is one of the key competencies that students must acquire to meet the needs and skills of the labour market, as recognised by the European Higher Education Area (EHEA)" (Noguera, 2018). Although teamwork and communication are desirable graduate attributes, research and computer industry literature (Wiley Workplace Learning Solutions, 2021) indicates that most students do not receive explicit training in these skills (Hansen, 2006; Calonge & Shah, 2016). Today's professional knowledge teams learn in multiple domains, from understanding how to work with others and gaining insights into one's own behaviour, new processes that must be adopted or new technologies to be integrated, new client requirements, legal requirements or countless other constantly moving targets. However, teams must first develop their teamworking skills if they are to successfully work together. The current chapter combines teamwork models the address team's needs (Tuckman, 1965), feedback between members (LaFasto & Larson, 1989), team roles (Salas, et al., 2013) and team communication (Katzenbach & Smith, 1993) and team mental model building (Mohammad, et al., 2010) as important supports for novice hybrid teamwork. While this corpus may be applied to any kind of team whether co-located, hybrid or virtual, the guidance from these theorists relates to improving team cognition through clarity of purpose and clarity of process and may therefore be useful in alleviating communication challenges introduced by technology mediation.

Bubaš (2001) notes the propensity of remote teams to lack cohesion due to their reduced capacity to communicate when that communication must be mediated by technology. Despite its limitations however, technology-mediated teamwork is growing in popularity and if the COVID19 lockdowns have shown the world anything, it is that remote work is a viable option in many situations (Al Mohamad, et al., 2024). This represents a challenge for transdisciplinary teams due to the variety of disciplinary perspectives held by their members, which introduce interpretation difficulties that must be resolved through team discussions and debate. Establishing good communication is therefore essential for effective transdisciplinarity (Jahn, et al., 2012). An opportunity exists to understand the role of technology in mediating teamwork so as to proactively leverage its unique affordances, whilst minimising communication hurdles that 'traditional' technology-mediated work entails.

Extended, or Mixed Reality tools and environments are claimed to promote a sense of shared presence and social "closeness" in users due to their virtual co-location (Witmer & Singer, 1998; Gee, 2003; Castronova, 2005). The current research looks at the potential of XR affordances to support hybrid team activities by increasing the communications bandwidth available to team members with a view to improving the quality of team mental models of project work. We discuss such applications of XR to support distributed teamwork in the current chapter, however a considerable body of teamwork literature now exists, and it would be remiss to ignore this corpus when determining how best to support hybrid teams.

2.3.1 Team Awareness

Over one hundred years ago, Perry and Barton, (1922) showed that the distinction and frequent differences between individual and group thought processes are common problems that hinder group communication. The researchers introduced the concept of a Social Mind to describe the complicated negotiation required to handle multiple simultaneous relationships within a group. Our research equates the social mind of a team with team mental models (Cannon-Bowers, et al., 1993), and one can see the influence of Perry and Barton's concept in the work of many teamwork scholars research in team awareness, for example LaFasto and Larson's (1989) work establishing the importance of intra-team feedback, or Salas, et al.'s, (2013) views regarding the importance of establishing team mission objectives and norms that are understood by all team members. More recent research suggests that work must still be done to "account for the considerable role that situation and context play" (Tamir & Thornton, 2018) in establishing a consensus social mind, which connects well with the perspectives of distributed cognition theories that consider the full team as the unit of analysis. Organized and shared understanding of relevant knowledge, combined with situation awareness by team members, echoes Cannon-Bowers, et al.'s, (ibid) definition of a team mental model where clarity of processes determines the relationship between mental model convergence and team effectiveness (Mathieu, Heffner, Salas & Cannon-Bowers, 2000). Cramton, (2001) highlighted that team awareness can be a challenge for remote teams due to what she has referred to as the "mutual knowledge problem" and notes that interdisciplinary and uni-disciplinary teams have been observed to face such challenges in their interactions when working online. The research highlighted cogitative load and the mode that feedback is received as being critical to the accurate and timely handling of complex, multi-party task information, (Cramton, ibid). Development of an accurate and aligned team mental model exemplifies such a negotiation of the mutual knowledge problem, where team members must work together to identify the key elements of their project scope and goals (Mohammed, et al., 2010). Exploring hybrid teams' approach to team roles is therefore an important consideration in supporting team mental model (TMM) development and our collection includes one heuristic dedicated to such supports (i.e., Mohammad, et al., 2010). Measurement of team mental models is complex and highly contextual (DeChurch & Mesmer-Magnus, 2010; Mohammed, et al., 2010). Mohammed, et al., (ibid) define a TMM as mental representations of the key elements within a team's relevant environment that are shared across team members, which places a focus of TMMs on building teams' situational awareness. This suggests a potential route to exploring team mental model building by equating it with situational awareness relating to project status.

Tools that mediate the coordination of teamwork should be based on designs that recognise the need to support and clarify team situational awareness issues. Gaddy and Wachtel (1992) looked at small groups and suggested that effective teams are self-aware. Although their research focused specifically on the "characteristics of nuclear power plants that affect team performance", they are particularly interested in "the human aspects of team performance". Their research has implications for DCog as they showed that environment has a considerable effect on human thought, (Gaddy and Wachtel (ibid)). Studies of small group behaviour are common in management literature and Stevens & Campion (1994) showed that the more traditional indicators for business success do not necessarily equate with success of the team. They recommend that tracking of Knowledge, Skills and Abilities (KSA) is more useful than traditional key performance indicators (KPI) as metrics for determining how well a team worker performs. This includes self-awareness as well as interpersonal awareness, i.e. awareness of conflict, use of problem-solving skills for resolution, etc. which are now regarded as essential transversal skills for teamwork (Ravitz, 2012). Distributed cognitive perspectives of teamwork (Blandford & Furniss, 2006) echo the importance of shared situational awareness for team members establishing clarity of purpose and clarity of teamwork processes. More recent work has aimed to present team awareness skills as elements within a socio-technical framework (Inayat, et al., 2017), which resonates with a growing awareness of the impact of technology on psycho-social behaviour (Bubaš, 2001). XR may offer potential to scaffold team situational awareness with systems that promote skill development in self-and interpersonal awareness through empathy and perspective taking.

An interesting hurdle for hybrid transdisciplinary teams relates to the increased difficulties that distributed teams face when attempting to co-develop shared team mental models. Transdisciplinary teams must employ extra effort at the start of their projects to build understanding of a shared mental model before they can begin to make sense of their complex problem spaces. Such shared cognitions in teamwork (Mathieu, et al., 2000) can be difficult enough within a single discipline, without the additional interpretations that arise from a plurality of perspectives. Developing shared-team and task-based mental models has a positive effect on a team's ability to establish processes, improves communication and leads to greater overall performance (Salas, et al., 2013). Heuristics aimed at addressing these themes would need to include "roles and responsibilities, team mission objectives and norms, the environmental context, and team familiarity", (Salas, et al., 2013). Cannon-Bowers, et al. (2001), enquired into the techniques that teams employ to co-construct a shared mental model of their scope of work. The study highlighted the types of information that must be shared, when best to share, and the interplay between team roles that will determine what should be shared, all of which represent useful design rules for the current research. Recognising that technology mediation may frustrate teams in establishing a consensus team awareness has been a motivation in our study. If this challenge is to be overcome, then a deeper examination of team interactions and intra-team communication is necessary before developing heuristics to address the problem space.

A final consideration regarding team awareness relates to intra-team empathy and perspective taking. Empathy is a key transversal skill and a key factor in team performance (Ravitz, 2012). Empathy is also a key factor in group decision making, where it is frequently necessary to adopt the perspectives of others to develop an awareness of nuance within a problem space. It is germane to view empathy as our ability to reach a more sophisticated version of consensus reality with another human. It may even help us to one day reach a little closer towards a collective understanding of actual reality. At the very least, it attunes us to the needs of the group or society in which we act, and it hopefully helps us to understand the impact that our own actions have both on other individuals and on these same groups.

2.3.2 Approaches to Teamwork

There is now a considerable body of literature relating to teamwork (Grant, et al., 2005; De Prada, et al., 2022; Salas, et al., 2024) with researchers focusing on aspects such as team effectiveness, team attachment and participation. This has led to a degree of construct confusion when distinguishing aspects such as team viability with related constructs such as satisfaction (Bell & Marentette, 2011). Teamwork science models have typically been based on an understanding of mental states of team members (Kraus and Lehmann, 1988) and newer studies examining contemporary topics such as team diversity (Wallrich, et al., 2024) or emotional security (Edmonson, 2018; Edmonson & Auger-Dominguez, 2024) build on this view. Models that consider team and team member goals are also popular (Singh and Asher, 1993; Cohen and Levesque, 1990). Formal approaches to teamwork that employ an explicit methodology have become popular in commercial teams and Agile methodologies such as Kanban scaffold a project work cadence that has greatly influenced contemporary professional working practices. Transdisciplinary teamwork leverages insights from Agile methodologies and the Kanban method has become an increasingly popular and effective approach to the organisation of team activities (Digital.ai, 2020). Some practitioners have adopted a bespoke approach that owes much to Kanban (Steelman, et al., 2015). For example, Lang, et al., (2012) outline a process for transdisciplinary teams comprising of three phases. In the first phase teams engage in problem framing and team building. The next step for the team relies on a solution-oriented approach to the co-creation of transferable knowledge. The final phase employs a retrospective and reflexive activity to re-integrate and apply learning and knowledge in scientific and societal practice. This blend of social and scientific factors in transdisciplinary teamwork complicates intra-team communication. Transdisciplinary teams therefore typically go to lengths to document their own definitions to ensure clarity of communication (Pohl, 2005; Pohl & Hirsch Hadorn, 2007), which offers a promising focus for generating the types of heuristic supports addressable by RQ1 and RQ1b.

2.3.3 Teamwork in Educational and Workplace Contexts

It is important to clarify potential differences that may be experienced by novice team members depending on the setting, particularly when comparing educational environments to professional workplaces. While both involve collaborative problem-solving and shared goals, the nature, duration, and context of the work shape team processes, outcomes, and opportunities for learning.

Educational and professional teams share several core features. Both types of teams work toward collective objectives, requiring coordination, communication, and negotiation of responsibilities (see Chapter 1, sections 1.1–1.2 and the preceding subsections of section 2.3 for an overview of these competencies). Effective teamwork also depends on aligning shared mental models, awareness of roles, and understanding of teammates' skills and knowledge (Cannon-Bowers, et al., 1993).

Predetermined learning outcomes are not generally considered within professional teamwork, whereas they are inherently part of any academic programme. In educational contexts, teamwork may function as a mechanism for learning about teamwork, as well as for knowledge integration and skill development. Students in transdisciplinary teams engage in negotiating understanding across domains, problem-solving collaboratively, and reflecting on shared knowledge, which are central learning outcomes in higher education programmes such as the CHARM-EU MSc in Global Challenges for Sustainability. These learning processes are scaffolded by structured feedback and technology-mediated collaborative activities that help students develop both domain knowledge and transferable teamwork skills (Pohl, 2005; Pohl & Hirsch Hadorn, 2007). Professional team learning, in contrast, focuses less on foundational skill development and more on task efficiency and knowledge application.

Student teams are usually short-lived, existing for the duration of a semester or a single capstone project. This compressed timeline limits opportunities for developing emotional security, trust, and a shared group identity, which are essential for effective learning through collaboration

(Edmondson, 2012). Professional teams often remain intact for longer-term projects, allowing members more time to develop familiarity, trust, and integration of expertise. Team composition also differs since student teams may only be drawn from the available set of disciplines within a transdisciplinary cohort, rather than hiring for specific pre-identified roles in a professional context, which introduces a degree of variability into student transdisciplinary teamwork regarding their interpretation of the project problems space and achievable solutions.

Communication and feedback are critical to coordinate activities and achieve outcomes, even when the mechanisms differ (LaFasto & Larson, 1989). Both student and professional teams utilise technology to support collaboration, although the purpose can vary from scaffolding and learning dominating in educational contexts, whereas efficiency and coordination dominate in professional contexts (Bubaš, 2001). Clarity of roles, defined tasks, and agreed norms also help structure collaboration in both types of teams (Salas, et al., 2013; Katzenbach & Smith, 1993), although as discussed elsewhere (see Chapter 4, Sections 4.7.8–4.8.8; Chapter 5, Sections 5.4.2.5–5.4.2.6), such clarity may not always be present in educational contexts, where learners may adopt distributed leadership techniques or functional role rotation. Mechanisms and context of feedback further affect learning. In educational settings, grading and assessment influence engagement, and feedback is often structured to guide the learning process (LaFasto & Larson, 1989; Hattie & Timperley, 2007). In professional teams, feedback is embedded in operational processes and evaluated primarily against project outcomes, emphasising efficiency and performance rather than the development of new skills. Institutional and cultural contexts also differentiate teamwork. Students operate within curriculum constraints and university norms, whereas professional teams function within organisational cultures, hierarchies, and business priorities. These contexts shape not only coordination and role clarity but also the types of learning and skill development that can occur within teams. Finally, students and professionals experience different extrinsic motivations, such as pressure to pass an exam versus a desire to be rewarded financially or pursue career advancement.

Overall, while both educational and professional teams depend on shared goals, communication, and coordination, differences in team composition, duration, institutional context, and feedback processes create distinct challenges for student teams. These differences reinforce the need for carefully designed scaffolds in higher education transdisciplinary projects, where instructors and designers must structure team formation, feedback mechanisms, and technology-mediated collaboration to support novice students in developing robust team cognition, shared understanding, and the capacity to integrate disciplinary perspectives effectively.

2.3.4 Interpersonal Relationships

Most our teamwork category of heuristics relate to interpersonal relations in some form. Tuckman's model of group development (1965) is a useful way to consider the milestones that a team must pass if they are to be successful together. We can say that interpersonal factors are likely to influence how quickly or slowly a team manages to reach each of Tuckman's stages of Forming, Storming, Norming and Performing. Poor group dynamics result in dysfunctional teams that may never move beyond the storming stage. Any application designed to support teamwork should recognise the influence of dynamic inter-personal factors to support team members as the team develops. LaFasto and Larson (1989) comment on this by stating that intra-team feedback is essential to good communication. They focus on the skills of the individual, their relationships with team peers, the impact of leadership, and of organisational context as factors influencing team health. Katzenbach and Smith (1993) have also commented on team communications in depth and their focus is on team efforts to maintain clarity. Their work showed the need for being specific in communications and employing a clear working approach that helps team members to recognise and manage relative priorities. Overall, this leads to less stress for members, and a healthier team. Empathy and perspective taking can be beneficial in establishing and maintaining team relationships (Ravitz, 2012) by contributing to the development of team affiliative associations that help to establish trust (Xin, et al., 2016) and improve intra-team communications (Salas, et al., 2013).

2.3.5 Team Formation

Student teams are typically drawn from a single cohort and the skill sets of team members is more likely to be similar, however recent efforts to introduce transdisciplinary teamwork into higher education curricula are helping to redefine how we think of student teamwork. In the workplace, teams are composed of diverse roles to address a given business goal. They typically stay together over the length of a project, which is often a considerable length of time. Professional teams have differences to student teams that can influence their team success. Even if we ignore the different extrinsic motivations, the length of time that the team remains together means that professional teams have longer for members to develop the emotional security needed to feel confident within the group (Elias, et al., 1997). Similarly, their group identity has time to develop, i.e. to be co-created by the team themselves as they work. RQ1's focus on novices emphasises the importance of supporting teams in developing peers connections at an early stage. Student teams are typically formed for the duration of a single semester or at most for the length of a capstone project. Team members may know little about their peers and they may not work particularly closely or regularly unless their coursework requires it. Bonding between members, or any sense of connection to the group itself, can be slow to develop (Whitmore, 2002).

Those responsible for forming teams should consider the many factors that influence interpersonal relations within teams, but especially educators forming novice student teams. As noted, student teams are more vulnerable to team formation problems and transdisciplinary student teams are especially so due to the increased complexity that they exhibit. Additionally, student teams have limited time to bond and function well as a unit over the duration of their engagement on an academic programme. The increasing need for transdisciplinary teamwork over recent years (Klein, 2020) further complicates the requirements for student teams to be successful. Transdisciplinary teams include a plurality of roles that work together to build bespoke processes and workflows to suit their unique problem space. As a team works together, they learn to improve both their performance and their processes (Cooke, Gorman, Myers, & Duran, 2013). The lack of experience in transdisciplinary student teams may represent a pain-point that leads to team frustration and negative outcomes in the face of such obstacles.

Remote teams, transdisciplinary or otherwise, face even more challenges than their co-located peers due to the communication hurdles discussed earlier. However, Dale, et al. (2010) have shown the value of online collaboration tools to assist transdisciplinary research teams in co-ordinated work. Their work highlighted the typical benefits of online collaboration, (i.e. reduced cost, time saving) but they also reported increased teamwork efficiency that speaks to the potential for communication technologies to improve current working practices.

Teambuilding can offer a practical solution (Whitmore, 2002) to improve a team's motivation to work well together. A closer connection to one's peers is beneficial for any team but particularly so in distributed teams (Marlow and Dabbish, 2011). Forming activities present useful opportunities for interventions focused on teamwork and the team interventions conducted during our second and third design cycles were planned to take place early in the CHARM-EU programme to target newly formed teams. Sullivan, et al. (2017) showed the potential for virtual reality to assist with team bonding and the exemplar tool employed in the current research speaks to this as a mixed reality tool designed to facilitate communication in newly formed teams.

Student motivation is recognised as a key factor in academic success (Langley, et al., 2004) and the use of mixed reality in the classroom has been shown to profoundly enhance student motivation to engage with learning content (Pribeanu, 2008; Di Serio, 2013; Kahn, 2019). While some emerging research has investigated the impact of the novelty effect on this motivation (Huang, 2020), there are compelling arguments across the body of VR/AR/XR and Game Base Learning literature that emphasize the increased sense of presence and co-presence that is reported as being motivational by users of virtual environments (Di Serio, ibid; Gee, 2003; Spagnolli, 2009).

2.3.6 Team Member Profiles

Team member profiles may provide a meaningful representation or abstraction of each team member that can prove useful in the design of a teamwork tool interface. Tanis (2003) has shown that cues to identity can be inferred virtually, and the use of user profiles may help to make team members feel more connected. The individual characteristics of team members may also be useful profile indicators for a teamwork tool and Salas, et al. (2005) have shown that good team makeup can introduce internal supporting mechanisms within a team. Team member profiles may include contextual data that aids other teammates. An example of this might be enabling team members to understand the strengths of individuals within the team, or to recognise where certain teammates might encounter difficulties. This is especially helpful in a transdisciplinary team environment where assumptions about team member experience can obscure relevant skills, which limits the team's potential to achieve synthesis.

2.3.7 Team Member Roles and Distributed Leadership

Salas, et al.'s work examines team roles to consider the impact of roles on team function. They found that supporting different roles and responsibilities can establish team mission objectives and norms within a team and foster team familiarity by building affiliative associations. They caution on the need to consider the environmental context where teamwork takes place as disturbances reduce team cognitive efficiency. This is a subject of particular interest in hybrid teamwork where the environment is distributed and heterogeneous. Team roles can be fluid in transdisciplinary teams, and this is a common approach in our CHARM-EU cohorts. Distributed leadership is an interesting lens through which to consider hybrid transdisciplinary teamwork, as DL depends on the agency and accountability of each team member (Curtis, 2024).

2.4 HCI / State of the art

It is important before proceeding further, to define the term XR for the reader and to clarify the definition used in this research. The term Mixed Reality has been represented as MR and XR in popular parlance. Recent usage has started to include the term Extended Reality (represented as XR) as the use of MR has been picked up as a product branding term by Microsoft for their HoloLens platform. Many popular media publications use the terms interchangeably, and semantically speaking they represent the same concept. Mixed Reality is a continuum of technologies ranging from Augmented to Virtual Reality (AR and VR). Flavián et al. (2018) describe this continuum as ranging from AR experiences that are layered on top of the real environment, to completely immersive VR experiences that obscure the real world by situating the user within an entirely custom environment. The most promising band of this spectrum, and a goal of the current research, focuses on Mixed Realities that are midway between AR and VR, where we can leverage the most useful affordances of each while avoiding discussions relating to particular platforms or compute paradigms. XR represents a significant improvement in our ability to communicate thanks to these unique affordances.

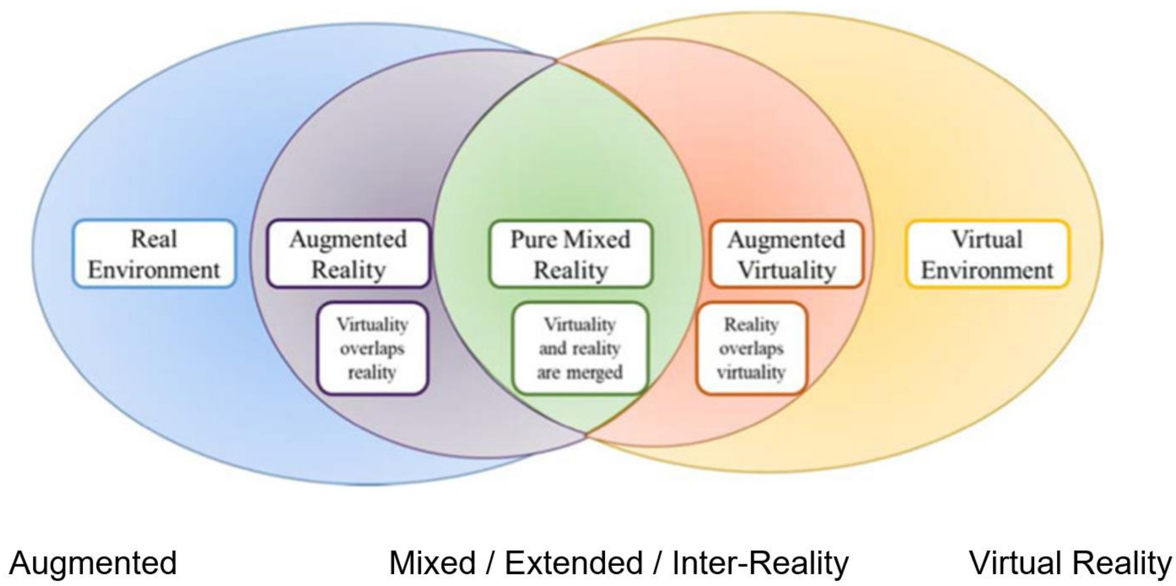


Figure 2-4. Flavián et al. (2018) conceptualization of XR. [Sub-titles added]

Our use of the term XR in the current research may confuse some readers that anticipate a traditionally technology informed view describing shared 3D environments. In a team context, the sharing aspect of XR is essential to our definition, however the particulars of technology platform are less relevant to our study. The current study began with such a technology informed perspective but moved towards a more abstract conceptualization for XR to describe any tool that scaffolds a shared cognitive space which can extend the realities of team members. This pivot occurred following student feedback during our design cycles, and we discuss its impact later in the current research (see sections; 3.4.1, 4.6.9 and 4.7.6 for details). In practical terms, the current research relies on paper protypes and web interfaces that extend aspects of cognition to support intra-term sharing and feedback within our interventions. See Chapter 4 'The Design Process', for a detailed discussion of these and particularly the design cycle reviews in sections 4.6.9 and 4.7.6.

2.4.1 XR

The notion of a conceptual space that exists beyond our everyday experience has arguably been with us since our pre-history. We see it in the realms of gods and of legends that were crudely rendered by the first artists. Such worlds have a conceptual structure that the peoples of that time would have easily recognised, but it was not until the invention of perspective in Renaissance Europe that we began to develop any formal language with which to accurately describe the structure of these imagined spaces. Art of the period resulted in what art historian Jurgis Baltrušaitis (1977) has referred to as a "multiplying of artificial worlds". Renaissance artists developed rules for the creation of such worlds and in so doing, gave the artist a new kind of control over their work. Contemporary conceptual spaces have come a long way from those prehistoric or even Renaissance works, but they are still realms that exist beyond our normal senses. They are rich and fascinating spaces that offer new, even previously unknowable insights and wonders. The first consumer headsets combined with early broadband connections made this apparent to those who were paying attention, and the potential of this technology to support distance education was promoted at the time by scholars like Daniel Mellet-d'Huart, (2012). XR is a novel technology, and novelty has been associated with increased creativity (Byrne & Tangney 2010;2014) and is noted as a source of innovation in education (Dahm, Rowan Byrne, Rogers, et al., 2021).

Scholars and professionals have a large corpus of research to draw on when engaging in XR studies, from interface and user experience design (Myers, et al., 2000; Inverardi & Tivoli, 2009) to information architecture challenges (Rosenfeld, 2015). Human Computer Interaction (HCI) studies typically examine either interaction models or architectural models (Beaudouin-Lafon, 2000), and both approaches hold value for this current research. Mixed reality has enjoyed a considerable jump in popularity in recent years, from consumer and professional retail to academic studies, we can safely say that we have moved well beyond the 'Virtual Winter' of XR development during the 2010's. Searching Science Direct for articles relating to 'virtual reality', 'augmented reality' and 'mixed reality' shows a year-on-year increase for each of these terms over the last twenty years.

In March 2021, Microsoft launched the Microsoft Mesh platform[1]. Mesh allows developers to build immersive multi-user, mixed reality applications. It is a huge platform that simplifies the route to market for XR developers by combining developer tools, application hosting and all of the Microsoft Azure cloud functionality, including AI and blockchain services. It is reasonable to assume that Microsoft sees a future where XR will integrate with their other productivity tools and their strategic focus is clearly on XR for business. Other big household-name technology companies are either already on the path to XR or are not far behind. Companies like Google, Facebook, IBM, Sony, Valve and many others have been busy developing XR hardware and software for their ever-growing user base. Facebook is also a major player in the space, beginning with their purchase of Oculus in 2014 and growing steadily since. Facebook's XR focus is aimed at the consumer space, but their mixed reality strategy also includes business customers via Facebook Workplace.

Despite the growth of academic articles in XR, the practical use of XR in higher education has been slower to progress. Klimova (2018) examined the user of Augmented Reality in teaching practices and showed that the number of programmes which included the technology were surprisingly low. Its potential is obvious to those who experience it and a wonderful example of this is Martín-Gutiérrez, et al.'s (2020) fascinating work which looked at a practical application of AR to teach acoustic guitar and music theory. Where XR is used in education, it tends to feature primarily as a minor activity or a show-and-tell piece for courses in New Media, Creative Media, Multimedia, Visual Computing and Computer Graphics. Deeper integration into course content is unusual, although there are efforts being made in Health Informatics and Biomedicine to leverage the unique affordances of this technology (Klimova, 2018). Biomedicine and Medicine have seen especially substantial progress thanks to XR's ability to allow delicate practice without the danger of harm, for example, in laboratory and surgical training (Palter & Grantcharov, 2014). XR use in curricula appears to be more popular in the United States and Martín-Gutiérrez et al. (2015; 2017) produced a thorough review of the most popular applications which primarily featured performance training and job-aid styled tools for engineering students. Other scholars have focused on establishing protocols and a framework to support this innovative technology in the classroom, for example, Kommetter and Ebner's (2019) Pedagogical Framework for Mixed Reality in Classrooms.

Regarding mixed reality's potential to support teamwork, less work has been done. This is not surprising given the high bandwidth needed to access networked virtual spaces, something that has only become readily available in recent years. However, the potential is well recognised and recent studies such as Sullivan, et al. (2017) and Salvetti, et al. (2018) have built on the work of Merchant, et al. (2014) to examine the affordances of XR that can support teamwork.

2.4.2 CSCW

Computer Supported Cooperative Work examines interdisciplinary group activities mediated by information technology. It takes a design-based approach to understand and produce tools that can support cooperative work. The term dates from Irene Grief's first usage circa 1984 (Grief, 1988; Schmidt & Bannon, 2013) but the background of CSCW can be traced back to the earliest days of computing, when the first network protocols were established. The designers of those early systems understood that computer networking involves people. Indeed, the earliest computers required many operators. This can be seen in deign choices that are still with us today such as human readable addresses, or the use of action verbs terminology to describe various functions in computer programming languages. Since then, the field has grown to include many other aspects of human computer interaction (psychology, interface design, etc.) and communications studies. Contemporary CSCW scholars have focused on collaboration through tools like video-conferencing (Denstadli et al, 2012) and are now beginning to turn their attention to mixed reality, such as the aforementioned work of Martín-Gutiérrez, et al., on Augment Reality and Virtual Reality in education (2017).

2.4.3 Remote Collaboration

Remote collaboration is becoming increasingly common in the modern workplace (Bloom, et al., 2015; Mas & Pallais, 2017; Choudhury, et al., 2019). This phenomenon was already in effect well before the events of the COVID-19 pandemic and there has obviously been a large jump in the numbers of workers and students engaging in remote work since that time. Remote work has established itself as a solution for many businesses. While we will likely return to the office and the classroom in large numbers eventually, the ability to work remotely is no longer unusual for any professional or educational projects. Companies are ahead of the academy here, but academic institutions are finally catching up due to the sudden need to adapt. Solutions such as hybrid curricula are steadily making ground and allowing for greater mobility and flexibility for students by recognising that individual circumstances mean there is a need to interact in different modes. Employees have become used to this new way of working and recent polls of knowledge workers report a sharp increase in preference for working remotely. Students are sure to follow and while there are of course limitations to remote work, there are approaches and best practices that mitigate these considerably. New tools like XR offer a way to move beyond some of these limitations thanks to their affordances for richer communication channels that allow for deeper and more meaningful human connections.

2.4.4 Social Presence

Social presence can be described as the feeling of being there with somebody else. The term represents that feeling of being connected to another person in a social situation. Short, Williams and Christie (1976) popularized the term when using it to explain their Social Presence Theory, wherein they claimed that communication media afford varying degrees of social presence based on their ability to transmit social cues. Social cues are those countless little expressions, either verbal or non-verbal (and frequently subconscious) acts that we employ to indicate to others how engaged we are with a social situation. Social presence is relevant to technology-mediated teamwork due to long standing claims that technology-mediated communication modifies communication and may influence interpretation (McLuhan, 1967). Reading a social cue can offer some insights into the intensions of others (Phillips, et al., 2011) and they have been shown to help establish trust (Xin, et al., 2016). However, the wide variety of factors influencing interpretation of social cues has complicated the study of social presence and researchers have adopted various perspectives when defining it. Experience of others as real people, a sense of group acceptance and integration, awareness of social protocols, awareness of co-presence and engagement with others, experience of engaging with something/someone/another, self-actualization and a variety of associated themes have been proposed as lenes to study social presence. Our review uncovered forty-six definitions and the most common relate to experience of others as real people, self-actualisation and a sense of group acceptance and integration.

Source	Dimensions	Definition
Abdullah, 2004	Singular	Experience of others as real people
Arbaugh, et al., 2008	Multi-dimensional	Sense of group acceptance and integration
Belderrain, 2006	Multi-dimensional	Awareness of social protocols
Bente et al., 2004	Multi-dimensional	Awareness of co-presence and engagement with others
Biocca, et al., 2001a	Singular	Experience of engaging with something/someone/another
Biocca, Harms, & Burgoon, 2003	Multi-dimensional	Multi-dimensional, including cognitive, affective and behavioural components
Gooch & Watts, 2015	Singular	Mutual awareness and reciprocity
Kehrwald, 2008	Multi-dimensional	Literature based meta-analysis
Blascovich, et al., 2002	Singular	Experience of others as real people
Cummings & Bailenson, 2016	Singular	Regarding medias capacity to support SP
Dikkers et al, 2012	Multi-dimensional	(1) Affective Association (AA); (2) Community Cohesion (CC); (3) Interaction Intensity (II); (4) Knowledge and Experience (KE); and (5) Instructor Involvement (IV)
Garrison, 2009	Multi-dimensional	Sense of group acceptance and integration, plus self-actualization
Garrison, et al., 2000	Singular	Self-actualization
Gibson, 1979	Singular	Sense of being in an environment
Goffman, 1959	Singular	Experience of others as real people
Gunawardena, 1995	Multi-dimensional	Self-actualization, plus experience of others as real people
Gunawardena and Zittle, 1997	Singular	Experience of others as real people
Hassanein and Head, 2007	Singular	Experience of others as real people
Heeter, 1992	Singular	Experience of others as real people

Jung et al, 2002	Singular	Scaffolded learning interactions
Kang et al, 2007	Singular	Sense of group acceptance and integration
Kim, 2011	Multi-dimensional	Experience of others as real people, plus degree of affiliative associations
Kozan and Richardson, 2014	Singular	Degree of affiliative associations
Lee, 2004	Multi-dimensional	Experience of others as real people, plus NPCs and objects
Lombard & Ditton, 1997	Singular	Focused attention
Loomis, 1992	Singular	Sense of being in a remote environment
McCreery, et al., 2015	Singular	Social Presence as team development
Moreno and Mayer, 2004	Singular	Experience of others as real people
Ogara et al., 2014	Multi-dimensional	Sense of group acceptance and integration
Palmer, 1995	Singular	Sense of presence in an interaction and awareness of the relationship that is creates
Picciano, 2002	Multi-dimensional	Sense of group acceptance and integration, plus ability to interact
Remesal and Colomina, 2013	Multi-dimensional	Sense of group acceptance and integration, plus Scaffolded learning interactions
Rourke, et al., 2001	Singular	Self-actualization
Russo, 2000	Singular	Experience of others as real people
Sallnäs, 2005	Singular	Experience of others as real people
Shin, 2013	Multi-dimensional	Experience of others as real people, plus degree of awareness of the ICT tool
Short et al., 1976	Multi-dimensional	Experience of others as real people, plus degree of affiliative associations
Slater & Wilbur, 1997	Singular	Regarding medias capacity to support SP
Sung and Mayer, 2012	Singular	Experience of others as real people
Swan and Shih, 2005	Singular	Degree of affiliative associations
Tu, 2002	Singular	Experience of others as real people
Tu and McIsaac, 2002	Singular	Experience of others as real people
Walther, 1992	Singular	Experience of others as real people

Whiteside, 2017	Singular	Social Presence as a literacy
Yen and Tu, 2008	Singular	Experience of others as real people
Zhao, 2003	Singular	Shared co-presence

Table 2-1. Definitions of Social Presence

It is useful to untangle the tapestry of social presence literature a litter further however before thinking about how it may be leveraged to support teamwork. Short, Williams and Christie's (1976) original definition defined social presence as a property of the communications medium, or it's capacity to transmit non-verbal social cues. The view persisted for nearly thirty years until Biocca, Harms, & Burgoon (2003) reframed the interpretation to include human perceptions by defining it as "the sense of being with another in a mediated environment". By emphasising that social presence is experiential rather than some fixed property of a medium, the authors reframed the conversation to consider human agency and subjectivity as influencing factors and showed that social presence is dynamic and evolves over time. Their argument is social constructivist and proposes that humans cognitively construct social presence by interacting with others. This definition is still rather one sided though and more recent work by Gooch & Watts (2015) has emphasised mutual awareness & reciprocity, and stress the subjective nature of social presence. Gooch & Watts definition holds that the level of social presence experienced by individuals can change during interactions and any efforts to measure it need to consider the context. Gooch & Watts' definition most aligns with a social constructivist and distributed cognition perspective of teamwork. Framed thusly, the co-creation of a team artefact such as a team charter, project plan or similar may be understood as a process of knowledge transformation through team learning. Contemporary research on social presence focuses on user perceptions of AI as social actors (Oh, Bailenson, & Welch, 2018), which is beyond the scope of the current research.

Given the immense variety of social cues that humans express, it is difficult for any individual technological medium to transmit all social cues equally. Many will be blocked or filtered out of the conversation due to the limitations of the technology in question. Take for example the common social cue of eye-contact. A text-based chat between two users might be very engaging, and both may decide to give it their full attention. But neither will perceive this engagement from their partner in any way other than the expressiveness of their response in the chat channel. The text medium cannot transmit the concept of eye contact, it simply is not relevant and is therefore lost. A videochat will obviously provide a richer experience thanks to the multimedia nature of the communication, and we can see that videochat has a better potential to transmit this type of social cue. However a videochat also has its own limitations, for example, the need for users to remain in place in front of a camera necessarily supresses any potential proxemic negotiations occurring between participants. Mixed reality experience offer the potential to transmit a wide variety of social cues, and one might expect therefore that they can offer a deeper sense of social presence to users. We can recognise the need for richer connections when communication is mediated and tools designers that are cognisant of this should look for opportunities to empower rather than disempower expressivity in communication channels.

Daft and Lengel (1986) leveraged the notion of social presence to develop their Media Richness Theory (MRT). MRT classifies a medium in terms of its "richness". Richness defines rate of information or learning that can be expressed through a medium. It includes factors such as the ability for a medium to transmit multiple social cues simultaneously, the potential for rapid feedback between users and the potential for natural expression by users. MRT frames media on a scale from lean to rich, with simple or static media on the lean end of the scale (e.g., unaddressed documents) and getting progressively "richer" or "warmer" as the information bandwidth increases. Multi-modal communication affords more detailed information to be transmitted and received. Daft and Lengel placed face-to-face communication at the top, or richer end of their scale. By this they tell us that they view face-to-face communication as the most information rich mode of interacting. Subsequent research has built on this premise by examining social presence throught different media on specific types of communication, e.g. feedback (Keil & Roy, 2002) indicating that richer media assists the receivers understanding considerably. This body of research examines presence in a virtual context but despite the current focus on immersive technologies full immersion may not be necessary to reap the benefits of XR's potential to promote a sense of connection. Hayes, et al. (2022) remind us of Heeters (1992) claim "that an environment in which one's own body interacts with a blended physical and virtual environment, yields higher levels of presence than one where the user is being embodied by an avatar". This aligns well with distributed and embodied cognition arguments, where experience of presence arises out of a complementary blend of multimodal interactions mediating the virtual and real worlds.

Social presence continues to be an increasingly popular lens with which to view engagement and the quality of connections between users of virtual spaces (Shirish, 2018). In the business world, the concept of Social Presence is in favour with high profile companies such as Meta who have been using the term in promotional material since the Oculus Connect 6 conference in 2019. It is evident that Meta plan to position their XR platform as a space that offers a social connection through a deeper sense of social presence for their users, however this understanding is not new and such sharing has been recognised in less immersive forms for many years within large companies that deploy enterprise chat applications across their organisations.

2.4.5 UX

Green and Petre's (1996) study of usability and how it should be analysed, produced what they refer to as a set of "Cognitive Dimensions". Their research presents an evaluation technique for interactive devices that considers their interpretation by a user. A task driven perspective allows them to think about design features and how these map to operations. The mental representation held by the user is a mental model of how an interface should behave (Mohamad, et al., 2010) and factors such as the closeness of mapping (interface representation to resulting function) can determine whether usage is easy or hard. Green and Petre's work has influenced our own, particularly in our qualitative analysis of student feedback regarding technical hurdles. Their set of cognitive dimensions have informed additions to our deductive codebook, used during the analysis of our second and third design cycles. Don Norman's (1998) work on affordances is an insightful comment on human perception and his work has influenced Distributed Cognition of Teams researchers Ann Blandford and Dominic Furniss's (2005) research, which informs much of our own work.

Muller et al. (1998) showed that a variety of factors can support or hamper one's ability to interact with a software tool. Their research looks a user centric view to describe how system status, user control and freedom, consistency and relevancy of information, error recognition and recovery, and task and work supports all contribute to usability. Countless other researchers have looked at interface design and interpretation, and our research considers the views of several, (Betts, 2016; Ceballos, 2016; Cortes, 2016; Hudelson, 2017; Hunter, 2016; Ravasz, 2016; Punchcut, 2016; Shanmugam, 2015; West, 2015). Many heuristics that have been proposed to assist with this type of team activity, can be seen as a response to information architecture challenges, where the rules for "labels, menus, descriptions, visual elements, content, and their relationships with one another create an environment that differentiates these experiences and facilitates understanding", (Rosenfeld, et al., 2015). These are important considerations in a socio-technical study or for that matter in any technology-mediated experience. We include UX in our collection to reflect this importance and emphasis the need to address the theme when developing robust solutions beyond intervention prototypes. Our own study does not place UX in a central role due to the considerable volume of existing research that already speaks to the themes introduced in this section. Our purpose in the current study is to develop heuristics supports for XR mediated transdisciplinary teamwork and we recognise the influence of UX in this regard, but our research places a focus on the learning experience (LX) impact of UX rather than technical aspects which are thoroughly covered in the related literature.

2.4.6 Critical Perspectives of Technology in Education

While XR and other enriched media communications software offer significant opportunities to scaffold learning, collaboration and perspective-taking, their adoption in higher education is not without substantial challenges and limitations. Practical integration has often been superficial, with XR deployed as isolated or "show-and-tell" activities rather than embedded into core curricula, limiting its ability to support sustained learning and transdisciplinary skill development (Klimova, 2018; Martín-Gutiérrez, et al., 2020). This reflects a broader novelty effect, where the initial excitement around technology can enhance motivation and engagement (Byrne & Tangney, 2010; 2014; Dahm, et al., 2021) but may not translate into long-term educational impact without careful curricular integration (See sections 2.4.1 XR, 2.4.2 CSCW and 2.4.3 Remote Collaboration). Technology-mediated communication can reduce social cues, alter the intelligibility of messages, and impose additional cognitive load on learners that creates barriers to effective team cohesion and shared understanding (Short, Williams & Christie, 1976; Walther, 1994; Hancock, 2001; See section 2.4.5 'UX'). These issues are compounded by ethical and inclusivity considerations: XR platforms may reinforce existing stereotypes, privilege particular interaction modalities, and assume universal access to high-bandwidth technologies, which may marginalize certain learners or exacerbate digital inequities (See section 6.4 regarding limitations of the study). In addition, XR adoption carries sustainability considerations as hardware production, energy consumption, and device obsolescence contribute to environmental impacts that are rarely addressed in curriculum design or institutional planning (See sections 2.4.2 CSCW; 2.4.3 Remote Collaboration).

XR and enriched media in higher education present additional challenges related to pedagogy, learner experience, and ethics. Effective integration relies on educator readiness; instructors must understand and intentionally apply XR tools to avoid superficial or inconsistent implementation (See section 3.8 Validity and Reliability; Chapters 4–5 The Design Process). Cognitive load is a key consideration, as immersive environments with complex interfaces can overwhelm learners, reducing engagement and learning effectiveness (See section 4.8.3 Intervention Design). Assessing learning outcomes in XR-mediated contexts is also complex, particularly for higher-order skills, collaboration, or conceptual understanding, often necessitating exploratory or qualitative evaluation rather than standardized metrics (See section 3.5.2 Quantitative data). Epistemological and pedagogical fit is critical: XR experiences that replicate real-world spaces may not fully leverage the medium's potential to support critical thinking, reflection, or knowledge co-construction (See sections 1.1 Background and Context; 4.6.3 Intervention Design – Cycle 1). Privacy and ethical considerations further underscore the need for careful, human-centered design, including minimal data collection, anonymization, and protections for participants (See section 4.8.3 Intervention Design). This study addresses these issues through iterative, educator- and learner-informed design cycles and theoretically aligned, purposefully scaffolded learning experiences.

2.5 Conclusion

Virtual environments offer benefits to the learner by increasing "the number of simultaneous communication channels and, hence, the more rapid socialisation of participants in terms of shared meanings of symbols and signals resulting in a greater degree of shared reality", (Blascovich, 2002). Multiuser XR has been shown to promote a sense of social closeness between users and XR and insights from the field of XR development offer potential to mitigate the barriers to communication that remote working brings. The following research questions have emerged from a review of relevant literature in the investigation of this topic.

- **RQ1.** How might we design XR systems that support novice hybrid transdisciplinary teamwork?
- **RQ1a.** What design heuristics can be used for such applications?
- **RQ1b.** How can the design heuristics be evaluated when implemented in a test artefact?

Recent advances in the fields of Augmented and Virtual Reality would suggest that XR can be useful in addressing these issues. As XR tools continue to improve over time, we can easily imagine their increased adoption and utility in the workplace and in the classroom. This new medium may also offer potential to support broader teamworking problems and remote learning in many areas of education and business. Indeed, adoption has already begun as can be seen with solutions such as Microsoft's Holographic Mixed Reality Technology Solutions for Business platform, HoloLens and the Microsoft Azure Mixed Reality Services(1). As remote and distributed teamwork become increasingly popular, student teams will need to develop the transversal skills that employers value so highly, including empathy, communication and collaboration skills. The increasing popularity of hybrid work introduces new pressures and challenges for teams, particularly with respect to a lack of connection with teammates and an increased sense of isolation for team members. These challenges are amplified within transdisciplinary teams due to the communication and process hurdles that they must work to overcome. Transdisciplinary teams represent a “hard type” and any interventions that works for such teams should work well for traditional teams too. XR affordances can address the challenge by providing a virtual canvas for purposeful symbolic interactions, coupled with it’s potential to promote a sense of social presence that helps teams become closer and more effective in their coordinated tasks. Distributed cognition theory offers a powerful lens with which to view team activities and leveraging this perspective can inform the design of a computer supported collaborative team interface for a mixed reality tool. A pragmatic, student centred, design-based research approach is the most appropriate method to research such an innovative and emerging field, and Activity Theory is a useful analytical framework to study a new field where many of the rules and protocols for interaction are still being established. All knowledge working teams can benefit from XR technology to improve their teamwork, and transdisciplinary teams in particular can take advantage of the unique affordances of virtual environments to help when establishing their own processes.

This current chapter collated landmark literature describing how XR hybrid transdisciplinary teams may be supported. The review is centred on three categories of supports which are summarised below for clarity, and later presented and discussed in Chapter 4, Section 4.5 ‘Cycle 0: Literature Review’.

UX

- General best practice guidance for UX

Teamwork and TMMs

- Team needs (Tuckman, 1965),
- Feedback between members (LaFasto & Larson, 1989),
- Team roles (Salas, et al., 2013)
- Team communication (Katzenbach & Smith, 1993)
- Supports for team mental model building (Mohammad, et al., 2010)

Distributed Team Cognition

- DCog (Hutchins, 1965)
- DiCoT (Blandford and Furniss, 2006; Webb, 2008)

3 Chapter 3. Methodology

3.1 Introduction

Our study began by collating landmark literature-based heuristic supports for novice hybrid transdisciplinary teamwork and team cognition before progressing to develop our own additional heuristics that were based on participant feedback relating to our design-based interventions. The complete set of heuristics were implemented and tested in a bespoke exemplar tool.

Our process addressed our research questions by examining established team science best practices, and related student feedback, to determine how we might best design XR systems that support novice hybrid transdisciplinary teamwork (RQ1). These were translated into design heuristics (RQ1a) that we implemented and tested using our exemplar tool (RQ1b). This was a protracted, iterative process that consisted of multiple steps over each design cycle, and we describe our approach in the current chapter.

RQ1. How might we design XR systems that support novice hybrid transdisciplinary teamwork?

RQ1a. What design heuristics can be used for such applications?

RQ1b. How can the design heuristics be evaluated when implemented in a test artefact?

Once we understood our problem space and how we intended to address it, we were able to begin designing our prototype exemplar artefact tool that incorporates our full set of heuristics in our final design cycle. Reaching this stage required an iterative refinement of our ideas and the heuristics as the research progressed. The current study employs a design-based research (DBR) approach beginning with an exploratory design cycle that enquired into student attitudes regarding the potential for XR affordances to support teamwork related transversal skills development. This sensitising phase of our study was the first iteration in a series of design sprints that employed a feed-forward process to inform each subsequent design cycle. Following such a process allowed us to segment our study into phases that move from a high-level investigation of a “broad problem space” and refining the focus to a “narrow problem space” before beginning to consider appropriate “solution space”, in a process that ascended the study from the abstract to the concrete (Marx, 1973).

Qualitative research focuses on the how people interpret their experiences (Merriam & Tisdell,

2016) which makes it an appropriate approach to study the nuanced inter-personal interactions within teamwork. The cyclical nature of a design-based research study offers the chance to begin with an exploratory or sensitising phase to clarify the issues that subjects experience in hybrid transdisciplinary teamwork and the current research began with such an exploratory design iteration in our cycle 1 intervention and analysis.

3.2 Participant Recruitment

Our study worked with five cohorts of students across three design cycles (See table 3-7 for details per cohort and per design cycle). In all cases, participants were purposively sampled due to their expressed interested in hybrid transdisciplinary teamwork and all consenting students were included. In our first cycle, the participants were prospective transdisciplinary masters' students who had elected to take part in an online transdisciplinary focused one-week winter school. These students were in the final year of their undergraduate programmes. The next two design cycles both engaged two cohorts each, a first semester group and a capstone group, across four programmes of the CHARM-EU M.Sc. in Global Challenges for Sustainability. We describe each design cycle independently in Chapter 4 "The Design Process", sections 4.6, 4.7 and 4.8. The majority of these students were recent graduates coming directly from undergraduate, or in a few instances from masters programmes, however cycle 3 also included one mature student with a professional background.

In each case, students were identified as having a strong interest in our theme due to their participation in either the winter school or M.Sc programme. As the researcher was involved with the winter school delivery, the gatekeepers were well acquainted with our research and it's alignment with the winter school theme, and readily agreed to grant access. This cohort engaged entirely online either in the Mozilla Hubs or MS Teams environments.

In the remaining cases, the researcher was a member of the teaching team and worked with the gatekeepers to deliver the interventions in a format that complimented the M.Sc programme content by prefacing each session with a brief teamwork lecture. Students were made aware that the research was distinct from their coursework, that the activities were unassessed and that their participation was optional. In all cases, ethics to engage with students were confirmed well in advance of the sessions. Timing was not difficult for the winter school group, but the subsequent iterations were scheduled to start at the beginning of the first semester and capstone projects, which require that we engaged with ethics before the summer recess to be ready for commencement of design cycles at the start of the new academic year. In all cases, students were invited to participate in the interventions at least one week in advance by email which clarified their rights, explained the context and relevance of the study and asked for their consent to take part in the research. Consent was collected using Microsoft Forms within the securely encrypted Trinity College Dublin Teams environment. Interventions with these students took place in a hybrid setting within the CHARM-EU hybrid classroom network. Teams were generally partially co-located with small groups in each location, but this was not always the case as some teams only had one member at a particular location and others co-located elsewhere. Follow up focus sessions were conducted virtually in MS Teams calls in all but one case. In this extra case our discussions were held in person, in a traditional focus group setting in the Trinity College Dublin CHARM-EU hybrid classroom.

3.3 Literature Scoping approach (Design "Cycle 0")

The scope of the literature review was defined during a series of dialogues over the course of several months of discussion between the researcher and supervisors, during which time a conceptual framework was developed to identify thematic areas that are of relevance to the study. Development of a conceptual framework allows researchers to systematically explore a phenomenon (Maxwell, 2012; Reynolds, et al., 2012; Brownell and Kloser, 2015; Ravitch and Riggan, 2016), while adding structure and guidance when approaching the study (Miles, et al., 2014). With each newly identified area of importance in our review, relevant sub-topics became apparent, and these were recorded as branches in a concept map. This allowed branches to be easily cross connected to other branches.

During the design of the conceptual framework that informs our study, key journals were identified and selected to ensure rigour by focusing on peer-reviewed outlets with established relevance to educational technology. These included Computers & Education (Elsevier, 1976–present), International Review of Research in Open and Distance Learning (Athabasca University, 2000–present, open access), Journal of Computers in Education (Springer Nature, 2019–present), Internet and Higher Education (Elsevier, 1998–present, formerly Microcomputers for Information Management), and Postdigital Science and Education (Springer Nature, 2019–present). All journals are indexed in Scopus and cover interdisciplinary areas of education, computer science, and social sciences, supporting the conceptual framework used to delimit the search.

Developing a conceptual framework was a foundational step towards producing our heuristics during the literature scoping review by establishing a design "cycle 0" where the literature review outputs set the initial focus of our first official design cycle intervention with students. Beginning with a conceptual framework was an effective way to organise our views as a first step towards developing our heuristics. This framework was produced in the Coggle mind mapping tool to explore the problem space and highlight connections between themes. As such it was an instrumental step in collating the heuristics from diverse literate relating to user experience, teamwork and distributed team cognition, all of which are encompassed by to our theme of supporting novice hybrid transdisciplinary teams. Our categories of heuristics were mapped as branches in the conceptual framework, with many sub-branches and connections between branches being revealed in this way. The following keywords were developed during this process; “Design Based Research”, “Novice hybrid teamwork”, “Mixed Reality”, “XR”, “Distributed Cognition”, “Activity Theory”, “Transdisciplinarity”, “21st Century skills”, “Educational Technology”.

For practical reasons, literature searches were limited to English language results. Scopus, Science Direct, Google Scholar, and relevant conference proceedings have provided a considerable body of fascinating papers, and one can easily recognise the growing volume of research activity focused on XR. This is also evidenced by a rapid increase in the number of publications in recent years. The terms Mixed Reality, Virtual Reality and Augmented reality were each noted as increasing in popularity, with year-on-year growth that has continued during the period of our study. As we progressed toward the end of our project, it was appropriate to reflect on this growth to gauge current potential interest in our research. The following updated figures from Science Direct illustrate this continually increasing interest in the field.

- “Mixed Reality” in 2024 resulted in 17,788 results versus 2021 which had 13,167 results.
- “Virtual Reality” 2024 resulted in 14,409 papers versus 9,343 in 2021
- “Augmented Reality” 2024 = 11,481 papers versus 6,164 papers in 2021.

"Distributed Teamwork" was considerably less popular but still shows increasing interest with 1,443 results versus 965 results for a Science Direct search over the same period. The term "Teamwork" resulted in surprising few papers from our perspective but also indicates increasing interest with 4,766 papers in 2024 versus 3,496 published in 2021.

At a more focused level, the node names within our conceptual framework doubled as search terms, and grammatical / semantic variations of each were applied to cast a wider net, (Kitchenham & Charters, 2007). For example, “approaches to teamwork”, “teamwork approaches”, “types of teamwork”, “teamwork methods”, etc. all carry similar meaning but using just one would limit the number of relevant results. Broadening the search in this way has helped with the development of theory-building (Finfgeld-Connett & Johnson, 2013) and allowed us to identify new sub-branches in our concept map.

Newer papers have been favoured where the subject leans towards a technical domain, although older technology papers were also included for context where relevant. No such limits were applied to literature searches relating to non-technical topics such as teamwork or distributed cognition theories. A general search strategy for identifying relevant literature has been helpful and Boolean operators were employed extensively to conceptually link topics. i.e., “Distributed Teamwork” AND "Mixed Reality" to flexibly link both terms.

Practical constraints further shaped literature inclusion: searches were limited to English-language publications, and newer work was favoured in technical domains such as XR or mixed reality, with older publications retained only where necessary for contextual grounding. No date restrictions were applied to teamwork or distributed cognition sources. Non-English publications, older technical papers lacking contextual relevance, and topics falling outside the conceptual-framework branches or keyword set were also excluded.

3.4 Overview of Design Approach: Activity Theory-Informed Design Based Research

3.4.1 Design Based Research

This current research views team learning through a socio-cultural-cognitive lens, and as such incorporates three dominant views from the learning sciences (LS), i.e. an integrative view with cognitive-psychological, social-psychological and cultural-psychological perspectives. Additionally, learning sciences are concerned with the critical analysis of learning interventions and practical solutions that are rooted in local context, which are central themes of our study. This situates our work well within a learning sciences tradition, which implies the use of appropriate methods. DBR is common in LS and suits our study particularly well thanks to its iterative exploratory approach based on cycles of design, testing, evaluation and reflection. In a study such as ours, where the purpose is to develop design heuristics that can support hybrid transdisciplinary teamwork, the unique mixture of subjective and objective elements within the socio-technical problem space means that a pragmatic approach offers the best opportunities to find useful solutions. Approaching such a problem with a Deweyan pragmatic attitude allows us to sidestep “contentious issues of truth and reality” (Feilzer, 2010) by framing the problem in terms of many truths rather than one single truth (Dewey, 1958). This is an appropriate mentality to adopt when considering such a nuanced and complex sociotechnical problem space as online teamwork, given the complexity of team dynamics and the intersubjective meaning making that is socially constructed through the process of teamworking; and more importantly, a pragmatic approach allows us to find strategies that offer real, workable solutions. This is the aim of DBR, to understand the context and find solutions that fit and have meaningful impact (Collins, 1990; Barab & Squire, 2004), and which may hopefully be generalisable to wider cohorts. Workable solutions need not be perfect as it is the process of cyclical refinements that lead to gradual design improvements. But to determine how a study should move forward it is necessary to understand why interventions are successful or otherwise in a specific context, and Activity Theory provides an evaluative frame in this regard to inform refinements of our design from one cycle to the next.

The social nature of cognition is another reason to be pragmatic about the choice of methodological approach. Pragmatists believe the terms such as “real” or “true” cannot be understood outside of a specific context and something that was true yesterday need not be so today, (Dewey, 1958; Rai & Rupen, 2020). When examined from a constructivist perspective, this implies that concepts of truth and reality are relative terms that can only be understood through the lens of prior experience. Nuanced differences in one's experience of reality will always exist for every individual and there are distributed thoughts and processes at play in the social space that are a jumble of subjectivity, inter-subjectivity, uncertainties, and inaccuracies, and social meaning only emerges from a negotiation between groups and individuals (Prawat & Floden, 1994; Gredler, 1997). A qualitative treatment of any social phenomenal will therefore be essential. It would be remiss however to ignore the value of useful tools that fall outside the scope of traditional qualitative methods, and the use of a supporting quantitative treatment aligns well with our pragmatic perspectives by offering a chance to meaningfully enquire into a socio-technical problem while supporting the research with secondary methods.

DBR is a meta-methodological approach that recognises the value of many methodologies, and it can therefore take various forms, which complicates the conversation regarding its strengths and limitations. Cultural/psychological DBR studies and social/cogitative DBR studies both focus on different aspects of the world, and consequently aim for different kinds of goals, and it is necessary to be explicit about the goals and to highlight the limitations of any DBR work. The typically small scope of DBR studies (e.g. in a single classroom, a single cohort, or single programme) can make it difficult to generalize findings, and scholars (Fishman, B. J. & Krajcik, 2003; Engeström, 2011; Bielaczyc, K., 2013) have thus criticized the scalability of DBR due to its overly narrow focus. While it is reassuring to consider that working with a distributed student cohort may generate richer data than we might usually see in a DBR study, careful attention to avoid overreaching in our goals of the study will be the best way to have confidence in our results.

DBR has been criticized in terms of its loose approach to methodology (Shavelson, et al., 2003; Kelly, A.E., 2004; diSessa, A. A. & Cobb, P.A., 2004; Bell, P., 2004). Anticipated success criteria may influence the design and become self-fulfilling, and care must be taken to avoid a situation where we set the design focus of the learning experience, while also developing the measures of what we see as learning (Wilson & Wardrip, 2004). Including input from stakeholders and the views of a wide community can help to mitigate such an outcome. Our study included student perspectives from five cohorts, including four cohorts studying the same academic programme in a hybrid learning environment, and this aggregate of views has helped us to remain focused on our research question by emphasising the feedback of real-world hybrid transdisciplinary novices.

DBR has also been criticised for failing to consider the impact of participant agency on research outcomes (Engeström, 1987; 2000). Engeström states of DBR that it ignores "resistance and agency of learners as a source of surprise and novelty" (Engeström, ibid). If this is true, then DBR may be blind to certain divergent data. An integrated mixed methods approach can help to address this by offering supporting data. Use of a convergent design (i.e. mixed method framework) will aid when integrating these data, and DBR's cyclical nature allowed us to merge the use of instruments and compare quantitative and qualitative results, both during and across each of our design cycles. Within cycles, mixed methods were applied and findings later combined to move our design forward in a direction relevant to students needs and perspectives.

The intent of a design-based research methodology is to work towards greater understanding of a problem space through iterations of design, testing and feedback of a tool, a strategy or an intervention (Brown, 1992). This approach requires breaking the work down into a series of iterations, where each iteration aims to improve on the previous one. The output of each iteration forms the input into the next phase of the research, ultimately aiming to arrive at a new theory or framework for conceptualizing learning. Design-based research shares many similarities with Agile software development practices, in particular the concept of a production or design sprint. In software engineering, a sprint is a project management technique that helps to organise the work effort required to tackle large projects successfully. It is particularly effective where requirements of the project are in-flux or subject to change and refinement (Beck, et al., 2001). Tasks are organised into deliverable bundles that are then worked on for a set period by the team. Once the sprint iteration ends, a retrospective session is conducted to evaluate the output and determine what has been learned during the sprint. Learnings from the team are fed forward into the planning of the next sprint iteration, and the project moves ever closer towards fitting the customer requirements (Dingsøyr, et al, 2012).

Design-based research is an appropriate choice of methodology for the study of any new technology, but it can be especially effective when that technology has the potential to become a platform for the types of emergent properties that occur during teamwork (Alvarez, et al., 2015). The more important findings and realisations are only likely to emerge through a process of working with participants and the tool, to discover issues as the work progresses. This information helps to improve the technology by allowing it to be adapted to meet the users' needs more closely through a process of continual refinement. To understand the potential for a technology such as Mixed Reality to support teamwork and team learning, we must design interventions that are relevant and testable, of course, but also flexible enough to allow unexpected phenomena to emerge. Such interventions must include a plurality of voices if they are able to be considered meaningful, since without such diversity we will be unable to find a solution that is acceptable to a sufficiently large group. One single solution may never be perfect for everyone, but we can aim to develop general principles and heuristics that are “good enough” to achieve a goal. As noted, the current research includes perspectives from five cohorts of novice transdisciplinary students, and while this cannot be called a huge volume overall, it has been sufficiently large to include divergent views and surprising feedback that prompted reflective refocusing of the design direction as the cycles progressed.

The exact process that a DBR study follows will depend very much on the practicalities of the situation. There are many approaches, but they typically follow the path described by Wang and Hannafin (2005), who see DBR as being Pragmatic, Grounded, Interactive, Iterative and flexible, Integrative, and Contextual. The core feature of all DBR approaches is that the work is split into phases or cycles. Learnings from each cycle are used to improve the next phase. Given the similarity with Agile, it should come as little surprise that some researchers are already drawing parallels (Noguera, et al., 2018). Scott (2020) outlines a simple definition of a design cycle, or iteration, as a four-step process including design, testing, evaluation and reflection (figure 3-1) and we have applied this phrasing in our research to clarify our description of steps taken within each design cycle.

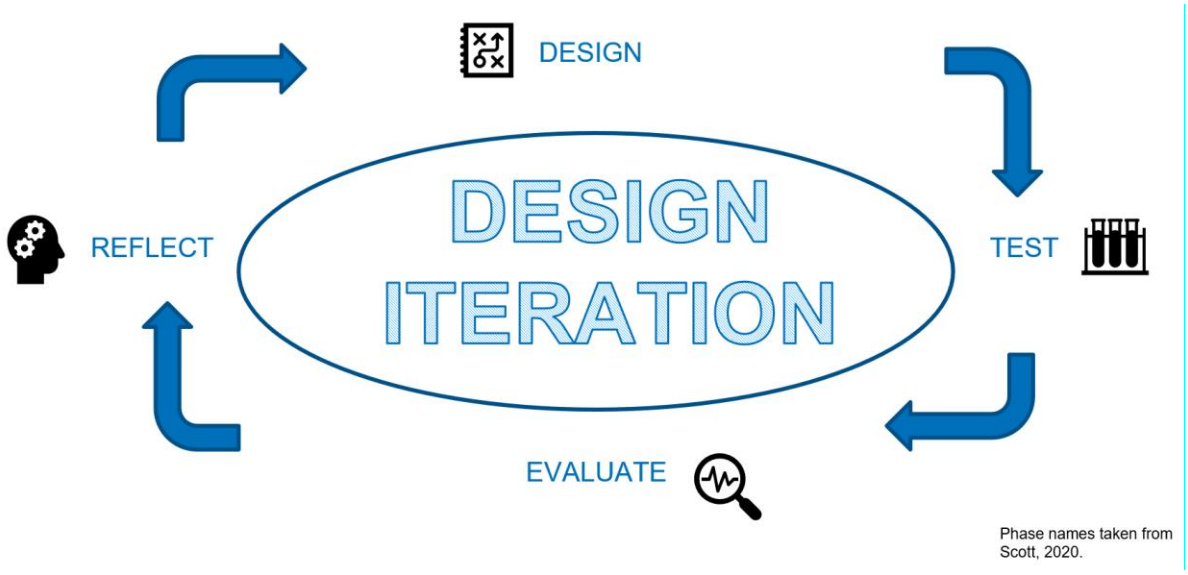


Figure 3-1. A Design Based Research loop, informed by Scott (2020).

Our Design Based Research (DBR) study included three design cycles, each of which generated insights into student views of hybrid teamwork tools. Figure 3-2 illustrates the cycles by applying Scott's terminology to describe where the phases of each cycle occurred in our study.

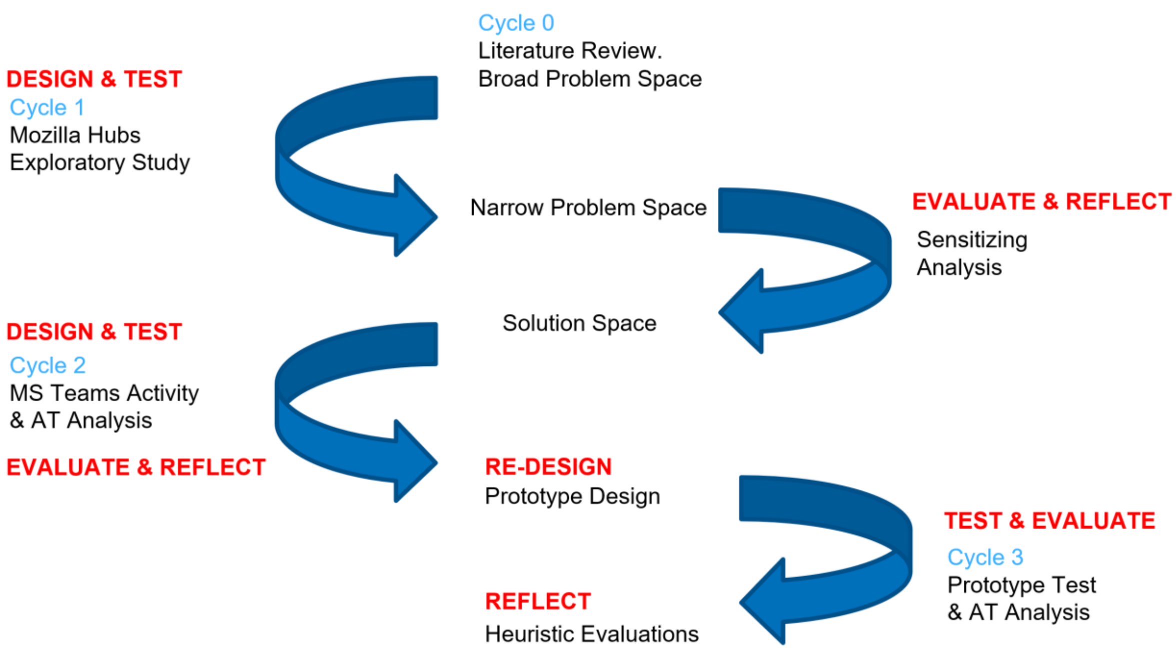


Figure 3-2. Our Design Based Research cycles.

DBR is an approach that must be open and willing to change or pivot as guided by output findings in each cycle (The Design-Based Research Collective, 2003). The current study experienced just such a pivot following our analysis of Cycle 1 student feedback. Cycle 1 data indicated that students did not value the potential of immersive XR environments to practice 21st century skills. Additionally, we identified technical hurdles which frustrated the onboarding of students to use XR tools. This required a refocusing on the part of the researchers to explore less immersive solutions and design directions within the problem space of our research questions. We explore the rationale for this pivot in more depth, at the end of section 4.6.9 'Cycle 1 Design Review', where we describe our preparations for Cycle 2. This change has tempered our expectations regarding the readiness of immersive XR for wider educational adoption, however regarding its impact on our study, a less immersive hybrid team learning experience remains compatible with the distributed cognition view of multiuser XR as an artefact to construct a shared conceptual space extending the realities of its users.

3.4.2 Learner Centred / Participatory Design

To understand the challenges most relevant to novice hybrid transdisciplinary teams, we can find no better source of information than the learners themselves. User / Learner centred design focuses on the needs of the user / learner. It employs an iterative process of design and listening to user feedback, to refine the design on each iteration in an approach similar to that of Agile Software Development and a compliment to Design Based Research. A learner centred approach can help a designer, developer or researcher to understand a problem from another person's perspective however end users are not designers and while their insights are essential, their description of the issues must be drawn out and considered qualitatively to produce useful data to feed into subsequent design iterations. Cultural Historical Activity Theory can help to inform such investigations to help categorise or rationalise learners' experiences.

We may describe the current research as a participatory design-based methodology, rather than solely user-centric. Our multi-cycle approach produced a plurality of student voices and opinions on technology-mediated teamwork which required probing to clarify the meaning of participant responses from our wide cohort of international participants.

3.4.3 Prototypes

"A prototype is a tangible, interactive representation or simulation of a product, system, or interface, typically created during the design process to test, validate, and refine design concepts and user experiences… [and] …a crucial step that enables designers and developers to explore and evaluate their ideas before committing to a final design", (The Behavioral Scientist, n.d.). Prototypes are an effective way to evaluate a proposed technical solution and our prototype that we designed to address student needs represents a vital step in the final cycle of our DBR study. The Mozilla Hubs experience in cycle 1 is a prototype intervention that provided data to begin addressing RQ1 by identifying the supports that would be helpful for hybrid novice transdisciplinary teams. Our final exemplar artefact used in the cycle 3 intervention is a prototype for the heuristics, and is itself an evolution of a paper prototype used in cycle 2 where refinements were informed by student worksheet and participant feedback during focus groups. Methodologically, the use of design cycles represents a series of prototype interventions (Bray, Hannon & Tangney, 2022) that each build on findings from earlier cycles.

3.5 Mixed Methods

Use of mixed methods has gained favour in contemporary research thanks to its way of doing 'what works' through the application of a mixture of compatible qualitative and quantitative methods (Carr, 1994; Creswell, 2012; Johnson & Onwuegbuzie, 2004; Mingers, 2001; Sale, Lohfeld, & Brazil, 2002; Tashakkori & Teddlie, 2003). Mixed methods align well with a pragmatic approach to research as it allows us to draw on a wide range of data to inform the study. This is not claiming that 'anything goes' but instead seeks to identify an appropriate method for generating data in a particular context. The concept of doing what works, allows us to produce models that are good enough to address a research question, and a convergent design permits drawing on a diverse range of data to give greater confidence in our solutions.

Malau-Aduli and Alele (2023) outline five reasons to apply mixed methods, namely, expansion of the study, benefits of complementary methods, triangulation of data and initiation to elicit divergent perspectives. Our explanation to these is discussed below under the relevant methods.

3.5.1 Qualitative data

Interviews and focus groups

Interviews are a useful tool that can help when generating primary data to identify student attitudes (Cresswell, 2012). Online interviews can follow a similar format as a traditional offline interview, but there are differences that the online medium introduces and Tuttas' (2015) recommendations for working with online interviews and focus groups have been useful in addressing these challenges through consideration of session length, connectivity concerns and ensuring that participants were comfortable. Interviews and focus groups across the three design cycles were all recorded using the Trinity College Dublin Microsoft Teams environment. This ensured privacy and encrypted storage of the videos before transcribing, after which time the videos were deleted. Our first two design cycles employed hand transcription to produce interview and focus group transcripts, while cycle 3 followed and benefited from the CHARM-EU inclusivity practice of enabling auto transcription for MS Teams sessions. This brought efficiencies but also new challenges as a small number of mistranscriptions were encountered which required the creation of two high-level, temporary inductive codes to tag the transcript during an initial review reading before returning to the video recording for clarification. This review process was developed to identify and correct transcription inaccuracies, ensuring clear interpretation during subsequent analysis. In total, sixteen mistranscriptions were revealed with the temporary codes “Unimportant but confusing transcription” or “Misleading mistranscription”. These instances typically related to poorly enounced vocative or similar issues, or a missing negation in a sentence which resulted in a non sequitur in the transcript, but these were easily corrected manually following the video review. Applying the process of multiple readings of transcripts is recommended (Crewsell, ibid) and was helpful in sensitizing the researchers to the data.

We designed our “focus sessions” (interviews, small group interviews and focus groups) in accordance with the feed forward concept used within design-based methods. This implies ongoing reflection between design cycles which may be viewed as an inner design loop within each cycle to create opportunities to reflect more deeply on our process and not drift from our research questions. Due to differences in cycles, several inputs steered our reflections. In cycle 1, our pre and post-test surveys were invaluable scaffolds for the development of the interview protocol. We found these questions to be useful in later focus sessions also, both as warm-up questions to help settle the participants (Creswell, ibid) and as an indicator to compare our cohorts. The cycle 2 interview protocol was developed from the outputs of cycle 1 and our literature review. Cycle 3 combined all earlier data as well as our findings from our cycle 2 interviews and our analysis of outputs from student worksheets that students had created during the cycle 2 intervention. Our cycle 3 interview protocol was considerably more structured than earlier cycles and may be reviewed in Appendix 2. Interview and focus group data is necessarily limited to those participants who are willing to engage in the sessions and this represents a limitation in any study. A mixed method approach is a suitable response to such limitations to broaden and/or deepen research. Use of complementary methods can help to contextualise participant responses to capture divergent views that produce a more holistic interpretation of data. Our study applied integrative triangulation where possible to support participant feedback relating to instance of mutual accommodation in team decision making.

Observation data

Observations were particularly useful for gathering open-ended firsthand information (Creswell, 2012) during our cycle 1 intervention when the researcher was present in the virtual space with the full cohort of winter school students. During this session the researcher acted as informal participant observer and noted instances of confusion with onboarding for some students, which was later confirmed in interview feedback relating to using the Mozilla hubs software. The hybrid nature of the CHARM-EU master programme meant that it was not possible to observe the full cohort during our cycle 2 and 3 interventions as students worked in various modes across five university campuses. This was a practical limitation of our study that a mixed method approach helped to address. During the intervention sessions the researcher was co-located with students in the CHARM-EU hybrid classroom at Trinity College Dublin, which facilitated a partial view of student activities. No specific issues or difficulties were observed although the co-located students did ask clarifying questions when starting their activity, especially during the cycle 3 session. Responses to these queries were shared with the full cohort via an open Microsoft Team session and associated chat channel to ensure that all students benefited from the information. The questions that were raised related to clarifications regarding how to interact during the session and in one instance, whether professional experience should also be considered when providing sentiment values. The questions primed the researcher to include useful talking points during the follow up focus sessions and these are discussed in our analysis of our cycle 1 heuristics in chapter 4, The Design Process (see sections 4.6.8 and 4.6.9).

Cycle 2 Activity Worksheets

Our cycle 2 intervention was delivered as part of the CHARM-EU M.Sc. in Global Challenges for Sustainability capstone course curriculum. Cycle 2 leveraged Activity Theory concepts to help students understand their problem space and start to conceptualise the factors that would influence their capstone projects in a bespoke worksheet designed for the activity. Byrd and Camba (2020) analysed student worksheets in their design-based study and applied findings to iterate on their design. Our intent in cycle 2 was similar, as our refinements would be applied later to our exemplar artefact design that builds on Activity Theory concepts and implements our heuristics. Our aim was not to teach Activity Theory but rather to introduce a framework for thinking about dynamic systems of human activity with a view to helping students identify potential project tensions. This was implemented as a paper prototype (i.e. a worksheet) that each team needed to complete during a team discussion. Teams were hybrid and used their dedicated MS Teams channels to conduct the meetings. The worksheet was split into two sections and contained instructions and suggested timing for completing the activity. Student were encouraged to spend twenty minutes generating ideas for the four themes of Tools, Division of Labour, Rules and Community, and how these related to their projects. For example, they should list the tools they planned to use, their approach to dividing and managing the workload, any rules or regulations that might affect the work and the impact of any communities that they would need to engage with. Following this step, each team needed to spend ten minutes discussing how their suggestions might interact with or otherwise influence one another. This scaffolded the next step which was to identifying tensions between the themes and students were given fifteen minutes to complete this part of the activity. Section 2 of the worksheet asked the students to spend the final ten minutes of their session generating "How Might We" responses to deal with the tensions they had uncovered. Finished worksheets were added to a course folder on MS Teams and then copied into the researchers private MS Team area for later analysis. The original copies were maintained on the secure course folder since they composed an element of the capstone coursework, although they were not assessed as part of the course and were only retained for student informational purposes. This point was noted ahead of time in the ethical addendum application for cycle 2.

Worksheets have been criticised for their potential to contribute meaningful data for a variety of reasons. Flick, 2018, notes that such sources frequently contain brief, task-oriented responses that lack depth. We addressed this in our design with targeted questions that expect brief responses. Our aggregation of this set helped to highlight patterns that hint at deeper meaning and these were triangulated with probing focus session questions to dig more deeply. Worksheets can highlight summative information but they typically do not illustrate the process involved in creating the output. We addressed this concern with the structure of our activity, which asked students to document their ideas within structured format that aligned with cultural historical activity theory. A third criticism of worksheet relates to inconsistent completion rates (Creswell & Poth, 2018). We anticipated this outcome and structure our worksheet to cover the more important themes first, however some teams did not complete all sections, and this outcome was a useful design input to consider simplifying our task for the final intervention.

A discussion of the worksheet data is provided in our Design Process chapter (chapter 4) and highlights how this influenced our final design cycle. Interested readers may also review an anonymised example worksheet submission in Appendix 4.

3.5.1.1 Coding and theming

Miles and Huberman (1994) describe the challenge of tagging transcripts with appropriately accurate codes. They caution us to be "explicitly mindful of the purposes of your study and of the conceptual lenses you are training on it – while allowing yourself to be open and reeducated by things you didn't know about or expect to find". This guidance echoes Creswell's (2013) advice that coding should be iterative and layered to reveal and construct meaning. Indeed, Creswell recommends that a combined coding approach should be used in open-ended qualitative studies. In grounded theory and phenomenological studies, coding traditionally begins inductively with themes and categories emerging from the data. Case studies and ethnographic approaches focus on a priori codes informed by theory, and the researcher must fit the data to the codes, however such approaches do not exclude inductive methods when an exploratory aspect is part of the study. When appropriate to the research design, as is the case with DBR, qualitative studies can benefit from a two-pronged approach to coding that begins with an inductive pass to sensitise the researcher to the data before applying deductive reasoning. This is the approach that others have employed (Bingham, 2023) and one that we have taken in our own work, although with subtle differences arising from our iterative research design. In our second design cycle, we aimed to explore students' attitudes to hybrid teamwork with a view towards refining our heuristics. With such an exploratory aim, an inductive coding is clearly the preferred approach to meaning making, however we were eager to test our deductive codebook that we had developed during our literature review and therefore included a second, deductive pass during the cycle 2 analysis. Cycle 3's aims were less exploratory as the reason for our intervention and focus sessions were to further refine and test the established heuristics. In this cycle, we applied the same rational of beginning with an inductive pass but unsurprisingly produced less inductive codes during our analysis as the structured nature of the focus sessions steered the thematic focus. Details of the differences in our approach are noted in the current section, and we include our theory informed a priori codes below.

Deductive Codebook

Indicative Literature	Theme	Deductive Code
Betts, 2016; Hsu, 2016; Hunter, 2016	Tools / Usability	Appropriate use of abstractions
		Instructions and guidance

		Timely feedback
		Comfort and accessibility
Blandford and Furniss, 2006	Distributed Cognition of Teams (DiCoT)	Arrangement of Equipment
		Horizon of Observation
		Naturalness Principle
		Perceptual Principle
		Situation Awareness
		Space and Cognition
		Subtle Bodily Supports
Ceballos, 2016; Hudelson, 2017; Korovkina, 2020; West, 2015	Tools / Usability	Controllers and Interface
Rubinstein, 1973; Vygotsky, 1978; Leontiev, 1981; Engeström, 2000	Activity Theory (Neighbouring activity systems)	External factor impact
Rubinstein, 1973; Vygotsky, 1978; Leontiev, 1981; Engeström, 2000	Activity Theory (Rules)	Methodologies
Rubinstein, 1973; Vygotsky, 1978; Leontiev, 1981; Engeström, 2000	Activity Theory (Community)	Social-protocols
Rubinstein, 1973; Vygotsky, 1978; Leontiev, 1981; Engeström, 2000	Activity Theory (Division of labour)	Work practices
Green and Petre (1996)	Tools / Usability	Fluency with tools
		Clarity of intent
		Consequences of tool use
		Ease of use
		Effort to change
		Effort to keep changing
		Expected behaviour of a tool
		Onboarding of a tool
		Suitability of tools to tasks
		Threshold to usability
		Tool interaction
		Tool usage patterns
		Use of tool features
		Working in multiple contexts
		Usefulness of tools
Hutchins, 1995	Distributed Cognition	Mental representations
Inverardi & Tivoli, 2009	Project requirements	Evolving requirements
Katzenbach and Smith, 1993	Communication	Clarity of expression
		Clarity of process
	Organisation	Task Management
LaFasto and Larson, 1989	Communication	Giving and receiving feedback
Myers, et al., 2000	Tools / Usability	Interacting with IT

Rosenfeld, et al., 2015	Tools / Usability	Tool design issues
Salas, et al., 2013; Mohammed, 2010	Team cognition	Developing shared mental models
Shanmugam, 2015; West, 2015	Tools / Usability	Display of textual information
Tuckman, 1965	Communication	Interpersonal clashes

Table 3-1. Deductive code book developed during our study

Cycle 2 Coding

Codebooks were initially developed using Excel and the coding process during each design cycle was undertaken using NVivo to manage the codebooks and ensure that our deductive themes were applied consistently and not missed or accidently excluded. The cyclical nature of DBR offered the opportunity to pilot-test our codebooks in cycle 2 before using them again in cycle 3.

The exploratory nature of our cycle 2 focus groups implied that an inductive coding would be helpful to uncover student sentiment regarding the intervention themes. However, we were developing our heuristics and knew that our third cycle would necessitate a deductive approach to support the theory-based elements. We therefore also undertook a deductive coding in cycle 2, as a first test of our deductive code book.

Beginning with the a posteriori indicative coding pass helped us to minimise anchoring bias from an overfamiliarity with the deductive code set. Once this step was complete the inductive codebook was set aside, and we began our deductive coding. Following this, we could consider both sets during our analysis to develop a richer and more comprehensive picture of the data (Creswell, ibid). Our intervention for cycle 2 supported the development of our concept exemplar artefact for cycle 3, with specific emphasis on the transdisciplinary teamwork scaffolds and helping students recognise project tensions. While the focus of cycle 2 meant that many of the wider set of themes from our new codebook were not encountered, we were happy to see that our participants valued natural experiences, understood the impact of tools on tasks and recognised how team interactions can affect team members.

Cycle 3 Coding

A smaller subset of both cohorts agreed to take part in the focus sessions as an additional item on the same ethical consent form collected in the weeks prior to the intervention using a Microsoft Form on the Trinity College SharePoint environment. This was exported to an excel file for ease of access before sharing invitations to the sessions. Unfortunate timing with student project deliverables in both cohorts meant that we did not manage to conduct full sessions (Creswell, 2012) and rather needed to run numerous smaller, interview and group interview sessions instead. Two of our capstone groups included members of the same team but this was unfortunately not possible for the first semester group due to fewer participants following up.

Cycle 3 was planned as two interventions, one for our novice first semester students and one for our more established capstone students. Cohort details are presented in table 3-2 below.

Cohort	Engaged in class intervention	Consented to participate in study	Participated in a focus session
Capstone	52	37	7 = [3,2,3]
First semester	44	36	4 = [1,1,2]

Table 3-2. Cohort and study participant numbers.

First semester students worked in hybrid teams and capstone students were co-located across the five CHARM-EU hybrid classrooms. We conducted six focus sessions in total over the two cohorts. For the first semester group we conducted two individual interviews and one pair interview while the capstone group had two pair interviews and one small group interview involving three participants.

Our study is based largely in theory due to many of our heuristics stemming from literature and an a priori deductive coding approach therefore appeared to be the best method to evaluate student impressions of our design for cycle 3. However, we have also developed our own heuristics during cycles 1 and 2 and were cognisant of the need to acknowledge the propensity of learner agency to produce unexpected outcomes. Indeed, this is a criticism of design-based research that Engeström (1987) has noted, and we discuss this in the current text (see section 3.5.3). Our response to this criticism has been to work with deductive and inductive approaches as per cycle 2, so that unexpected themes could be surfaced. Rather than combine codes into one large set, a cleaner approach is to work with individual inductive and deductive codebooks (Creswell, 2012) before combining findings to develop insights. Initiation through probing questions helped to ensure a depth in responses and our two-step coding approach helped to highlight any emergent themes while maintaining the theoretical alignment via a deductive coding.

During our final cycle we wanted to gather student feedback relating to our heuristics and the corresponding design implementations. With such a large set of heuristics it was necessary to adopt a rigid structure in our focus sessions to be able to cover all the items in good time. As noted, we developed focus session questions for each heuristic, and this determined the format for our analysis by allowing us to segment our transcripts using NVivo annotations per question.

Annotations

Item	Content
1	Welcome and housekeeping
2	Baseline transversal skills - Ravitz
3	c1a: What were your impressions of the instructions for the activity/app?
4	c2a: What did the emoticons make you feel about your team / teammates? What about the team average values?
5	c2b: How well do you feel you could express your sentiment using the emoticon sliders?
6	c2c: Do you feel that you know your teammates better after the activity? How did the interface influence that?

Figure 3-3. Sample of NVivo annotations for Cycle 3 transcripts.

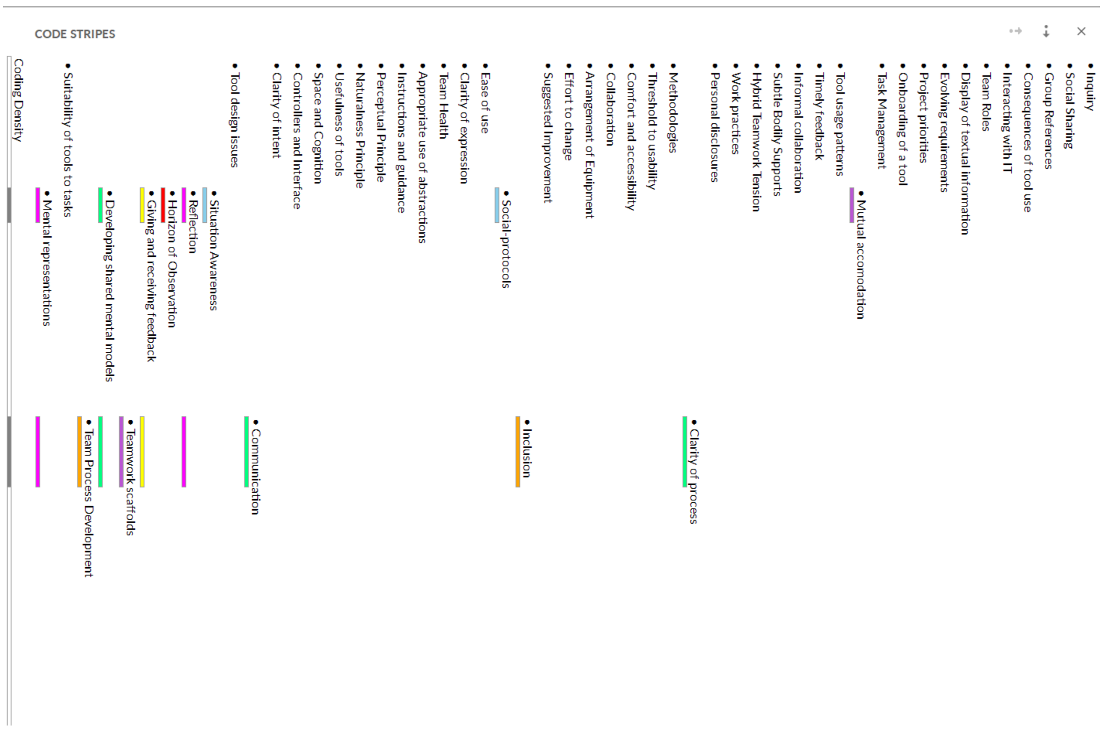


Figure 3-4. Example NVivo code stripes (Deductive). Case 3, question c2a.

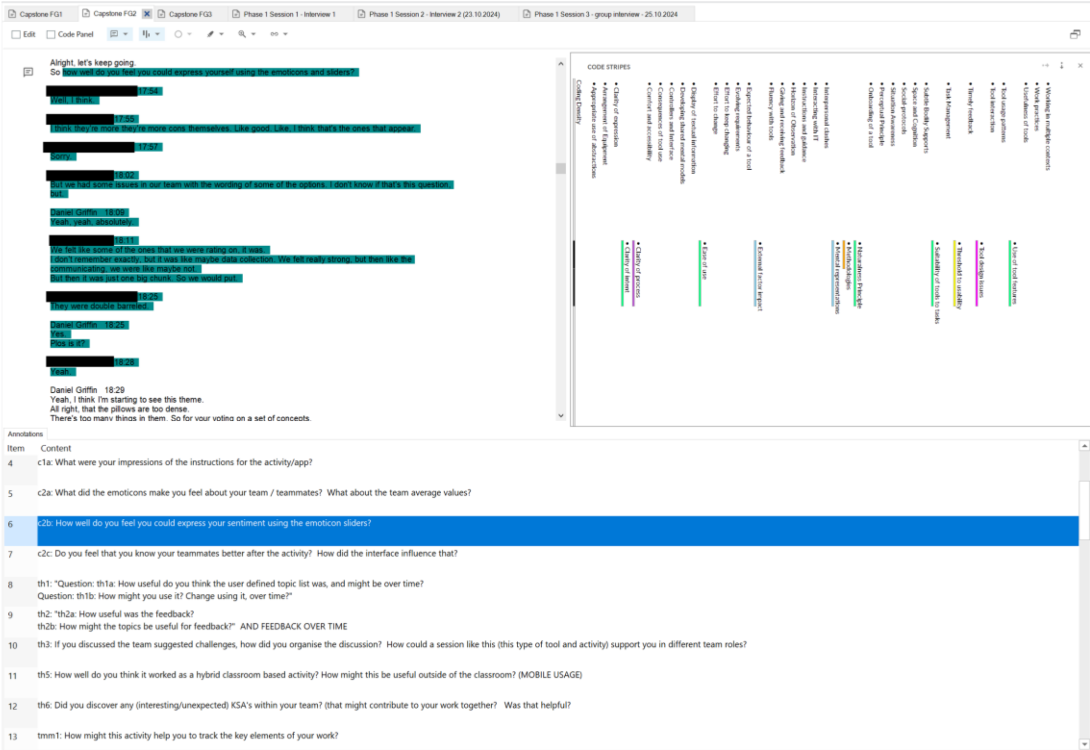


Figure 3-5. Coding process. Questions were marked as annotations in each session and then coded using an exploratory inductive pass followed by a theory informed deductive coding.

We began by annotating each transcript in NVivo to mark-up the texts as sets of individual questions. With each transcript annotated, we could then begin the coding. This approach of first creating annotations and then coding within the annotation facilitated the collation of the codes across cases while preserving detail relating to which cases contained which codes. This prepared us well for the analysis which follows the same pattern to examine each heuristic individually across cases (see Chapter 5 for details). Themes were noted and coded as they were encountered in the text using NVivo.

3.5.2 Quantitative data

Surveys

Surveys provide a quick, cheap, and targeted method to generate meaningful data from online populations (Wright, 2005) and they are an excellent way to reach distributed cohorts. In our first design cycle, we used pre and post-test surveys to evaluate students self-rating of their 21st century skills and identify areas where they felt underprepared for hybrid transdisciplinary teamwork. This method addressed RQ1 by identifying appropriate areas to support our hybrid transdisciplinary novice cohorts, and RQ1b by suggesting additional heuristics based on real-world contextually valid student perceived challenges. Both surveys were based on a popular validated instrument (Ravitz, 2012) with questions grouped by the following themes.

- (CT) Critical Thinking Skills
- (CO) Collaboration
- (CM) Communication Skills
- (CR) Creativity and innovation skills
- (S) Self-direction skills
- (G) Global connections
- (L) Local connections
- (U) Using technology as a tool for learning

Both surveys were delivered via online Microsoft Forms so that data were submitted directly into the Trinity college Dublin MS Teams environment. Forms data can be trivially accessed via Excel which avoided the need to handle data outside of the secure environment. Our cycle 1 cohort was small (pre-test n=7, post-test n=5) and we would not claim statistical significance with such a tiny sample. However, we viewed the surveys as a reasonable test of the instrument questions to determine their relevance to our problem space. Our satisfaction with the Ravitz questions led us to adapt their format in later cycles by embedding them directly into our focus session as warm up questions (Creswell, 2013). This decision also helped to avoid over surveying the CHARM-EU M.Sc cohorts who were contributing to the CHARM-EU pilot programme research and already dealing with a lot of surveys in their courses.

A	B	C	D	E	F	G	H	I	J	K
Category (Ravitz, 2010)	Critical thinking skills	Critical thinking skills	Critical thinking skills	Collaboration skills	Collaboration skills	Collaboration skills	Collaboration skills	Collaboration skills	Collaboration skills	Communication skills
21st century skills examples	Media literacy	Transdisciplinarity / Evaluation / apprasial	Transdisciplinarity / Handling Complexity	Interpersonal / Possibly intercultural too	Planning, coordination, co-operation	peer assessment and reflection skills, document management skills, planning, project	presentation skills, group coordination	reflection, intra-group communication skills,	Peer assessment, communication	charting / info graphics
Questions	Compare information from different sources before completing a task or assignment	Analyse competing arguments, perspectives or solutions to a problem	Try to solve complex problems or answer questions that have no single correct solution or answer	Work in pairs or small groups to complete a task together	Work with other students to set goals and create a plan for their team	Create joint products using contributions from each student	Present their group work to the class, facilitators or others	Work as a team to incorporate feedback on group tasks or products	Give feedback to peers or assess other students' work	Structure data for use in written products or oral presentations (e.g., creating charts, tables or graphs)
Responses	Don't know / Neutral	Don't know / Neutral	Don't know / Neutral	Agree	Agree	Agree	Agree	Agree	Agree	Agree
Responses	Don't know / Neutral	Disagree	Disagree	Agree	Don't know / Neutral	Don't know / Neutral	Agree	Don't know / Neutral	Don't know / Neutral	Disagree
Responses	Don't know / Neutral	Agree	Strongly agree	Strongly agree	Strongly agree	Strongly agree	Don't know / Neutral	Agree	Strongly agree	Don't know / Neutral
Responses	Don't know / Neutral	Don't know / Neutral	Don't know / Neutral	Agree	Don't know / Neutral	Don't know / Neutral	Agree	Don't know / Neutral	Don't know / Neutral	Disagree
Responses	Agree	Agree	Don't know / Neutral	Agree	Don't know / Neutral	Agree	Disagree	Don't know / Neutral	Don't know / Neutral	Disagree

Figure 3-6. Example subset of cycle 1 survey responses (based on Ravitz, 2012), capture of MS Forms online version.

Quantitative data processing

Triangulation is a useful approach for validating mixed method data and we have found quantitative data to be valuable in this regard. During cycle 1, survey data supported the interview feedback. In cycle 2, we considered data from student worksheets and focus groups. Our cycle 3 students generated large volumes of quantitative data for each of the discussion topics as part of our intervention while working with the exemplar prototype tool. These data were contrasted with focus session feedback to support our evaluation of the heuristics in answering RQ1b. The cycle 3 data were exported from the remote Amazon Web Services database and downloaded as a comma separated variable file after each of the cycle 3 interventions. Since a subset of each cohort chose not to give their consent to us working with their data, we began by undertaking a data cleaning exercise in Microsoft excel by starting with a list of consenting students emails and cross referencing against this to delete the unusable records via a pivot table. This resulted in 819 records for the first semester group (two sessions, 375 rows + 444 rows) and 956 records for the capstone cohort (one session).

To facilitate our analysis, an extra data processing step was taken to merge team IDs into the cleaned data sets. This is a destructive approach that would not be suitable for persistent data as it breaks the normalisation of the relational database structure by collapsing the data into a single table. However, it is a suitable post-processing technique which simplifies further analysis in non-relational aware tools. Our first step was achieved by copying the cleaned scores table and modifying the copy to include an extra team_id column. This table was then updated to populate the newly added team_id column using an INNER JOIN, which is the optimal and most widely supported method for merging relational data in SQL based relational database management systems.

With the data cleaned and packaged into a useful format, we began our analysis of the time series data to look for instances of mutual accommodation of sentiment scores within teams. Charting of the data was achieved via a bespoke Python script. The Python language benefits from an enormous set of libraries that can extend the language, and for charting we relied on the Pandas, Matplotlib and Seaborn libraries to produce a set of 275 charts across our two cohorts (see examples in Appendix 5). Team topic combinations were then associated using a 'groupby' function. We then iterated over a loop plotting the sentiments as colour coded line charts for each student within the team-topic sets. Once plotted, each chart was outputted as a separate PNG file. MySQL and Python code samples may be found in Appendix 6.

3.5.3 Activity Orientated Design Method (AODM) and the identification of culturally historical systemic contradictions.

We have noted Mwanza's comments which echo those of Engeström regarding the lack of standardised methods to operationalise Activity Theory, indeed, Mwanza proposed AODM as a response to this recognised methodological gap. AODM has previously been used to successful characterise "learner practices with tools or technologies whilst paying attention to learner motives and social and cultural issues that exist in the context in which learning activities are carried out", (Mwanza, 2002). In the context of our own study, AODM has allowed us to include and consider student voice and opinions to test our heuristics when answering research question RQ1b. The culturally historic aspects of Activity Theory are revealed when working through AODM's eight steps which was instrumental in identifying student perceived tensions. Additionally, AODM's Activity Notation has been invaluable in helping to communicate the context and details of our study. Mwanza's original study (2002) and the Mwanza-Simwami (2011) review of AODM usage in the field, covers three cases where AODM was employed to characterise how learners interact with new tools. In these cases, AODM was used to examine stepwise operational processes at an individual task level to understand instructional practices in the context that they occur (Greenhow and Belbas, 2007) and identify noteworthy everyday experiences with software to understand the implications of teachers' and students' work on a design project (Dolonen, 2009). In each case, AODM helped to understand learner objectives by examining underlying culturally historical motivations and provided "a number of formal ways of investigating and representing what is happening in the learning process at a fine-grained level" (Mwanza-Simwani, 2011). These three applications of AODM align with our own approach and aims, however there is a notable difference in our analysis that should be described. In previous AODM based studies, learners are viewed as subjects, or actors who act to achieve an objective. Learner agency is an important concept here since it aligns action with motivation. Our approach differs by placing a focus on each heuristic and the idealised outcome of that heuristic. Applying AODM's structure allowed us to clearly state the link between each heuristic and its idealized outcome by systematically mapping the factors that mediate the activity (tools, rules, community, roles, and contradictions) to ensure that each heuristic was evaluated in terms of what supports or blocks its success in real-world practice. Earlier research applying AODM to learner agency illustrates its ability to analyse why and how individuals engage in activities. In terms of our application of AODM, each heuristic represents a deliberate approach to action, and the idealized outcome of the heuristic reflects the motivation behind that action. Applied thusly, AODM offers a structured way to assess the link between heuristic and outcome.

The following counter arguments have been considered during our study. Firstly, AODM traditionally maps real-world activity systems rather than evaluating prescriptive heuristics. As an initial response, it is important to highlight that AODM has already been used in interventionist DBR research, i.e. the cases referenced in this section. Additionally, our approach to using vignettes examines each heuristic in a real-world team context rather than abstractly, which makes it an empirical application rather than solely theoretical. A second criticism of our approach might focus on the traditional application of AODM where the subject is a person or group. Our response to this criticism is that our heuristics shape how team members interact within the activity and therefore behave as cognitive actors that shape team behaviour to guide the activity. A final criticism of our approach may suggest alternative analysis methods such as affordance analysis or qualitative thematic analysis, but these methods do not allow for a deeper socio-cultural investigation and may misinterpret our overlook learner motivations. For example, affordance analysis focuses on perceptions of the properties of tools and environments, whereas AODM includes a more holistic socio-cultural analysis of team dynamics. Qualitative thematic analysis identifies themes but ignores systemic interactions, whereas AODM outlines a structured way to explore how each heuristic functions in the context of each team.

The current research employs AODM across three design cycles.

- Cycle 1. As a descriptive framework to explain the intervention activity and conceptualise third generation activity theory tensions identified in survey data and participant interviews.
- Cycle 2. As a descriptive framework to explain our intervention to frame tensions that were noted by students in their activity worksheets and focus groups, (and introducing CHAT as a worksheet template for students to reflect on and conceptualise their project problem spaces). Identification of tensions in our cycle 2 student feedback informed the design and content of the cycle 3 exemplar tool.
- Cycle 3. As a descriptive framework to contextualise the analysis and interpretation of participant focus session feedback relating to each of our heuristics and discover tensions by listening to their perspectives of the exemplar tool design. Our approach in this cycle addresses our broad collection of heuristics as individual analysis vignettes, or micro-AODM analyses that are each informed by qualitative student feedback.

Use of AODM in the current research

The current study employed AODM as a descriptive analysis framework across three design cycle. AODM was useful throughout the study to assist with the conceptualization of student experiences and aid our reflections between design cycles. In the final cycle, we characterized students' experiences of hybrid transdisciplinary teamwork as they engaged in a structured collaborative team discussion using a live feedback tool. The analysis of this was based on a micro AODM analysis vignette, which was a practical approach to assessing the large number of design heuristics, and student feedback helped to identify tensions uncovered through the design implementation. Our approach builds on Mwanza's method however there are several differences between our implementation of AODM, versus Mwanza (2002) and other AODM researchers cited by Mwanza-Simwami (2011) in her review of AODM applications, i.e. Greenhow & Belbas (2007) and Dolonen (2009). Our approach goes beyond identifying contradictions to test and refine design heuristics for structured student team learning. The studies are contrasted below in table 3-3.

	Mwanza's AODM (2002; 2011)	**Greenhow & Belbas (2007)**	**Dolonen (2009)**	**Griffin & Byrne (adaptation)**
Goals	Identify contradictions & improve system efficiency.	Analyse e-learning interactions & contradictions.	Examine technology-enhanced learning environments.	Assess & refine design heuristics for team learning.
Scope	General application of CHAT in technology design & workplace learning.	Online higher education courses.	Learner interactions in technology-supported learning.	Student teams working with a learning intervention.
Methodology	AODM 8-step structured model using CHAT to analyse system components and conceptualize student experiences.	Examined discussion forums, logs, & student interactions in e-learning.	Analysed student activities within technology-supported learning environments.	Analysed transcripts using NVivo annotations and coding, with supporting secondary data from surveys, student worksheets and

				in-app data across three design cycles.
Use of CHAT	Identified contradictions in technology-mediated activities.	Identified contradictions in online learning structures.	Examined student interactions & engagement in technology-mediated settings.	Assessed tensions in hybrid team collaboration to inform the development and refinement of design heuristics.
Role of Mediating Artefacts	Acknowledged, but not central.	Implicit, but not central.	Explicitly examined as part of technology use in learning.	Central focus. Interpreted using AODM informed by teamwork, DCog and DiCoT literature.
Design Approach	Identified tensions in an activity system and proposed design recommendations.	Conceptualized tensions to inform course improvement recommendations.	Characterized the role of technology in student engagement.	Iterative design cycles refining team collaboration processes via a collection of heuristic supports.
Timeframe	One-time analysis of an activity system.	One-time analysis of e-learning interactions.	One-time analysis of tech-supported learning.	Three design cycles with evolving interventions.
Data Sources	Qualitative (Interviews, observations) +	Qualitative (Discussion forum	Qualitative (Observations,	Qualitative (focus sessions) + Quantitative

	Quantitative (system logs)	logs & student interactions).	Interviews, Surveys)	(survey responses, student worksheets and in-app data).
Intervention-Based?	No. Primarily analytical and diagnostic.	No. Focuses on course evaluation and recommendations.	No. Descriptive, focusing on how technology impacts learning.	Yes. Iterative design cycles to explore students' attitudes concerning hybrid teamwork to develop and refine a set of design heuristics.
Key Contribution	Provides a structured approach for applying CHAT to technology design.	Investigates collaborative knowledge-building in online courses.	Investigates how technology shapes learner engagement in education.	Contextualises feedback to refine heuristics by developing an evidence-based approach to improving student team learning through a series of structured interventions.

Table 3-3. Differences in application of AODM across 4 studies.

3.5.3.1 The AODM Toolkit

Mwanza's AODM method can be operationalised using an associated toolkit that consists of four elements, which we comment on below regarding their application in our research.

- The Eight-Step Model
- Activity notation
- Technique of Generating Research Questions

- Technique of Mapping Operational Processes

These elements can be applied iteratively in a six-stage process that Mwanza describes as follows.

- Stage 1. Interpret the situation being examined in terms of Activity Theory
- Stage2. Model the situation being examined
- Stage 3. Decompose the situation
- Stage 4. Generate research questions
- Stage 5. Conduct a detailed investigation
- Stage 6. Interpret and communicate findings

The Eight-Step Model

The eight-step model guides the researcher in identifying the various elements of third generation activity theory model by asking probing questions for each element. The questions associated with the eight steps are presented below in table 3-4. These steps have guided each of our design cycles when analysing the data produced by that cycle's intervention activities.

AODM Toolkit: The Eight-Step-Model		
Identify the: -		Question to Ask
Step 1	Activity of interest	What sort of activity am I interested in?
Step 2	Object-ive	Why is the activity taking place?
Step 3	Subjects	Who is involved in carrying out this activity?
Step 4	Tools	By what means are the subjects performing this activity?
Step 5	Rules and Regulations	Are there any cultural norms, rules or regulations governing the performance of this activity?
Step 6	Division of labour	Who is responsible for what, when carrying out this activity and how are the roles organised?
Step 7	Community	What is the environment in which this activity is carried out'?
Step 8	Outcome	What is the desired Outcome from carrying out this activity?

Table 3-4. AODM Toolkit: The Eight-Step-Model, (Mwanza, 2002).

Activity Notation

Activity notation, presented in table 3-5 below, compliments AODM by offering terminology and guidelines for decomposing activities into sub-activities, highlighting that actors engage with mediators to reach an objective. We employ Activity Notation throughout the current research.

AODM Toolkit: Activity notation		
Actors (Doers)	Mediator	Object-ive (Purpose)
Subjects	Tools	Object
Subjects	Rules	Object
Subjects	Division of Labour	Object
Community	Tools	Object
Community	Rules	Object
Community	Division of Labour	Object

Table 3-5. AODM Toolkit: Activity Notation, (Mwanza, 2002).

In our study Activity Notation helps to clarify our description of the analysis and the reader will note our use of such phrasing throughout this thesis.

Technique of Generating Research Questions

Mwanza's AODM technique of generating research questions, presented in table 3-6, is intended for deeper probing of data to refine research questions. As our analysis does not seek to refine research questions but rather to examine our heuristics by contextualizing participant feedback to identify perceived tensions, we did not make full use of this technique. However, the technique still offered potential insights since tensions may represent issues with the heuristics, and we therefore reflected on each of the prompts when conducting our analysis. This element of the toolkit scaffolds AODM analysis by helping the researcher formulate questions that are indicated through notational combinations identified using Activity Notation (i.e. conceptually bound by the nodes of the related sub-activity triangle). This is achieved by reflecting on the following six questions in the context of the sub-activity.

AODM Toolkit: Technique of Generating Research Questions
What Tools do the Subjects use to achieve their Objective and how?
What Rules affect the way the Subjects achieve the Objective and how?
How does the Division of Labour influence the way the Subjects satisfy their Objective?
How do the Tools in use affect the way the Community achieves the Objective?

What Rules affect the way the Community satisfies their Objective and how?
How does the Division of Labour affect the way the Community achieves the Objective?

Table 3-6. AODM Toolkit: Technique of Generating Research Questions, (Mwanza, 2002).

Technique of Mapping Operational Processes

The AODM toolkit technique of mapping operational processes maps tensions identified in sub-activity systems to the area of activity associated with that sub-activity. As an illustration of this, consider a systemic tension that exists in the case of a user attempting to enter data into a calculator when its battery is failing.

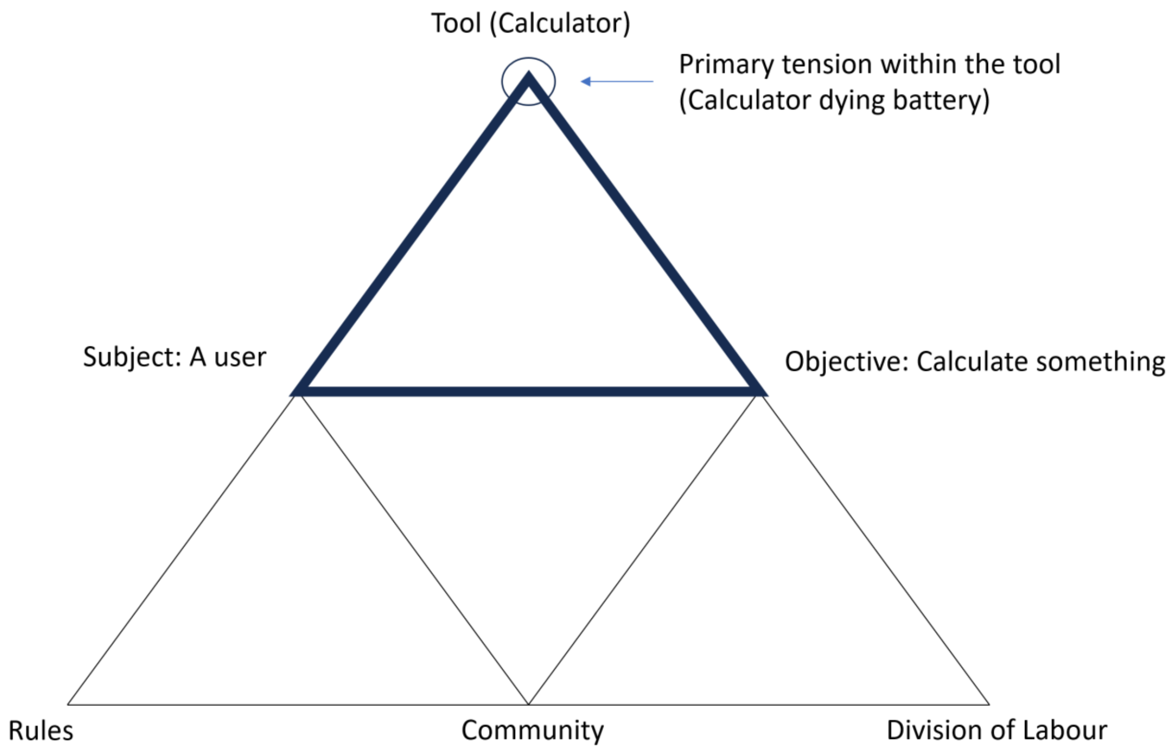


Figure 3-7. Example of a primary tension within a tool that prevents a subject achieving an objective.

Activity notation isolates the issue to the subject-tool-object triangle (figure 3-7) and the technique for mapping operational processes allows us to home in and determine that the area of contradiction is the tool itself (figure 3-8). In this simplistic case, an internal or primary contradiction in the tool is easily identified. In a more complex example where tensions exist between elements, the technique for generating research questions may be necessary before we can understand the problem well enough to begin the mapping.

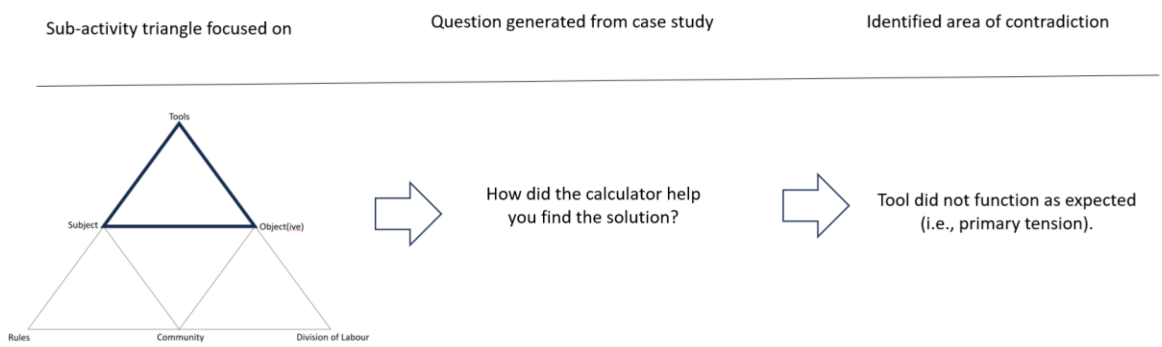


Figure 3-8. Illustrative application of AODM's Technique for mapping operational processes (adapted from Mwanza, 2002).

Mwanza's AODM technique for mapping operational processes has been less useful than the other AODM toolkit components in our study due to our focus on evaluating heuristics in our analysis. Heuristics represent guiding principles rather than rigid step-by-step operational flows and while we did explore uses of the technique when examining participant feedback to help sensitise ourselves to the data, operational process mapping is best used in analysing well-defined, sequential workflows. We therefore avoided extended usage of the technique in the current research but recognise its potential in more technically focused studies.

3.5.4 The Change Laboratory Toolkit

Working with AODM is an effective way of identifying tensions that exist within an activity system although as Mwanza says herself, "the AODM representational approach does not solve all the problems of representing contradictions on the triangle model, but at least it gives a clear indication of the number of contradictions identified in a particular sub-activity within a single system.", (Mwanza, 2002). AODM must be supported by other techniques where there is a need to understand how tensions emerge, or how they should be overcome to create an opportunity for expansive learning. Engeström's explanation of systemic contradictions can be helpful in exploring the culturally historical nature of tensions and we rely on this in our analysis. Engeström's notation is supported with graphical iconography from Bligh and Flood's (2015) online Change Laboratory Toolkit, and we have applied their systemic contradiction icons (figure 3-9) in our diagrams to support discussions later in the current text (see individual AODM analyses per heuristic, in sections 5.4, 5.5 and 5.6). This extends our AODM analyses to identify the cultural historical context of tensions noted by students for our heuristics.

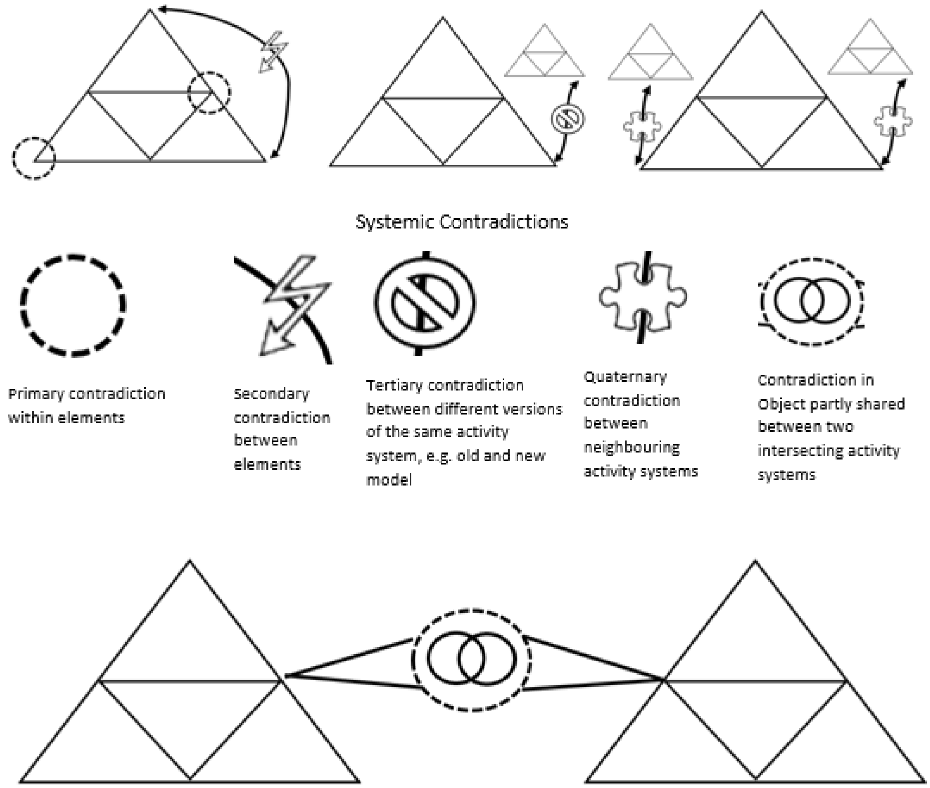


Figure 3-9. A graphical representation of Systemic Contradictions, (Bligh & Flood, 2015)

The Change Laboratory method (figure 3-10) developed by Engeström & Virkkunnen, (1996) "is an intervention-research methodology where people work together in a structured and cyclical way to envisage new activity in their organisation" (Bligh & Flood, 2015). The method is used longitudinally over the course of a group project typically lasting between two to six months and aims to create or otherwise highlight activity tensions that can prompt an expansion of learning (Engeström, 1987) for group members. Change laboratories are structured and include various supports for those involved in the activity, including, a source of reference and theory known as the 'model/vision' which participants can use to help contextualise their work, and a set of 'mirror-data' relevant to their problem space that should help them to draw inspiration or spot patterns. Additionally, the setup traditionally includes a method to record activity details and a place for a researcher or observer. The Change Laboratory method is designed to be carried out over a period of at least a few months and its full potential was not applicable to our study. However, we have found this format to be a good source of inspiration for our final exemplar tool design and layout, and we describe the various elements and their relevance to our study in chapter 4: The Design Process (see section 4.8.3 'Intervention Design').

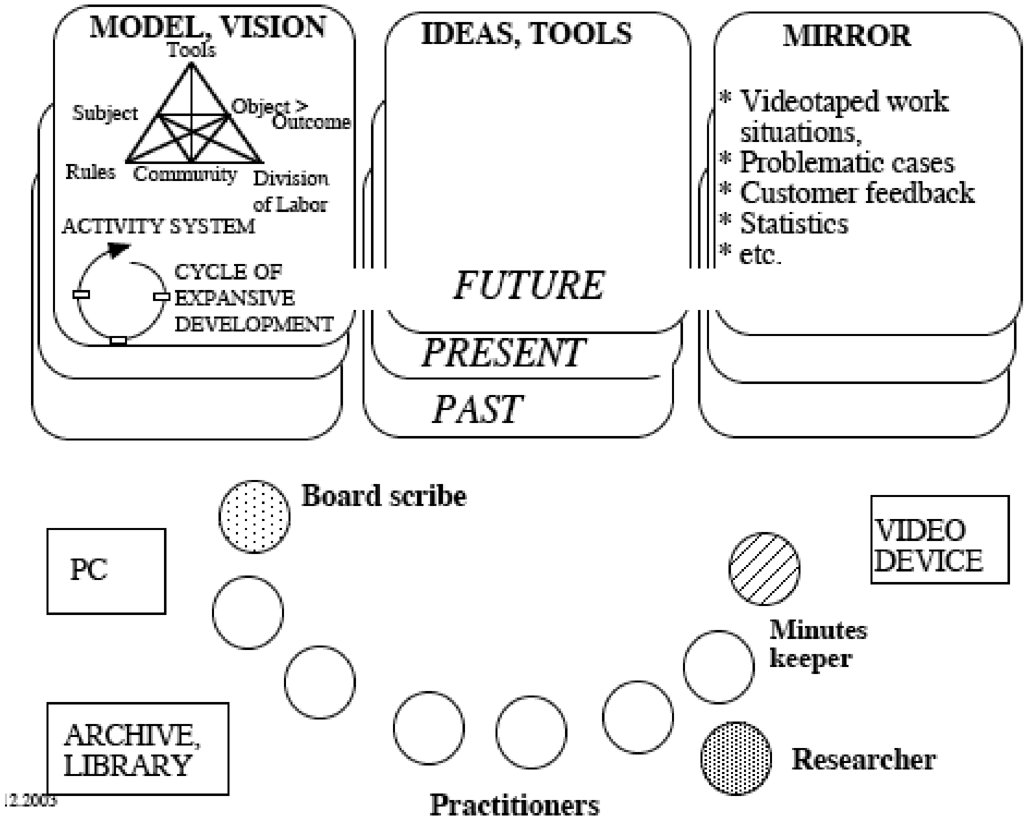


Figure 3-10. The Change Laboratory model (Engeström & Virkkunnen, 1996, cited in Bligh & Flood, 2015)

3.6 Ethics

Ethical approval was received in November 2020 for a low stakes study to explore the potential for mixed realities in supporting transdisciplinary teamwork, with specific focus on the Mozilla Hubs environment and to a lesser extent, non-immersive tools like MS Teams. The study took place during the CHARM-EU winter school in January 2021. As mixed reality is a new experience for many users, using it for an intervention represented a potential risk to students. Following meetings with the relevant gatekeepers, it was determined that there was scope to conduct a low stakes study as part of the winter school social event. Low attendance was anticipated at the social event and even fewer students consented to be part of the study, however a sufficient number attended to conduct a semi-structured focus group where the researcher guided the discussion by asking participants their opinions on the potential of Hubs to support a variety of transversal skills. This discussion was based on survey questions that were drawn from Ravitz, et al., (2012). The ethics application proposed a design with several instruments, i.e., survey, student created digital artefacts, a focus group and interviews. Students created digital artefacts as part of the social event, and these were discussed during the focus group and interviews. Surveys were conducted pre and post for the Hubs activity and some aspects of the responses were discussed during interviews.

The cyclical nature of our design-based research study allowed us to organise ethics for cycle 2 and 3 as addenda to the original application, with cycle 2 confirmed in June 2022 and cycle 3 in June 2024. As our study focused primarily on novice teams, each application needed to be confirmed before summer recess to ensure that the ethics could be in place in time for the start of the Autumn semester when new student teams would be formed. The same set of methods were used throughout, with minor differences relating to the evolution of the cycle 2 worksheet into our cycle 3 software tool.

3.7 Positionality and Design Philosophy

This current research is interpretivist and qualitative and takes a techno-social constructivist stance with the view that knowledge is co-constructed through interactions between people, tools, and environments. As such it cannot escape subjectivity and bias (Creswell, 2012). Qualitative research is best suited to study such subjective phenomena that are difficult or impossible to measured numerically, and this has influenced our design-based approach to organize our study as it moves from the context of discovery to the context of justification (Kaplin, 1964). Design based research (DBR) has been praised for its pragmatic approach to addressing subjectivity by producing meaningful interventions and practices (The Design-Based Research Collective, 2003) that are effective within particular learning contexts.

Our framing philosophy is informed by Cultural Historical Activity Theory (CHAT) and Distributed Cognition (DCog). The research adopts a systems-oriented perspective that views teamwork as an activity system where cognition, tools, and social structures influence the team's performance. This view of cognition as a distributed and situated phenomena emphasizes how cognition is shared, coordinated, and emergent in hybrid teams. Proportionality was managed by balancing CHAT's structural analysis of activity systems with DCog's focus on cognitive coordination and artifacts. The emphasis shifts to align with the analytical focus, i.e. CHAT provides a macro-structural view of tensions in teamwork while considering the teams activity as the unit of analysis, and DCog compliments this by enriching the micro-level analysis of the distributed cognition within the team to frame the actions and operations carried out by team members.

A challenge for research that examines new educational tools is to help “researchers and designers understand the real-world demands placed on designs and on adopters of designs”, (The Design-Based Research Collective, ibid). This challenge arises out of a gap that exists between theoretical research, educational practice and technical limitations of contemporary hybrid teamwork tools. Design Based Research is therefore an appropriate pragmatic choice that is well suited to studying such a new and rapidly evolving problem space as distributed teamwork in XR. Design based cycles provided an opportunity to refine the research as the project progressed, but it is important to recognise that personal perspectives and socio-cultural heritage can exert an influence on how research is conducted, and indeed even how it can be interpreted (Rowe, 2014). We must also consider that researchers are attracted to specific research questions for the same reasons (Creswell, ibid). My position as a member of an ethnic majority living in an affluent country, with considerable prior technical experience, places me in a position of privileged exposure to the concepts, tools and methods discussed in this research (Holmes, 2020). XR holds great promise as an educational tool but it comes at a cost that is currently out of reach for many, and perhaps others may find my views to be techno-utopian. My belief that absolute knowledge of the experience of others is not possible, has informed my interpretivist views and choice of pragmatic approach to the current research. Including a plurality of voices in the research is an essential element for its integrity and validity. Coming to understand this has been my motivation to design the research such that student voices, the perspectives of educators, and other communities of practice are included. Adopting a design-based research approach offers the potential to minimise biases by including opportunities for reflection and discussions with stakeholders that will inform subsequent design cycles, with the aim to find solutions that are meaningful and workable in many contexts. Heuristics allow for an adaptive, iterative approach to guiding design improvements in environments such as the emerging field of XR, where rigid frameworks may be premature.

3.8 Validity and Reliability

In the previous section we disclosed our positionality regarding the subjective nature of qualitative research, which implies that extra care should be taken when addressing issues of validity and reliability in qualitative work (Creswell, 2013). We stated the need for iterative methodologies such as DBR to guide the gradual refinement of meaning making as new, contextual insights emerge (The Design-Based Research Collective, 2003). We likewise noted that DBR is well suited to addressing issues of subjectivity by iteratively improving the validity of a study through the application of complementary methods over design cycles, although care must always be taken when considering how diverse data should be integrated to build a reliable research design if subjectivity is to be addressed appropriately (Creswell, ibid). We address these concerns on several levels. "Qualitative validity means that the researcher checks for the accuracy of the findings by employing certain procedures, while qualitative reliability indicates that the researcher's approach is consistent with different researchers and different projects", (Gibbs, 2007, cited in Creswell, 2012). Our mixed method design incorporates diverse data within each design cycle to confirm the accuracy of our findings and steer interpretation through multiple levels of reflection in each iteration. A more detailed description of these steps is recounted below. Regarding reliability, steps were taken to ensure a best practice approach to our analysis, data handling and data management in each cycle, and this is also detailed in the current section.

The cyclical nature of our DBR study meant that we worked with five cohorts across three design cycles.

Cycle	**Cohort Description**	**Interaction Mode**	**Methods**	**Sample Size**
1	CHARM-EU Winter school students (prospective masters students, 2019)	Online MS Teams sessions and a Mozilla Hubs Activity	Surveys	Pre-test n=7 Post-test n=5
			Interviews	n=2
2	CHARM-EU First Semester cohort (MSc. class commencing 2022) and Capstone cohort (MSc. class commencing 2021)	Hybrid Classrooms with MS Teams sessions across five European universities.	Worksheets	n=52 Capstone students
			Focus groups	3 teams of Capstone students (n=5; n=4; n=6), plus 7 students who were opportunistically sampled from the first-semester cohort to discuss the intervention themes.
3	CHARM-EU First Semester cohort (MSc. class commencing 2024) and Capstone cohort (MSc. class commencing 2023)	Hybrid Classrooms with MS Teams sessions across five European universities using a bespoke intervention web-app tool.	Time series data from a bespoke web-app intervention tool that was designed for the study.	Semester 1: n=36 of 44 following data cleaning for consent. Capstone: n=37 of 52 following data cleaning for consent.
			Interviews and small focus groups	First semester cohort n=4 Capstone cohort n=7

Table 3-7. Overview of study participants engaging across 3 design cycles.

Each cycle included a set of questions (Ravitz, 2012) relating to 21st century skills. Our first cycle used the Ravitz instrument delivered as an online survey, and we found that they covered our themes so well that we later included them in the subsequent cycles as warmups for our focus sessions (Creswell, 2013). Feedback on the Ravitz questions was very positive, with the students in each cohort self-rating themselves with high confidence on 21st century transversal skills although these data were contrasted with contradictory evidence that students struggled using the XR software. This first example from cycle 1 of our study illustrates where new data has prompted a design decision, and this is indicative of the mixed method approach using in other cycles, with diverse data types.

DBR’s cyclical approach strengthen the validity of our study through iterative refinement across design cycles. Our research employed a pre-cycle literature review and three design cycles to define and then iteratively refine our heuristics. We have additionally applied triangulation where supporting data were available. In cycle 2, this involved a comparison of student worksheets and student focus session comments, which helped to identity new heuristics and highlight student concerns about their hybrid teamwork as useful inputs for cycle 3. As this cycle employed our exemplar software artefact, we included general user experience reports in our interview protocol as a design response for our UX heuristic, to contextualise feedback and avoid potential conflation between descriptions of heuristics and their design implementation. Triangulation was also possible in cycle 3 where we contrasted quantitative time-series sentiment data against participant feedback to characterise moments of team mutual accommodation. Our study improves its validity by establishing a repeatable and transparent analysis process using AODM to uncover team tensions when assessing our heuristics. Standardising our AODM approach ensures repeatability, and we emphasize this in our own study by conducting structured focus sessions to group and manage participant response data when conducting the analysis of each heuristic in a repeating vignette format. Vignettes in qualitative research are typically employed as elicitation techniques to explore participant attitudes (Barter & Renold, 1999) and our literature review did not identify research that employed vignettes in their analysis without first using them as part of the study's data generation. A recent meta-analysis of vignette usage in qualitative research (Verneuer-Emre, et al., 2022) praises the approach for it's potential to measure "normative judgements, subjective beliefs, and behavioural intentions", although this was also limited to studies employing vignettes for data generation. Jenkins et al. (2010) discuss the use of vignettes in qualitative interviewing, highlighting their role in eliciting detailed responses and exploring participants' interpretations of scenarios. Although their focus is also on data generation, the principles they outline can be adapted to structuring analysis. Our approach to segmenting our analysis with vignettes offers a few benefits. By maintaining contextual richness in each analysis, we facilitate the readers understanding of phenomena through participants' perspectives and experiences in much the same way that vignettes can help participants to consider the context of research topics. Links between heuristics can be highlighted to support comparison, which is compatible with CHAT's emphasis on identifying systemic contradictions and transformations in activity systems.

Each of our focus sessions employed the same set of questions, which had been refined through AODM analysis, and asked these of our participants in a similar format per session. Trustworthiness of responses is heightened through this repeating format, combined with probing questions to stimulate student reflexivity and participant response validation. The subsequent coding was scaffolded in this regard by including pre-formatting of transcripts with identical annotations that clarified which responses related to each question during the analysis. Inductive and deductive coding strategies were individually applied to address potential anchoring bias before combining codes to clarify our analysis. Contextual, ecological validity was strengthened through real-world testing of our XR teamwork tool in a real-world hybrid learning environment. This situates our test to evaluate our heuristics in answering RQ1b, within an authentic team activity system where we examined real-world students attitudes.

4 Chapter 4. The Design Process

4.1 Chapter format

Our Design Process chapter is structured to align with the methodological approach used in our study. DBR employs design cycles that include stages of design, testing, evaluation and reflection in each iteration, and we have opted to present our work in a similar fashion to illustrate how it evolved over the course of the design cycles where cycle output findings became design inputs for the subsequent iteration. This chapter describes the three design cycles that shaped the development of our heuristic set. Full methodological details of recruitment, context and data procedures are provided in Chapter 3 (See sections 3.2 to 3.5) and are not repeated here. Instead, this chapter concentrates the design decisions that emerged through the iterative process. Here, we focus on how those methodological components were used within each cycle and how cycle-specific participant feedback contributed to heuristic refinement. Our discussion of each cycle concludes with a design review section for that cycle and our notes on any new or refined heuristic outputs.

4.2 Introduction

We describe each cycle in detail later in this chapter (See sections 4.5 to 4.8). We consider our literature review phase a “Cycle 0” in that we apply the same rationale of moving the study forward by reflecting on earlier activities and as such, our first official design cycle paid close attention to the topic areas identified in our conceptual framework. We initially focused on fully virtual immersive environments to understand how the reported (Witmer & Singer, 1998; Gee, 2003; Castranova, 2004) sense of social presence afforded by virtual reality (VR) might benefit virtual teams. It soon became clear during our phase 1 intervention that students struggled to manage the browser-based VR software, and this was confirmed in follow-up student interviews. This indicated that simple or even simplistic controls might be better suited for those users new to virtual experiences. Further feedback during the phase 1 interviews supported this observation and even through the interviewees (n=2) enjoyed using the software, they were aware of that such experiences were not always well received by students. We asked our interview participants for their impressions about VR’s potential to support teamwork and their responses were largely negative. These data suggested a pivot to focus on aspects of mixed reality that could be replicated in other types of computer supported collaborative teamwork experiences. The final implementation used in our cycle 3 intervention was therefore streamlined to address these findings, with the researchers opting for a web application format rather than a more immersive implementation. This simpler implementation remains consistent with our definition of XR as a shared cognitive space that extends the cognitive capability of individual team members. Students in cycle 1 and 2 both agreed that fully virtual experiences would be too taxing for their laptops, and we took cycle 2 students' confirmation of this point as a good support for our decision to lower the technical barrier while retaining a strong connection with our theme. Cycle 2 generated rich data relating to students' views of hybrid work through MS Teams and tensions they foresaw in approaching a hybrid transdisciplinary teamwork project. Our focus in this cycle was to explore student attitudes to hybrid teamwork dynamics and to dive deeper into students' experiences of social presence outside of a fully virtual environment. Unsurprisingly, we found that our student hybrid teams were very motivated to understand and connect emotionally with their teammates. During our cycle 2 focus groups we noted that students reported positive team experiences using smilies and other emoticons in threaded multimedia conversations and that this helped them somewhat to mitigate the limitations they experienced in connecting emotionally with their remotely located teammates. By combining feedback from the first two cycles, we settled on an interface style that pairs large and easy to use web accessible sliders with visual feedback of the sliders value via an associated emoticon for the interface in our cycle 3 intervention tool.

Transdisciplinary teams must put a lot of their early team formation efforts into gaining insights about the world views and perspectives of their teammates (Pohl, 2005). This is an essential step to make before diverse transdisciplinary groups of individuals can have meaningful discussions relating to how they plan to approach their disciplinary synthesis and work together in a way that is consistent with expected academic rigour. Our design supports this need by first helping team members to express their sentiment on a set of topics, and then compare themselves to a team average value for each. We chose an average to highlight intra-team differences and present an opportunity for the team to discuss them and understand why they exist.

To specifically support transdisciplinary student teams, our tool specifies the CHARM-EU M.Sc programme learning outcomes (PLO) as the default set of team discussion topics. These learning outcomes were known to our CHARM-EU students, as they are central to the aims of their masters programme. We reasoned therefore that these recognisable themes would be meaningful scaffolds for the initial team discussions. However, in our literature review we noted the heuristic that teamwork tools should be flexible to support growing teams, since team requirements change over time (Green & Petre, 1995; Tuckman, 1965). Our tool affords students such flexibility through the inclusion of additional user centred / user defined topics that can be discussed in the same way as the default topics. The PLO topics are preloaded into the database rather than being hardcoded into the app, which supports the option of deploying the app easily in teamwork situations outside of CHARM-EU.

A conceptual framework was developed in a concept map format to address the challenges that we perceived with distributed teamwork practices experienced by our students. The themes of the concept map are inspired from professional work experiences of the researcher while supporting internationally distributed multidisciplinary student teams in undergraduate project-work over many years. These online teams frequently suffered from team cohesion problems that stemmed from poor team communication. This observation resonated with a personal enthusiasm for mixed reality as a communication medium, at a time when it appeared to have finally started to attract mass consumer attention with the promise of a more social online experience. Regular project feedback between supervisor and research student helped to concretise the scope over the first half year of the project as we explored approaches to teamwork and team formation that could scaffold the relevant literacies necessary for distributed teamwork. Supervisory feedback primarily addressed procedural academic issues and the consistency of the methodological approach, rather than the substantive findings. To explore this novel problem space, we focused on a combination of the scaffolds for general teamwork and team transversal skills development needed for healthy teams, plus supports specifically targeting the distributed and mediated nature of the teams' interactions. This informed the creation of three categories of heuristics, i.e. UX, teamwork and distributed team cognition. Our sample of established teamwork theorists are represented for their views relating to supporting distributed team health and growth as well as team mental models, and these cover nine heuristics in our collection. Although our study does not seek to measure details of team mental model building, it is an important theme in teamwork and team cohesion and we included a heuristic to address the development of team mental models. The remaining twelve heuristics speak to the themes of distributed cognition and distributed cognition of teams, both of which view cognition as being mediated by artefacts. This framework was developed through a series of meetings between the researcher and supervisor over the initial year of the study, with reflections and refinements being recorded in a web-based concept map using an online tool (coggle.it). Novak (2009) notes the benefits of this approach for developing knowledge structures and Byrne and Tangney (2014) argue that it can be a beneficial approach for early-stage researchers to frame and think about their work. We extended the literature set with findings from our first two design cycles, which relate to supporting hybrid students in XR hybrid transdisciplinary teamwork. Our additions were mapped to six 'user centred concern' heuristics covering distributed team orientation and onboarding.

4.3 Design Approach: DBR in Practice

Various approaches to carrying out DBR have been proposed (see, Angeli & Valanides, 2009; Barab and Squire, 2004; McKenney and Reeves, 2012; Philips, et al., 2012, and the Design-based Research Collective's (2003) 4-stage methodology, cited in Jong, et al., 2021). The Design-based Research Collective is the most highly cited source, and they describe a design cycle as four stages of "design, enactment, analysis and redesign". This resonates with Scott's (2020) conceptualization of design cycles that involve stages of design, testing, evaluation and reflection, and where redesign is implied as the focus of subsequent design cycle. Practitioners of Speculative Methods condense the steps into three, termed; provocation, engagement and inquiry (Ross, 2023, cited in Scott, 2023). The important point is that a design is proposed and tested in some way, that analysis may then be done and reflected upon so that a refined version of the design can be produced. Our methodology chapter described our approach to this DBR study based on three design cycles, each of which employed the mentioned steps to produce and evaluate heuristics. We describe each cycle in detail later in this section. We consider our literature review phase a "Cycle 0" in that we apply the same rationale of moving the study forward by reflecting on earlier activities and our first official design cycle (1) paid close attention to the topic areas identified in the conceptual framework developed during literature review, while maintaining our planned focus on a learner cantered design. We began our study by focusing on fully virtual environments to understand how the reported (Castranova, 2004; Gee, 2003) sense of social presence afforded by VR might benefit virtual teams. However, it became clear during our cycle 1 intervention that students struggled to manage the browser-based VR software. This indicated that simple or even simplistic controls might be better suited for those users new to virtual experiences. Further feedback during the cycle 1 interviews suggested that even through the interviewees (n=2) enjoyed using the software, they were aware that such experiences were not always well received by students. One of the two students in this cycle did not recognise the value of mixed reality for teamwork, while the second suggested that while it could offer potential to explore ideas since "it would make it a bit more easier to grasp what you're trying to get at", that such experiences would be limited to tasks tailored to 3D work, since "being in an environment where it isn't geared to that sort of task" might be overly complex for other kinds of teamwork.

Students in cycle 1 and 2 both agreed that fully virtual experiences would be too taxing for their laptops, and we took cycle 2 students' confirmation of this point as a good support for our decision to lower the technical barrier while retaining a strong connection with our theme. Cycle 2 generated rich data relating to students' views of hybrid work through MS Teams. Our focus in this cycle was to dive deeper into students' experiences of social presence outside of a fully virtual environment and to generate their feedback regarding their remote/hybrid teamwork experiences. Unsurprisingly, we found that hybrid teams are concerned with the same issues as co-located teams, and that they are very motivated to understand and connect emotionally with their teammates.

"being in person does add that extra effect of being able to understand one another's emotions"
"That connection can be really, really challenging…"
"I feel that makes it harder to form closer bonds"

During the cycle 2 focus groups we noted that students reported positive team experiences using emoticons in threaded multimedia conversations and that this helped them somewhat to mitigate the limitations they experienced in connecting emotionally with their remotely located teammates. This aligns with our literature findings that such types of sharing can support team building. Combining feedback from the first two cycles prompted us to pivot our focus towards aspects of virtual reality that could be replicated in other types of virtual experiences. Our literature review indicated that Social Presence is supported through collaborators sharing of social cues and our ultimate design instantiates these ideas in an interface style that pairs large and easy to use web accessible sliders with visual feedback of the sliders value via an associated emoticon.

Transdisciplinary teams must put a lot of their early team formation efforts into gaining insights about the world views and perspectives of their teammates (Pohl, 2005). This is an essential step to make before diverse transdisciplinary groups of individuals can have meaningful discussions relating to how they plan to approach their disciplinary synthesis and work together in a way that is consistent with expected academic rigour. Our cycle 3 intervention supports this need by first helping team members to express their sentiment on a set of discussion topics, and then compare themselves to their teammates and to a team average value for each topic. We include an average to highlight potential intra-team differences and present an opportunity and prompt the team to discuss their different perspectives so as to understand why they exist and how they may affect teamwork. The goal is not to raise the average or even to consider it as a goal, but simply to act as a talking point that scaffolds the team discussion during the activity, aligning with the DiCoT Space and Cognition principle (Blandford and Furniss, 2006).

To specifically support transdisciplinary student teams in our cohort, our tool specifies the CHARM-EU M.Sc programme learning outcomes as a default set of team discussion topics. However, in our literature review we noted the heuristic that teamwork tools should be flexible to support growing teams, since team requirements change over time (Tuckman, 1965). Our tool affords students such flexibility through the inclusion of additional user centred / user-defined topics that can be discussed in the same way as the default topics. User-defined topics describes bespoke topics that teams identified as potential tensions they would like to discuss. Each team member can add new topics, and these are queued in app as they get submitted. This provides an information buffer (Blandford and Furniss, 2005) that allows teams to self-moderate the pace of their discussions. In the following section, we examine each design cycle in detail and explain our application of the Mwanza (2002) 8-step Activity Orientated Design Method to guide the development of each cycle's heuristics.

4.4 Activity Theory Informed Design Cycles

Activity Theory (AT) is an early Soviet era psychological meta-theory that grew out of the work of Alexei Nikolaevich Leontiev and S. L. Rubinstein (Kaptelinin & Nardi, 2007). Vygotsky (1962; 1978) argued that the human mind is not merely objective and that it develops knowledge and understanding through activity. Park, et al., (2013) applied AT to a meta-analysis of action learning, problem-based learning, and project-based learning approaches to teamwork. The researchers selected AT for its potential to identify "the emergence of social norms based on key members' interactions in a group" (Park, et al., 2013). This view is widely supported in the literature (Engeström, 2000; Marken, 2006; Yamagata-Lynch, 2003, 2007). This has relevance for our own study of a new domain where dynamically emerging norms and expectations are still being developed regarding how interactions should take place. Our approach speaks to the limitations of DBR (discussed in section 3.4.1) by adding a theoretical framing to impose structure and inform our evaluation of each cycle. A difficultly commonly noted with DBR projects relates to remaining true to research aims in the face of the evolving landscape as the study as it progresses (The Design-Based Research Collective, 2003). In this regard, AT provided our DBR study with an analytical approach that is sensitive to the developing relationships and diverse voices within hybrid transdisciplinary teamwork, while complimenting DBR methodologically, to integrate feedback and steer the study through cycles of design, testing, evaluation and reflection as we developed and refined our heuristics.

4.5 Cycle 0: Literature Review

In chapter 2 (section 2.3), we described our set of heuristics drawn from the literature review regarding team cohesion and team building (Tuckman, 1965; Inverardi & Tivoli, 2009), team feedback (LaFasto and Larson, 1989), team roles (Salas, et al., 2013), team communications (Katzenbach and Smith, 1993), team mental models (Mohammad, et al., 2010), topics relating to distributed cognition (Hutchins, 1965) and distributed cognition of teams (Blandford and Furniss, 2005; Webb, 2008). We also included an additional broad heuristic relating to user experience (Muller, et al., 2018). This set of twenty-three heuristics is intended to support hybrid teamwork by scaffolding team process and distributed team cognition. We understood that such a large set would require refinement to be operationalised, and this process was undertaken during the subsequent cycles.

4.5.1 Cycle 0 Analysis and Findings

Heuristics

Our literature review provided useful design inputs relating to what is already known of team cohesion and formation. Tuckman's model (Tuckman, 1965), (i.e. Forming, storming, norming, performing, and adjourning) is a famous example of very high-level heuristics for teamwork where the stages represent team growth. Teams move through the steps as they progress with the work. The first three stages of Tuckman's model are most relevant to novice teams, although successful student teams frequently complete every step. Tuckman is not entirely prescriptive about when a team should move to the next stage but his work highlights that the team's requirements change at different stages of a project life cycle as the team develops. A very practical heuristic that we can draw from this is that our software should adapt to the users changing requirements (Inverardi & Tivoli, 2009), and our tool addresses this by providing a feature that offers support for user generated topics for ongoing discussions.

If a team becomes stuck in Tuckman's storming stage, they are viewed as a "pseudo team" by Katzenbach and Smith's (1993) model of team effectiveness, which describes teamwork across five levels ranging from working groups of individuals to high-preforming teams whose members hold themselves accountable to one other. Teams can mature through these stages or remain indefinitely at any level, or indeed even slip backwards into team dysfunction. Many of Katzenbach and Smith rules represent the types of hurdles that transdisciplinary teams face, for example their set of guidelines relating to goals, that team members need to select goals, express those goals in a common way and understand relative priorities. These are difficult tasks for transdisciplinary teams due to their uniquely diverse make-up and differing disciplinary perspectives. The model includes guides for team formation (e.g. team size and composition, which is dictated in our cohort). Additional rules are covered however, and these were useful design inputs in our final cycle prototype team tool (e.g. providing functions that allow user to be specific in communications, help them in recognising and managing relative priorities, and by facilitating a clear working approach).

Another popular teamwork model by LaFasto and Larson (1989), describes successful teams as depending on five key factors. They view intra-team feedback as a key ingredient in successful teams, and state that "to foster team relationships, members must become adept at giving and receiving feedback", (LaFasto & Larson, ibid). This is a core design heuristic that we leverage in our tool (i.e., an ideal system should include functions and scaffolds for users to provide intra-team feedback), and with respect to our problem space, the improved social presence of XR supports this feedback. This is consistent with Short, Williams, and Christie's (1976) perspective, and aligns with the expectations of Gee (2003) and Castranova (2005) who see the increased information bandwidth as enhancing both feedback quality and interpretation. Keil & Roy (2002) successfully applied Social Presence Theory to measure the effect of intra-team feedback in lean and rich media, although they did not include XR at that time. It is our view that feedback mediated via XR may be better received thanks to enhanced empathy and a more natural sense of person-to-person communication. An overview of the design heuristics drawn from Cycle 0 are presented below in table 4-1.

Source	**Code**	**Heuristic**
User experience		
Muller, et al. 1998	ux1	System Status, User Control and Freedom, Consistency and Relevancy, Error Recognition and Recovery, and Task and Work Support
Teamwork theories		
Tuckman, 1965;	th1	Tool should adapt to the users changing requirements
Inverardi & Tivoli, 2009		
LaFasto and Larson, 1989	th2	Support intra-team feedback
Salas, et al, 2013	th3	Support different roles and responsibilities
	th4	Support team mission objectives and norms
	th5	(consider) the environmental context
	th6	Foster team familiarity (to build affiliative associations)
Katzenbach and Smith, 1993	th7	Be specific in communications

	th8	Recognise and manage relative priorities
	th9	Employ a clear working approach
Team mental models		
Mohammed, et al. (2010)	tmm1	User-defined topics create mental representations of the key elements within a team's relevant environment that are shared across team members
DCog and DiCoT		
DCog (Hutchins, E., 1995)	dc1	Embodiment of information within the system
	dc2	Co-ordination between agents,
	dc3	The impact of set and setting (ecosystem) on the process taking place.
	dc4	Cognitive process is delimited by the functional relationships among the members
DiCoT (Blandford, A. & Furniss, D., 2006)	dc5	Physical Layout: Space and Cognition
	dc6	Physical Layout: Subtle Bodily Supports
	dc7	Physical Layout: Situation Awareness
	dc8	Information flow: Buffering
	dc9	Artefacts: Representation – Goal Parity
	dc10	Artefacts: Coordination of Resources
DiCoT extended (Webb, 2008)	dc11	Development of practice
	dc12	Development of practitioners

Table 4-1. Cycle 0. Literature derived heuristic supports for novice hybrid transdisciplinary teams.

4.5.2 Implications of Cycle 0

Cycle 0 focused on integrating landmark literature relating to teamwork and distributed team cognition supports that recognise of the effects of technology mediation on communication. Our initial set of heuristics defined in the review should be valuable for any distributed team, but we had yet to include students' perspectives regarding mixed reality mediated teamwork experiences. This set the agenda for our next design cycle (1) where we worked to explore students views regarding the potential of XR for teamwork. We note the techno-social aspects of our study and refer to our positionality regarding the importance of student voice in addressing bias. Participant feedback is essential to revealing our students' attitudes and a key method in design research. We therefore viewed such feedback as an important input for refining the literature-based heuristics, and a potential source of new heuristics relating directly to our students' experiences of working in a distributed context.

4.6 Cycle 1. Mozilla Hubs, group activity and pair work.

4.6.1 Introduction

Cycle 1 (figure 4-1) focused on the student cohort of the CHARM-EU winter school. The winter school was a one-week pre-pilot test run for a variety of activities and tools that were intended for use by hybrid students of the CHARM-EU M.Sc. in Global Challenges for Sustainability. The programme emphasised transdisciplinary and hybrid teamworking as its core learning objectives.

We had several aims in this cycle. We wanted to explore students' perspectives of coordinated work in an immersive reality, while also observing how the students conducted themselves, how they used the mixed reality software, and interacted with one another when working on a paired task activity. Coordination, collaboration and communication are commonly cited as activities that define teamwork (Xiao, 2013) and an exploration of these transversal skills offered potential foci for how we might design XR supports apropos RQ1. Cycle 1 provided insights necessary for us to move from a broad problem space towards a refined narrow problem space with better clarity of student's views regarding XR's potential to support distributed teamwork and transversal skill practice.

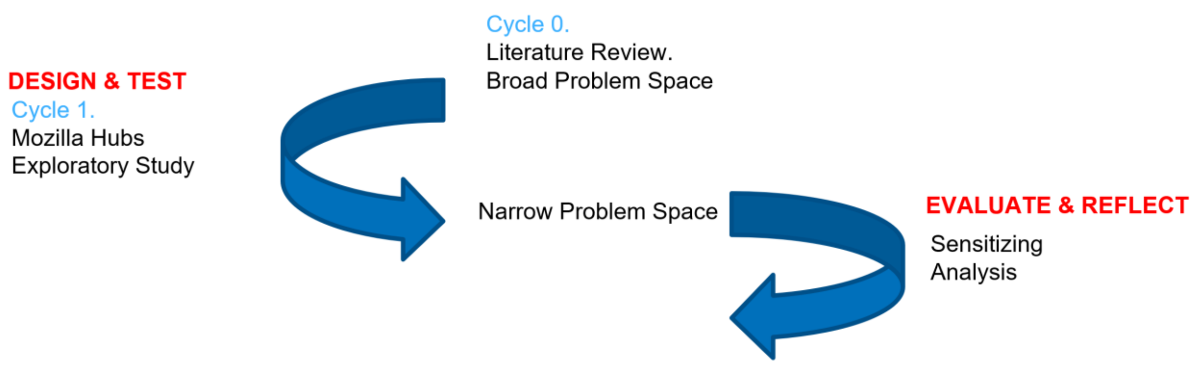


Figure 4-1. Cycle 1, conceptual refinement phase.

4.6.2 Participant Selection

As the researcher was involved in the delivery of the programme, access to the gatekeepers was organised in advance via email and approval was promptly granted. The students were representative of prospective master's students who would be working as novice hybrid team members, having similar ages and profiles and an expressed interest in transdisciplinarity and hybrid working. As such this group aligned well with the novice hybrid transdisciplinary team members reference in our RQ1. The full cohort were invited to take part in the research by email prior to beginning the winter school and consent was organised via MS Forms submission, which clearly described that the study was separately organised to the Winter school and that participation was not obligatory. Seven individuals consented to take part in the activity and focus group, with two of these agreeing to be part of the interview phase. The interview participant did not work together during the activity however this allowed us to generate independent student perspectives regarding the intervention. The cycle 1 intervention did not include enough participants to work with full teams and a pair-task activity was used for practical reasons. Our unit of analysis expanded to full teams as we began to work with larger cohorts in subsequent cycles.

4.6.3 Intervention Design

The CHARM-EU Winter school (February 2020) took place during the COVID-19 lockdown, and this presented an opportunity to propose a virtual social event to the programme gatekeepers as a nice addition to the programme, and a suitable setting for our first design intervention. Participating students were invited to meet in a browser based virtual environment on the penultimate evening of the winter school for the XR event. We created an instance of a Mozilla Hubs world (figure 4-2 and 4-3) with some customisations for our cohort, including branding of the five CHARM-EU partner universities and the CHARM-EU logos scattered throughout the space. Students were encouraged to find and interact with these objects once they had joined the space. Students and staff appeared as avatars that they selected and personalised on the login screen before joining the session. Additionally, the researcher had a video feed from their webcam which was pinned as a floating video frame in the centre of the space to act as a focal point to gather the group together for a discussion.

The virtual activity was a prototype to explore our heuristics. The teamwork category, relating to team growth, feedback, clarity of communication and mental model building were realised in a combination of the activity tasks and the affordances of the virtual environment. Communication related DCog and DiCoT heuristics were implemented by taking advance of said affordances of the software (e.g. embodiment of information within the system), while task related (e.g. coordination between agents, aiming for goal party, coordination of resources) were addressed via the intervention design and activity guidelines. The open-ended nature of activity pair-task encouraged learner agency to flourish, which supported the contextual validity by eliciting authentic student views and behaviour during the session.

Figure 4-2. CHARM-EU Winter school Mozilla Hubs event environment showing institutional logos.

Figure 4-3. CHARM-EU Winter school social event 2020 in Mozilla Hubs, with participant names obfuscated.

The agenda for this event included a short collaboration activity pair-work scavenger hunt where students were asked to locate an academic paper from their class work and to upload it into our specially created Hub's world as a virtual object. The researcher acted as a facilitator to guide students through this task with verbal instruction, mentioning the various interface elements that students needed to use. Once the document had been uploaded, the cohort were asked to interact with an object that one of their peers had created. No further instruction was given, and the students were free to choose how to interact with their peers' objects. This resulted in a broad range of behaviour including purposeful reading and examination of papers, as well as some students grabbing objects and throwing them around within the space. This informal event represents a first exploratory iteration in our larger design-based research project. The activity indicated difficulties that students had within Hubs, and this gave us some useful initial guidance towards refining the problem space, and the related student feedback prompted us to simplify our concept for the exemplar tool interface that we later employed in answering RQ1b.

4.6.4 Observations

Observations and researcher notes were useful in generating data during the CHARM-EU social event and the researcher adopted an informal 'observer as participant' role while students worked in the virtual space. This helped to guide the follow-up interviews as it prompted some questions relating to how students interacted and helped to address Engeström's criticism regarding DBR's failure to be open to divergent data. Student agency is a rich source of such divergence and a potential indicator for which supports may be needed. At this early stage we were satisfied to observe how our students interacted with the environment and what issues they encountered, and Basili's work (2006) on measuring Agile goals helped to inform our approach in this regard by prompting us to reflect on "what", "where", "who", and "when" things are done in relation to software users achieving predetermined aims. This was an essential first step in answering our first research question regarding how we might design systems that can support novice teams. We observed that some students struggled to operate the interface correctly when it was noted that several attendees could not immediately enable their microphones. Our design did not anticipate user interface hurdles, and this divergent data is an example of the type of challenge which Engeström cautions against, and which observations can reveal. In terms of outputs, our observations were a useful starting point for the subsequent cycle 1 interview design, but they have also contributed to answering our second research question to produce relevant heuristics, particularly in terms of simplifying our intervention design but also in the practical consideration to avoid fully immersive virtual environments in our later design cycles.

4.6.5 Surveys and Interviews

Pre and post-test surveys were used to poll student attitudes in relation to transversal skill development in a virtual world such as the Mozilla Hubs environment, to uncover aspects of technology-mediated hybrid teamworking that students may consider challenging. Such challenges may indicate areas requiring support and may therefore point to new potential heuristics for our collection. The cohort were participants on a winter school that was focused on transversal skill development in the context of a pilot in the development of a larger master's programme. As such they were suitably representative of the types of novice hybrid transdisciplinary teams that we target in our first research question. Pre and post-test surveys were administered to the subjects using an instrument that had been validated (Ravitz, 2012) to measure student attitudes to transversal skill development with traditional information communication technologies (ICT). While the instrument had not been validated for mixed reality experiences, we feel that this leap is reasonable given the usage of XR as a communications technology. The cohort was very small (n=7) and in fact the response rate on the post-test dropped to only five individuals. We are therefore not claiming any statistical relevance of the data and a deeper statistical analysis would be meaningless. Nevertheless, the data were helpful in guiding the subsequent design iteration by helping to establishing a sense of how students feel about such technologies. The surveys asked respondents to indicate their attitudes on a five-point Likert scale ranging from strongly agree to strongly disagree. Responses show that all participants considered themselves to be either comfortable, or very comfortable in using various ICT tools. A variance from pre to post test was observed, particularly regarding the transversal skill of giving and receiving feedback which dropped in the post test. Our reading of the data informed the creation of a set of follow up interview questions. This intra-cycle design step is consistent with a Design Based Research approach of feeding information forward from one step to the next.

4.6.6 Informal Focus Group / Debrief

Immediately following the Mozilla Hubs activity, the researcher asked the participants to gather in the central area of the virtual space to take part in an informal discussion regarding their experiences of the tasks. The discussion also included a review of any artefacts that participants had created or engaged with during the intervention to gain insights of how students interacted, and their sentiments regarding the experience. The discussion also covered the same set of questions on transversal skills as those used in the survey (Ravitz, 2012), with a particular emphasis on the theme of teamwork in mixed reality (XR) to elicit feedback regarding participants experiences of distribute teamwork. Due to the presence of students who had not provided consent, it was not possible to record the session. However, key responses were documented and used to inform aspects of the follow-up interviews. Challenges enabling the audio controls were reported by students during this debrief.

4.6.7 Interview Data

An invitation to take part in the research had been shared in advance and this included an invitation to a follow-up interview. Two students agreed and these sessions produced valuable data that confirmed the challenge with voice communication between participants due to the complexity of the user interface. Survey data had identified giving and receiving of feedback as a transversal still where students saw challenges, and this was therefore probed by the researcher and was confirmed by interview participants. Cycle 1 generated just under five thousand words of student feedback over two separate one-hour interviews. We prepared for the sessions by collating our sub-set of the Ravitz, et al. (2010) instrument questions to form the basis of a set of interview questions. The selection of this subset of questions resulted from the informal notes taken during the group discussion and questions were asked in relation to the student's experiences of the mixed reality environment. This was helpful in exploring areas of 21st century skills that were underdeveloped in the cohort, and a useful guide in steering us towards understanding which types of supports could be addressed to answer RQ1. For example, in addition to asking if the participating students had direct experience of a particular skill (e.g "work with other students to set goals and create a plan for your team"), we also asked them how useful they felt the mixed reality environment might be for working with that skill (e.g. "how could this environment be helpful when working with other students to goals and create a plan for your team"). The initial feedback regarding student attitudes to practicing or using skills in XR was bimodal, with one student open to the idea of using XR for such types of activities, and the other feeling it would be overly complicated. However, when asked to elaborate on how well XR might support teamwork in general, both subjects shared positive views and considered the environment to be a useful tool for teambuilding.

"I think that just being in a virtual reality space together makes it seem like you are, you know, siting across the table together and working. Because you are sort of sharing a dimension together somehow"

"it makes it more interesting and it makes it more real"

Difficulties when initiating communication were evident, which may indicate problems with the design of the task rather than the Hubs tool, or due to lack of clarity regarding the activity rules. Further supports would be required to conduct a more complex intervention within such an environment.

"I wasn't sure whether we were supposed to have it on".

"I didn't know how to start a conversation; I didn't know if people were hearing me 'cause sometimes I was not sure".

There are indications of participants adopting a social protocol, for example with one interview subject stating that they only decided to select a custom avatar after noticing the appearance of others, indicating that the student was interested in having better control over their self-expression in the environment.

"only changing my avatar [...] when I realized that people had different things on"

While both interview subjects engaged in the activity, neither managed to complete the tasks that were given, and this therefore limited the scope of questions that could be asked during the interviews. A coding of the interview transcripts guided us to "move towards consolidated meaning" (Saldaña, 2016), and our review of the interview sessions showed some interesting indications of participant sentiment with respect to communication and interactions using XR tools.

4.6.8 Heuristics updates from cycle 1

DBR requires constant reflection to minimise the introduction of researcher bias. In this cycle we wanted to explore students 21st century skills challenges that might be relevant to XR for teamwork. To guide our study when considering how best to translate each cycle's outputs into inputs for the subsequent iteration, we applied AODM's eight steps (Mwanza, 2002). Applying AODM helped to conceptualise students reported experiences of XR for teamwork so that we could identity and then appropriately frame any perceived challenges to narrow our design problem space. The technique is supported by eight questions that researchers should ask themselves before inferring conclusions from data. The answers help to conceptualise activity systems by describing them in terms of the third generation CHAT elements. Third generation activity theory emphasises the cultural historical significance of activity by comparing the activity being studied with earlier or parallel activity systems to understand how a situation, process or artefact came into being. By following this line of inquiry to compare activity systems, one may identify tensions that do not stem from the particulars of any given context (i.e. the current activity) but are instead rooted in earlier or parallel practices. This is an important consideration when designing a new approach or new solution that may introduce unanticipated tensions and is therefore suitable for a problem space where such tensions are not obvious. The approach also responds to the need to seek divergent perspectives stemming from learner agency (Engeström, 2000). In a technology-based intervention research study, tertiary systemic contradictions would highlight different attitudes between traditional experiences of teamwork versus the intervention activity.

We now describe how AODM was applied when contextualising cycle 1 data by following the eight-steps to explain each element.

Subject

Our subjects were undergraduate and recently graduated students that had expressed an interest in transdisciplinary teamwork by electing to be part of the winter school.

Objective

Their stated aim was to learn about hybrid transdisciplinary.

Tools

The mixed reality experience can be viewed as a set of tools, and this includes many features that we might easily overlook. Multiple communication tools, or channels, including, voice, gesture or pictorial representations are possible, and the choice of channel (or combinations of channels) was also considered. User interface design is clearly a significant factor and Mozilla Hubs presents a pleasant, simple and functional interface that is intended to be easily understood by inexperienced users. Even so, in the winter school event, participants were noted as having difficulty in locating the voice controls and movement within the space was reported as being difficult to perform.

Rules

The rules of social protocols, netiquette (a neologism describing expectations of online behaviour), customs and conventions all play a part in any hybrid activity involving multiple actors. When the subjects were asked to interact with a peers newly created object, they were bound by these rules. Other classes of rules include the rules imposed by the technical nature of the XR space and the limitations that this might create. Or indeed the rules that arise out of the software design, for example the choice of physics model that a virtual environment uses can influence the subjects experience and capabilities considerably.

Division of Labour

At least two subjects interacted with the objects, the first (its creator) and the subsequent (anyone else that interacted with it). Activity Theory sees the activities of individuals as influencing that of others through their division of labour. An example from our winter school study would be how or where the first participant placed the object to begin with, which would then influence how the subsequent participant could interact with it.

Community

The community in this scenario is understandably large as it encompasses everyone from the student cohort to the staff engaged in the event, or indeed anyone that might have influenced the experience through their knowledge or interests.

Synthesis

Describing the system in this brief AODM helped frame the initial context of our study to focus on XR interfaces for distributed teamwork. By applying AODM we uncovered a tension relating to onboarding novice hybrid learners. A third-generation activity interpretation of the tension suggested that technology experience from prior activity systems of ICT tools may not prepare students well for XR mediated work.

The following table (4-2) lists the set of heuristics at the end of cycle 1. This includes those heuristics drawn from our literature review and three new additions developed from our AODM analysis of cycle 1 student feedback.

Source	Code	Heuristic
User centred concerns		
Cycle 1	c1a	Don't assume users will recognise UI controls
	c1b	Team tools should provide detailed instructions
	c1c	XR onboarding is difficult for new users
User experience		

Muller, et al., 1998	ux1	System Status, User Control and Freedom, Consistency and Relevancy, Error Recognition and Recovery, and Task and Work Support
Teamwork theories		
Tuckman, 1965;	th1	Tool should adapt to the users changing requirements
Inverardi & Tivoli, 2009		
LaFasto and Larson, 1989	th2	Support intra-team feedback
Salas, et al., 2013	th3	Support different roles and responsibilities
	th4	Support team mission objectives and norms
	th5	(consider) the environmental context
	th6	Foster team familiarity (to build affiliative associations)
Katzenbach and Smith, 1993	th7	Be specific in communications
	th8	Recognise and manage relative priorities
	th9	Employ a clear working approach
Team mental models		
Mohammed, et al., (2010)	tmm1	User-defined topics create mental representations of the key elements within a team's relevant environment that are shared across team members
DCog and DiCoT		
DCog (Hutchins, E., 1995)	dc1	Embodiment of information within the system
	dc2	Co-ordination between agents,
	dc3	The impact of set and setting (ecosystem) on the process taking place.
	dc4	Cognitive process is delimited by the functional relationships among the members
DiCoT (Blandford, A. & Furniss, D., 2006)	dc5	Physical Layout: Space and Cognition
	dc6	Physical Layout: Subtle Bodily Supports
	dc7	Physical Layout: Situation Awareness
	dc8	Information flow: Buffering
	dc9	Artefacts: Representation – Goal Parity
	dc10	Artefacts: Coordination of Resources
DiCoT extended (Webb, 2008)	dc11	Development of practice
	dc12	Development of practitioners

Table 4-2. Heuristic set at the end of cycle 1, including 3 new additions [c1a, c1b, c1c].

4.6.9 Cycle 1 Design Review

AODM's eight step questions guided our analysis of the cycle 1 interview feedback and conceptualising the feedback through the lens of third generation activity theory helped to identify tensions that affected the ideal outcome of our intervention.

Tensions noted in Cycle 1

Students reported good ICT experience but struggled with the interface. A tension existed between the subject and tool, stemming from participants not understanding how to operate the tool. This tension implied a training need existed or that extra information would be helpful, and this has informed our first heuristic from cycle 1. Figure 4-4 illustrates this tension below.

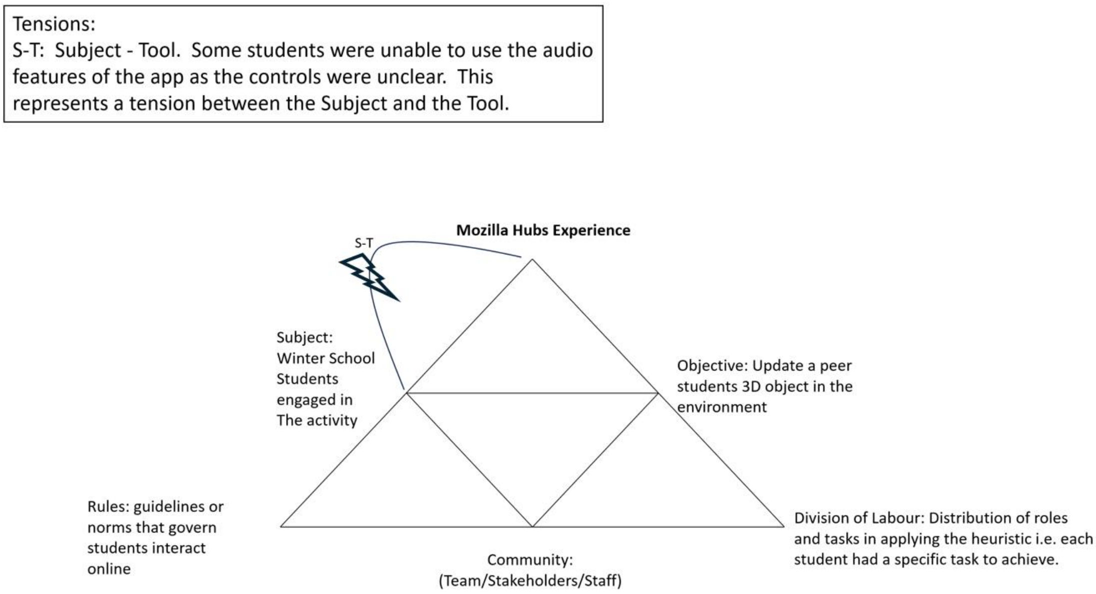


Figure 4-4. Cycle 1 AODM tensions, (a)

A second finding resulted from an exploration of how students interacted with a peer's object during the intervention. Students did not know how to behave when asked to interact with their peers' objects, which may be attributed to expected behaviour and netiquette, or other related social protocols, since focus participant feedback indicated that at least some participants were reluctant to interfere with peers' objects. This conflicted with the activity instructions and we therefore conceptualise this as tension between the activity rules and division of labour (figure 4-5).

Tensions:
R-DoL: Rules - Division of Labour. Students were slow to rework their peers' submissions which may indicate a tension between the community and the division of labour.

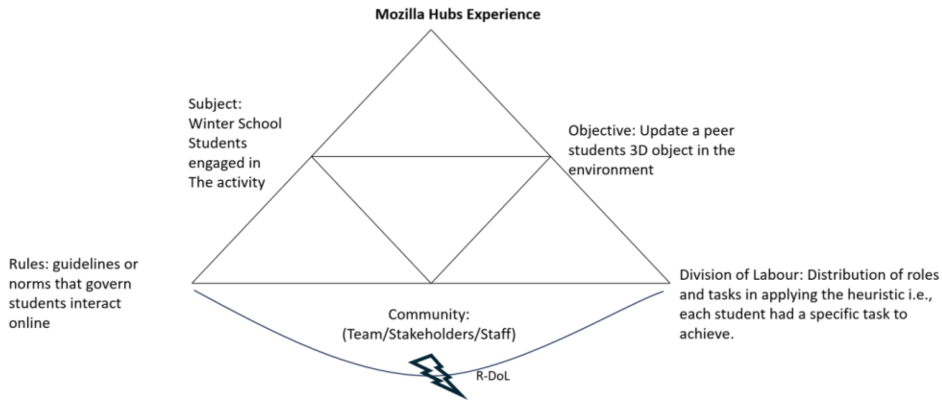


Figure 4-5. Cycle 1 AODM tensions, (b)

Heuristics updates from Cycle 1

A data point that was identified as a hurdle for XR users within our phase one study (cycle 1), relates to how users begin communicating in a shared/social mixed reality environment. Students from the winter school activity reported that they did not know how to begin interacting with others because their microphones were mute, and that they did not notice the relevant user interface button to enable it. This type of challenge is an example of a human computer interaction problem that CSCW researchers' study through the lenses of user interface and user experience design, and there are many heuristics to negotiate such hurdles already established, e.g., making no assumptions regarding the skill or dexterity levels of users; use nonoverlapping layouts; don't require the user's full attention; etc (Myers, et al., 2000; Mohammad, et al., 2010). Our UX heuristic supports this, and our first three user centred heuristics speak to the same challenge by scaffolding leaners use of XR tools with supplementary information to assist with onboarding and orientation. The heuristics drawn from these findings clarify that we should not assume whether users will recognise UI controls, that tools should provide detailed instructions, and that XR onboarding is difficult for new users.

Preparing for cycle 2

The feedback from cycle 1 indicated that students questioned our rationale for using immersive XR systems such as Mozilla Hubs for teamwork and we describe here how this prompted a decision to simplify our interface once it came time to develop the final design cycle prototype. This represented a considerable change in terms of the anticipated final design. Complete details of the cycle 3 protype had yet to be decided at this stage, of course. But our expectation at the initial proposal of the project focused specifically on immersive mixed realities, and our cycle 1 analysis highlighted the problematic nature of such experiences from the perspective of hybrid learners. Presented with incompatible design constraints, we followed the student feedback first and then re-examined our assumptions regarding our design outputs in this light. While this necessarily had more of an impact on our final cycle 3 prototype design (see section 4.8.3 for details), it can also be seen in the design of cycle 2, where we needed to consider that any approach to sharing feedback would later need to be simplified and streamlined to allow for translating this into an exemplar software tool in the final cycle 3 design loop.

Our first research question places a focus on supports for novice hybrid transdisciplinary teamwork and our cycle 1 exploration of students 21st century skills helped to steer our study towards addressing team related transversal skills gaps. In our pre and post-test surveys exploring student's attitudes to 21st century transversal skills, three items dropped from positive to negative between surveys (average 'agree' to average 'disagree' on a five-point scale from strongly agree to strongly disagree.

- Give feedback to peers or assess other students' work [4 to 2.8]
- Generate my own ideas about how to confront a problem or question [4 to 2.8]
- Evaluate the credibility and relevance of online resources [4.1 to 2.6]

While this does indicate a significant change in our sample, one cannot claim generalisability or statistical significance for such a small study. However, it presented a design input and direction for our next design cycle. Other questions also dropped but remained positive above the median. Giving feedback to peers [2.8 average, versus a median of 3.2 for the averages of all questions in the post survey] was the theme that best aligned with our teamwork focused research questions. This suggested that team feedback could be a fruitful and impactful avenue to explore more deeply during cycle 2. Our cycle 0 literature review had highlighted the importance of communication towards clarity of process and team goals, and how these are the foundations of the team's mental model building. Novice transdisciplinary teams must work on their team synthesis, and this presented a suitable process where the team communications and feedback could be scaffolded in a technology-mediated hybrid teamwork intervention.

Our goal in cycle 1 was to explore XR's potential to scaffold transdisciplinary team related transversal skill development and seek participant views relating to this. The move from problem to solution space required an exploration of how we might first identify XR systems that support novice hybrid transdisciplinary teamwork, before approaching RQ1 in addressing how we might deign them. Focusing on that solution space identifies potential heuristics that can address authentic student challenges, which speaks to RQ1b. Interview data suggested that XR onboarding is problematic, and that introducing extra informational supports may be helpful in addressing this challenge. Survey and interview data both highlighted a perceived 21st century skills gap by participants concerning the giving and receiving of feedback within technology-mediated team environments, which presented a focus for our cycle 2 intervention design. As our literature review had illustrated the potential of Activity Theory to analyse dynamic systems, we noted parallels with the challenge of transdisciplinary team synthesis where structure is required to balance the views of team members, stakeholders and community. We reasoned that a simplified CHAT descriptive analysis would offer teams a framework to reflect on and share their concerns and perceived challenges regarding transdisciplinary team synthesis while also offering a frame to scaffold the structured giving and receiving of peer feedback regarding each team members individual disciplinary perspectives.

4.7 Cycle 2: An Activity Model exploration for the support the cohesiveness and effectiveness of remote teams: A CHARM-EU Case study.

4.7.1 Introduction

Cycle 2 (figure 4-6) aimed to generate insights into how distributed transdisciplinary teams can best collaborate to co-define and understand a shared problem by scaffolding team discussions relating to project hurdles. This cycle introduced a format for the giving and receiving of peer feedback relating to each team members perceived project challenges from their disciplinary perspective. This was a transition from "problem space" to "solution space". Cycle 1 outputs targeted student onboarding and understanding of how to begin working with an XR tool, which resulted in three related heuristics. However, cycle 1 survey data and interviews both suggested that giving and receiving feedback were underdeveloped 21st century transversal skills within our cohorts, which implied that a deeper investigation of this theme would be a useful direction for our next cycle. This was achieved through a combination of complementary methods. Our intervention in cycle 2 asked students to identify and discuss any perceived external factors influencing their team discussions, and how these might shape their understanding of project goals. It was also an opportunity to give and receive feedback as a prompt for reflection on transdisciplinary team integration. Students completed a worksheet (Appendix 4) based on concepts from Engeström's' (1987) extended conceptualization of Activity Theory in the intervention. While we were particularly interested in students' views relating to their tool use, our data generated insights into how students feel that extrinsic rules, team division of labour and the communities they engage with might also have an impact on their teamwork. Following this hybrid-class based intervention, a series of four focus groups were undertaken to further explore student views relating to these themes.

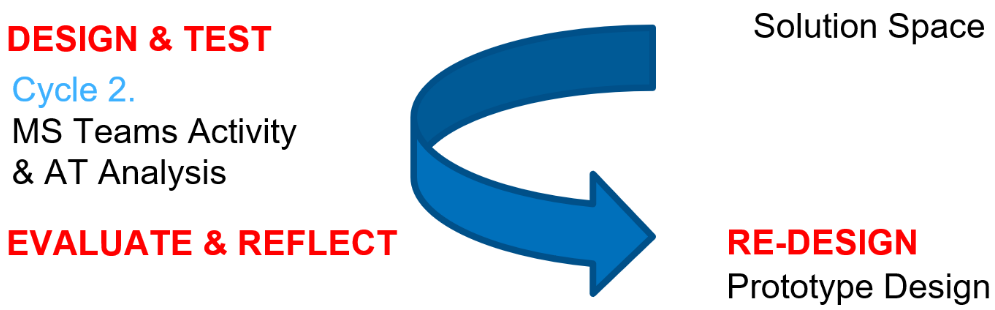


Figure 4-6. Cycle 2, moving from problem space to solution space. Cycle 2 tested a paper protype via MS Teams, which was later re-designed as a software tool.

4.7.2 Participant Selection

Capstone students of the CHARM-EU M.Sc. were the primary cohort during cycle 2 of our study. This transdisciplinary cohort work primarily in a hybrid team setting where team members may be dispersed across any of the CHARM-EU alliance member universities. As such they are highly representative of the types of novice transdisciplinary teams identified in our first research question and were therefore purposively sampled with no additional inclusion or exclusion criteria. The entire cohort undertook our in-class team learning intervention as part of their coursework however care was taken to emphasise that involvement in the research aspects were optional in email invitations and again before the activity began. Fifty-two students granted consent to include their data and a subset of three teams (n=5; n=4; n=6) agreed to engage in the follow-up team focus group discussions. As the researcher was a teacher on the programme, students from the first semester cohort identified themselves as being interested in the research and a final fourth group were then opportunistically included as a convenience sample of seven students from the class of 'phase 1' (this is CHARM-EU terminology for the first semester of the master's programme). While this group did not engage in the intervention and had not yet undertaken their capstone project, they had a good deal of relevant experience working in hybrid teams from their first semester team project. Although this group did not take part in the cycle 2 team intervention, their views on distributed teamwork provided relevant insights for the design of cycle 3.

4.7.3 Intervention Design

In cycle 2, student teams collaboratively completed a worksheet based on concepts from Cultural Historical Activity Theory to describe their project in terms of the CHAT model and collate their perceived project tensions (see example in Appendix 4). Cycle 1 refined the focus of RQ1 to identify the transversal skills of giving and receiving intra-team feedback, and cycle 2 represents a first design solution that implements our heuristics to scaffold this important transversal skill by eliciting feedback from each team members disciplinary perspective. Leontiev's CHAT model is a useful framework for thinking about complex dynamic systems of human activity and we felt that CHARM students, who study techniques to tackle global wicked problems, might find it to be a useful tool for their cognitive toolbox. We developed and delivered learning content to support a group activity, although our goal was not to focus overly on teaching Activity Theory. Instead, we asked the teams to use AT as a frame for a team discussion that would help them develop an accurate team mental model of their project scope. This aspect of the intervention was designed to scaffold team members in reflecting on the mix of disciplines and team capabilities by considering their peers disciplinary perspectives, as a step towards team synthesis. While the intervention related to all our heuristics, the teamwork category of heuristics was likely most obvious to students, particularly with regards to supporting intra-team feedback, team mission objectives and norms, and as a support for different roles and responsibilities. This also directly addressed our heuristics relating to being specific in communications and helping team members to recognise and manage relative priorities by employing a clear working approach. Additionally, the design was intended to foster team familiarity by building affiliative associations within the team as an outcome of the activity. Our distributed team cognition heuristics were also represented, especially regarding establishing team situational awareness via the giving and receiving of feedback relating to perceived challenges. The intervention worksheet additionally acted as a mediating artefact to buffer the discussion information and help students build shared team mental models relating to goal parity and their coordination of team resources, and this produced contextually rich data to steer our research.

This cycle helped us to produce new heuristics while generating structured data relating to the types of tensions anticipated by novice hybrid transdisciplinary team members, which was generated in focus groups and a worksheet which asked students to identify the CHAT elements relating to their projects, and to list any perceived tensions. The structured nature of the worksheet also presented administrative advantages for us when preparing for our cycle 2 focus groups as we needed only to collate worksheet data to identify patterns in student's attitudes to hybrid teamwork tools and perceived project tensions. This contributed to answering RQ1 by helping to focus our study on real-world tensions and identifying the types of contextually relevant supports that would be practical and actionable in the subsequent cycle.

Of the eleven teams that engaged in the activity, three did not manage to complete section 2 of the worksheet ("Section 2: How might we respond to or otherwise mitigate the tensions?") due to poor time management during the session. A further two teams gave non-sequitur or overly brief answers that failed to accurately address the question. The remaining six teams managed to discuss how they planned to improve their teamwork experience. It is gratifying to note that these teams recorded positive, proactive strategies in their worksheets which we summarise below for reference.

- Empathy (noted in 2 teams)
- Be aware of each other's learning goals and support each other accordingly.
- Take time to listen to everyone's understanding and expectations of the project.
- Express shared values (empathy, respect), talk about finding common ground.
- Establish an open communication channel early on.
- Creating a sense of belonging amongst each other so we feel free to share any struggles.
- Being mindful of [...] personal contexts

These sentiments helped us to identify a theme in our data that such distributed learners value expression of emotions and personal disclosure from their teammates. We did not explore the cultural backgrounds of our cohorts to examine possible impacts of multicultural mix on team values as this was beyond the scope of our research question, although one student noted that cultural expectations of when to speak frustrated intra-team communication in one team, and that the team were motivated to improve their communications to overcome this. This indicates a desire for closer teamwork, which aligns with feedback from follow-up focus groups that generated rich data speaking to the CHARM-EU students' motivation to develop intra-team relationships. The heuristic outputs from this cycle reflect these themes and at the design level, have influenced our interface implementation for the exemplar tool used in Cycle 3.

4.7.4 Observations

Limited opportunities for observations were expected during the intervention due to the hybrid nature of the activity with students working across five university campuses which prevented the researcher from seeing the full scope of team interactions. Observations were useful however within the cycle 2 focus groups session to complement the semi-structured nature of the sessions by highlighting moments for deeper probing questions within our semi-structured design (Creswell, 2013). We were specifically interested in emergent themes that aligned with the worksheet topics, such as confusion regarding roles, discussion of tools and tool purposes, confusion relating to tool use and any mention of specific communities. Any instances of questions to teammates relating to their disciplinary expertise or examples of social presence were also expected to be interesting. These subtopics were collated in advance in our interview protocol spreadsheet and tagged with a medium importance flag, versus high importance for the main discussion topics which directly related to the literature-based heuristics. For example, when discussing aspects of social presence, we noted that the theme resonated with participants and we probed deeper with questions designed to determine whether these related to Affective, Interactive or Cohesive (Rourke, Anderson, Archer, and Garrison, 1999) aspects of their distributed teamwork experience. Similar, when discussing team mental models, we asked secondary probing questions to help characterize participant responses in terms of Cannon-Bowers, Salas, & Converse's (1993) mental model types, i.e. equipment model, task model, team interaction model or team model.

4.7.5 Cycle 2 Focus Groups

Reviewing Our Heuristics

We began with an a priori step to develop our deductive code book based on the relevant literature due to the considerable number of our heuristics that stem from the literature. This produced a set of 42 anticipated codes which we then set aside before beginning the focus group sessions. Two sessions took place with everyone in a different location. In the third session participants were remotely co-located and the final fourth session of phase 1 students took place in-person in the Trinity College CHARM-EU hybrid classroom. All four focus groups were recorded as MS Teams meetings on a private area of the college MS Team platform to simplify access control, and these recording were then transcribed and imported into NVivo for analysis. We conducted an inductive coding of the transcripts next, resulting in 19 new inductive codes. We then re-coded the texts using our deductive code set to help with identifying possible biases in our inductive set. When comparing both sets, we note that the deductive codes are considerably under-represented (maximum of 5 instances with most reaching only 2 or 3 mentions of the related theme at most per code). This is unsurprising given the exploratory focus on the sessions. However it is encouraging that the highest instances of codes in both codebooks relate to similar themes covering clarity of expression/feedback and awareness of social protocols. The presence of these themes in our inductive codebook bolsters the literature based deductive set and shows that our participants were sensitive to issues of team dynamics. Our focus groups indicated that the CHARM students recognize when social cues are filtered by communications technology and that this feels unnatural to them.

"I think it's because we are not in the same room so we can't really read others faces"

They referenced difficulty in making eye-contact and lacking the ability to affect proxemic distance as challenges. The feedback indicated that hybrid students experience reduced social presence in this regard and that this frequently caused them to miss social cues. This resonates with our proposed heuristic that is based on Katzenbach and Smith's (1993) guidance to employ a clear working approach in team communications. Participants repeatedly stated a desire for stronger connections with teammates, to the extent that the Montpellier class from this cohort even elected to visit their peers in Barcelona to get to know them better outside of the hybrid environment. This indicates support for our heuristic that is informed by Salas et al.'s, (2013) assertion that healthy teams foster team familiarity to build affiliative associations. The sentiments expressed by our cycle 2 participants aligns with Short, Williams and Christie's (1976) work on social presence and Edward Hall's (1966) work on proxemics, confirming our view that such factors are stifled in hybrid work. Some student teams attempted to adopt strategies to compensate for this, but these varied in their success. One successful example relates to a team named 'Team-X' who posed with arms crossed in an X when signing off from group video presentations. But this example were mentioned as being unnatural and somewhat forced. Technology dependability was also noted as a theme that caused stress for students, with one mentioning that a “laptop breaking is actually a huge impact on our team”. This concern was echoed by others, with one team experiencing three broken laptops during one semester. This resonated with feedback in our cycle 1 data where some students reported that their devices struggled with the virtual environment. We drew a heuristic from this that our interface needed to be simple enough to run on any device, including smaller screens such as mobile phones in case of temporary access problems due to broken technology. These themes are described below in the Activity System description of cycle 2.

Focus Group Data

Cycle 2 feedback was generated over four focus group sessions. The first three sessions were CHARM-EU capstone teams that had engaged in the intervention activity. A fourth group of first-semester students were opportunistically invited to share their perspectives regarding challenges encountered with hybrid team-based learning during their class projects as this group had identified themselves to the researcher and expressed an interest in the research. A semi-structured interview protocol including open ended questions was developed in advance based on literature review and cycle 1 data analysis.

Cycle 2 Coding and themes

The deductive codes (table 4-3) and inductive codes (table 4-4) encountered during the cycle 2 analysis are presented below. Deductive codes align with literature and sources are indicated in the relevant table. Inductive codes are explained and accompanied by an illustrative quote from the cycle 2 participant feedback.

Deductive Code	**Theme**	**Indicative Literature**
Clarity of expression	Communication	Katzenbach and Smith, 1993
Consequences of tool use	Tools / Usability	Green and Petre, 1996
Developing shared mental models	Team cognition / TMMs	Salas, et al., 2013; Mohammed, 2010
Giving and receiving feedback	Communication	LaFasto and Larson, 1989
Naturalness Principle	Distributed Cognition of Teams (DiCoT)	Blandford and Furniss, 2006

Social protocols	Activity Theory (Community)	Rubinstein, 1973; Vygotsky, 1978; Leontiev, 1981; Engeström, 2000
Suitability of tools to tasks	Tools / Usability	Green and Petre, 1996
Tool usage patterns	Tools / Usability	Green and Petre, 1996
Working in multiple contexts	Tools / Usability	Green and Petre, 1996

Table 4-3. A priori codebook (cycle 2, deductive codes encountered during cycle 2 coding).

Inductive Code	Interpretation	Illustrative Quote
Adapting to technology	Behaviours and strategies that are adopted by learners/users to work with technology (Zoom mentioned in feedback, however MS Teams was actually used).	"But I guess that is a zoom (sic) specific thing. Like if we were in person, we would never just do this weird thing. So that signing off of call we do this thing and that actually creates a bond that's also a joke. It's something we can all do on the screen as well"
Communications Preferences	Expressions of attitudes regarding communication modalities.	"We didn't want another app. Like we have WhatsApp, we have Teams, and this is also in CHARM, that we were a bit you know, annoyed, with this many apps"
Communications Tactic	Behaviours and strategies adopted to facilitate communication.	"We had an issue about halfway through of people interrupting and I at least made a conscious effort, and I think everyone else did, to put the hand up. That it would make sense. But specifically for raise the hand, that I would be more aware when someone does something I would maybe think of something else and hold the thought while they're talking. But also if someone is saying something and I don't really have something to say I will show them that I' like reacting, I would use reactions, and I also do in zoom as well."
Desire for social cues	Instances or expressions of disconnection	"I think the tools can also be a barrier towards feeling the team"
Dislike of text messages	Communications preference subcategory.	"I would be more comfortable I think face to face, but it's just I can't really follow messages"
Division of labour	References to roles within our cohort of hybrid teams.	"we sometimes gave each other an extra task because sometimes a Whatsapp would happen and you'd go back to an earlier message but the threads became too long or we're not involve in the conversation at that moment so then we decided we'd get the facilitator of that week to

		decide if a message, like if it had a task in it or if it was important”
Examples of Psychological Safety	Expressions of psychological safety (also termed emotional security) indicate an environment where the team may grow by trying things out without fear of reprimand.	“with my group in phase 1, humour only came very very late in the process. And I think we had been working together for a couple of months and the people from Montpellier came to visit Barcelona, and we kind of got to know each other a little bit more in person, and I was in a group with two people from Montpellier but we hadn’t met before, and then after when they left, because we got to know them a little bit, when we met online again I feel that there were more jokes and everything was a little bit lighter”
Examples of Social Presence	Instance of connection between teammates that were reported by participants.	“when we just started making more social conversation rather than just instantly, only academic conversation, then it becomes a lot easier and you kind of remind yourself that there are people behind the screen”
Expectations	Expectations of hybrid teamwork before starting the CHARM-EU M.Sc. programme.	“in the end everyone was so different to what you had originally think (sic) but just the way that people pose or look into the camera, you just have this whole image in your head of what a person will be like”
Experience of staff supports	Experience of technology supports in participants experience of hybrid teamwork.	“I felt there was a big difference between the locations, if you looked online at the screens, how prepared everyone was. Like sometime class started 15 minutes later because a screen didn’t work, or the sound didn’t work, or somebody didn’t test their presentation, or screen share their screen, and I think having somebody who has that knowledge on the technical skills and is dedicated to that task to support both the students and the presenters”
ICT experience	Positive or negative sentiments of prior ICT experience.	“it’s nice to have meeting in those sorts of tools” “Before that I was already using it for my job, so it was not very hard at all” “I found it not as easy I must say. At the beginning I did not know any of the platforms, not even the names sometimes, but for sure not to use them, I'd never used even Outlook actually.”

Impact of covid	Impact of COVID-19 on attitudes to hybrid work.	“Covid was super important, specifically for our generation, for technology and how we perceived it”
Impact of workload	Attenuation of novelty effect regarding hybrid work (single instance of code)	“I’d say it’s probably some people might be able to relate to that where this time last year it’s all new and exciting and you do a lot and meet new people, but now I don’t think”
Limitations of technology	Hardware and communication challenges.	“it’s quite an obvious one but it’s something that has affected half the team already. but your laptop breaking is actually a huge impact on our team.” “we’re able to express a little bit of emotion through the calls but it’s nothing in comparison to being together”
LX Preferences	Preferences for collaborative learning experience.	“kind of collaborative, more so than just a lecture” “That connection can be really, really challenging because I remember in my phase 1 group, I was the only one on my own, and then there were 3 and then 2 with each other, and I really, like a lot of the times, I started to interpret within the group [...] they have this underlying understandings with each other that I don’t have, or they have bonded with each other that I don’t have.”
Meta-cognitive awareness	Reflections on peer opinions.	“when we started CHARM we had groups and Teams and WhatsApp and all these different chat channels and I would check what my profile picture was in all of them and try to find something that was representative of me and something that would make people think I’m nice”
Meta-cognition	Expressions of self-awareness.	“I’m just an emotional person so I express that fairly easily”
Netiquette	Examples of team interaction norms.	“It can really change the team dynamic if you’re not assigning people to the role because then some people feel I’m not talking much and I won’t anymore because you already have this team dynamic and it’s won’t change because they are loud and I’m not or something”

Onboarding and Orientation	Challenges with beginning hybrid teamwork.	“before starting the phase 1 group, it would be so helpful to have something to teach people how to work in an online environment well. Because yeah everyone had different difficulties, but I feel like everyone has difficulties in phase 1. And I heard that in other phase people were more aware of these pitfalls and acted more conscious from the beginning and I heard way less trouble form the different phases”
Preference against openness	Preference to refine work before sharing.	“the whole writing process is I feel too much, like I don’t want to people seeing typing, the way I start sentences, I just want them to see it when it’s a first draft”
Preference for Hybrid	Examples of participant enjoying hybrid work.	“It was almost easier because there was at least some element of it being in person” “but in hybrid maybe we are sharing more personal things than in our online meetings”
Preference for individual work	Individual before group work preference.	“I prefer to work on my own reflection first and then share it.”
Preference for in-person	Dissatisfaction with hybrid / virtual.	“It was only because we were able to build those connections and spend time with each other that we were able to work so well together” “… I was better friends with the people that I was working with. Like I was only working with one girl in the location, but I definitely felt that we were friendlier that the other in the group because they were in Budapest and Montpellier”
Preference for Online	Stated benefits of hybrid work.	“having everybody on a call and having all the tools there that you can pull up your report, it adds structure and clarity and focus more so that a classroom setting”
Preference for Openness	Openness and sharing promote team health and cohesion by raising team situational awareness.	“I think we do try as best as we can for an online group to sort of be involved with each other and let each other know how we’re doing.”
Preference for visual communication	Design choices.	“I am more efficient at looking rather than listening”
Preference for visual modality	Design choices.	“it’s quite easy to follow a thread when you’re visually looking at something”

		"I want to gauge our understand if someone is getting where I'm going with something and if they're not looking at me I can't look at their visual expression and I just keep talking and talking and talking coz I don't know they're thinking."
Prior experience of online work	ICT fluency.	"it was not really extremely challenging to get used to that" "For me, none of the technologies were difficult to use, there was no learning curve. It was just difficult getting used to using them so often"
Reduced psychological safety	Examples of reduced psychological safety. See, Examples of Psychological Safety, above.	"Well, i think it also depends on the people you work with, for example, what team you're in and the dynamic within your team, how comfortable people feel around each other, but obviously it's a little bit more, I don't want to say awkward, but obviously you miss a lot of things when you are online"
Reduced Social Presence	Lack of connection.	"I do thank that online, we do not go as deep and when you see someone's emotion, you might not have a handle on it. We might just continue working"
Self-censoring	Impact of technology-mediated team communications.	"I think that actually we did have that problem, we would maybe jump in a lot, and I remember yelling them, you're jumping a lot in. And more generally online, it's harder to know when to interfere with the discussion. And actually, you really need more listening capability when you 're online, coz I feel more disrespected when I'm interrupted online than in person, in the sense like, because you're not in the same room, you're cut off from me. Being online you need more listening capability, and it takes time before you're able to jump in."
Sharing tasks	Examples of role adoption and distributed leadership within teams work practices.	"It also became useful when we were dividing labour, because then whoever was doing the refencing at the end wasn't left with having to combine references from five different people."
Team Bonding	Impact of ICT mediation on hybrid team health.	"I think in general, the level of emotions both positive and negative are a bit less in online meetings, although I think we have more of a tendency to have a better expression of emotions offline."

		"I personally didn't feel engaged in the team until I met everybody in person" "Yeah to get to know the people you're working with, because we are much colder when we are working with people we don't know. So we also don't even get the chance to bond before we really start working."
Team Commitment	Examples of teams transitioning from "forming" to "storming"	"I mean maybe after a couple of weeks, which may be longer than you would expect, but after a couple of weeks it was very easy to think ok, I'm only gonna see the people, I mean maybe I'm going to see them in the future when I graduate, so I think it would make everyone life easier if we try to make a connection online."
Team Norming	Establishing team processes and practices.	"when you kind of get to know the people onsite, you get to know, this is sad, this is mad, or just the way we are in general. So we know how to handle each other better."
Team Processes	Examples of team processes and practices.	"At the beginning we tried to set some rules to work properly. But in reality, I would say, either it was not really well applied, or you know, it's so different in every situation that fixed rules don't really work, or at least people won't naturally apply them to their thinking, etc. And I think that specifically for feedback, I kind of have the memory of saying ok, let's try to jump in or give feedback constructively, etc. but in the end, we still had quite a lot of little tensions and stuff that we had to fix frustrations that were really not well communicated."
Team self-support	Desire for team bonding.	"Sometimes, humour doesn't work, but with this team we did have a session where we also tried to be more personal with each other and have some jokes"
Technical hurdles	Hybrid teamwork technology hurdle.	"one things that I noticed is that sometimes for programmes in Teams, it's not a very heavy programme but my MacBook doesn't work."
Work Practices	Current experiences of hybrid transdisciplinary teamwork.	"Because you're all working at such a fast pace that you're only really thinking of yourself and then once you're done you like, ok is everyone else finished? And then that's fine, we've all made

		it. But in the work process, it's not really that collaborative that you can complement everyone else"

Table 4-4. A posteriori inductive code book and supporting quotes.

The naturalness principle was a strong theme in this cycle (see table 4-5, below). Clarity of expression, use or awareness of social protocols, the suitability of tools to tasks and the giving and receiving of intra-team feedback were also prominent. This contributed to our decision to adopt a simple web-based implementation of the heuristics in cycle 3. The number of cases indicates each cohort where the code theme was encountered, while the references column indicates the number of instances of that code.

Deductive Code	Cases	References
Naturalness Principle	4	18
Clarity of expression	3	12
Social protocols	4	12
Suitability of tools to tasks	2	12
Giving and receiving feedback	3	10
Tool usage patterns	4	8
Developing shared mental models	4	6
Consequences of tool use	3	5
Working in multiple contexts	3	5

Table 4-5. A posteriori (cycle 2, instances of deductive codes encountered).

Our inductive analysis indicated a strong desire for social cues by our cycle 2 participants (table 4-6), which we implemented via social cue sharing of emoticons. As with table 4-2 above, the table below describes the number of cohorts cases where the theme arose, and the number of instances of that code is given in the references column.

Inductive Code	Cases	References
Desire for social cues	4	31
Communications Preferences	4	23
Adapting to technology	4	21
Preference for in-person	3	20
Team Bonding	4	20
Reduced Social Presence	4	19
Communications Tactic	3	18
Limitations of technology	4	14

Division of labour	3	13
Reduced psychological safety	3	12
Technical hurdles	4	11
Work Practices	4	10
Examples of Psychological Safety	3	9
ICT experience	3	9
Onboarding and Orientation	3	8
Meta-cognitive awareness	4	6
Preference against Openness	2	6
Preference for Online	2	6
Prior experience of online work	3	6
Team Norming	2	6
Experience of staff supports	2	5
Preference for Hybrid	1	5
LX Preferences	1	4
Self-censoring	2	4
Team Commitment	3	4
Preference for Openness	2	3
Preference for visual communication	2	3
Team Processes	2	3
Team self-support	2	3
Dislike of text messages	1	2
Expectations	1	2
Impact of covid	2	2
Preference for visual modality	1	2
Sharing tasks	2	2
Examples of Social Presence	1	1
Impact of workload	1	1
Meta-cognition	1	1
Netiquette	1	1
Preference for individual work	1	1

Table 4-6. A priori (cycle 2, inductive codes).

4.7.6 Cycle 2 Design Review

The propose of a design review is to produce and clarify design outputs and to inform design decisions before moving to the next design loop. Our review of Cycle 2 is informed by Cycle 2 findings, but also considers feedback from Cycle 1, since the objective of our final Cycle 3 is to integrate these perspectives into a test artefact. As noted earlier (section 3.4.1 and section 4.6.9), our study evolved from a project aimed solely at immersive XR, to one that moved to view XR in abstract terms of a shared virtual team learning space that can be comprised of any number of cognitive expanding enriched media technologies that the team employs to conduct their work. In our study, this meant simplifying our expectations about how such tools can be accessed as well as when and where they should be used. In this section we now describe the feedback of Cycle 2 through the lens of Mwanza's eight step model to contextualise the findings and describe our approach to combining our design aims with our students feedback to clarify our design outputs for Cycle 2. Three new heuristics were produced in this cycle, (see Cycle 2 in table 4-6 below).

Activity System interpretation of Cycle 2

The first three steps in Mwanza's eight-step model focus on questions of what, why and who, i.e. what is the focus of the activity, and why is it being enacted by these particular subjects. In the context of the M.Sc. in Global Challenges for Sustainability, these steps are pre-determined. The question of what and why are answered by the learning goals of the masters programme, while the question of who is determined by the demographics of the cohort. As our cohort were engaged in the master's programme, their activities were determined by the programme design, (i.e. transdisciplinary team project work). Similarly, each team shared a common goal in the early stages of their projects to develop their approach towards transdisciplinary synthesis. In this sense, there is no divergence in terms of teams' purpose, and we concluded that the remaining five steps [4 to 8] of the AODM method should produce richer data when considering how to interpret cycles 2 and 3, by considering those factors that may differ on a team-by-team basis, i.e. attitudes regarding tools, rules, division of labour and community influence.

Subject

Our subjects in cycle 2 were three student capstone teams who were purposively recruited and one first semester group who were opportunistically included following their expression of interest to the researcher during class. Both cohorts were covered by the same ethics application and the invitation was extended by email with the requisite notice. The first-semester group did not engage in the intervention, but their viewpoints were still valuable in understanding student attitudes to online and hybrid teamwork. Both groups shared the same motivation and goals for developing their transdisciplinary hybrid teamwork competencies, as indicated by their common interest in the master's programme.

Objective

The intervention focused on building team member understanding with the objective of via the sharing of sentiment feedback relating to potential challenges that lay ahead in their transdisciplinary team synthesis and project work. There was also a tacit objective to create an opportunity for team reflection and build team cohesion. The student's objective in the intervention activity was to achieve the learning goals of the session by using the worksheet to scaffold a team reflection regarding perceived transdisciplinary team challenges from each team members disciplinary perspective.

Tools

The MS Team platform and a bespoke worksheet based on Cultural Historical Activity Theory (Appendix 4) were employed for the intervention activity. Related tensions are highlighted in the cycle 2 conflicts section below. While the data are interesting, several worksheets are incomplete as they were too detailed for some teams to complete in time. In Activity Theory parlance, this represents a primary tension within the tool preventing the subject from fully reaching the objective. The evolution of our tool in cycle 3 simplifies the requirements to address this specific tension.

Rules

Information relating to how teams should conduct the activity was provided as part of the intervention. Teams also highlighted other rules and social protocols during the focus groups sessions, and these are also discussed below in the tensions section.

Division of Labour

No instructions were provided as to how the teams should organise themselves as this was seen as an interesting variable to be investigated in the focus groups. During the follow-up we noted subtle differences in how each team organised themselves, with some team members taking it on themselves to act as mediator or chair for the session through a process of reading and thinking aloud to guide the team through each section of the worksheet.

Community

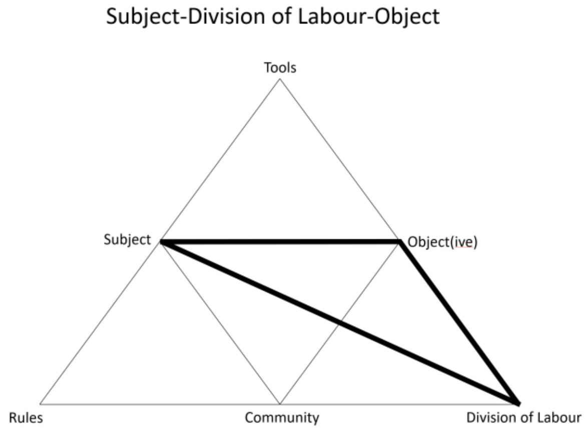
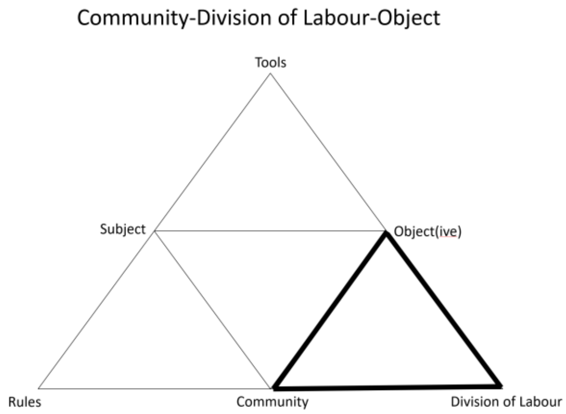
Community membership is generally uniform for all team members although due to the international nature of the programme, cultural differences do exist and may shape team interactions in unexpected ways. This was anticipated but was not apparent in the cycle 2 data.

Tensions noted in participant feedback

Participants mentioned noticing a disconnect between team members during hybrid work. Mediation of their work via tools like MS Teams, produces a secondary AT tension between subject and tool, which we characterised as a desire for social cues and getting to know peers.

Tensions noted in Cycle 2 student worksheets

Our cycle 2 intervention activity included an activity worksheet (Appendix 4) that asked student teams to reflect on and document this team project by characterising it under the headings of CHAT elements. As only some teams completed the worksheet, a primary tension in the tool was noted which indicates our task in cycle 2 was overly complex for the allotted time. Teams were asked to generate a list of project tensions they anticipated encountering during their capstone work. We decomposed these concerns into related sub-activity triangles and mapped them to identify operational processes by applying Mwanza's AODM to conceptualize the issues reported by participants. Grouping the complete set of tensions by sub-activity was helpful in developing a set of inspirational mirror-data that we included in our cycle 3 intervention. As this was a considerable volume of data with some forty-one different tensions being noted by students, examples are provided below in table 4-7 to illustrative our categorisation process. Student quotes from the worksheet describe the perceived tensions alongside the AODM mapping. Our analysis of these data employs the fourth item in Mwanza's AODM Toolkit, i.e. the technique for mapping operational processes. This tool is intended for interpreting and communicating research findings realting to activities and sub-activities. The tool does not identify tensions, as with the more well-known tool from the toolkit which we use extensively in our cycle 3 analysis. Instead, this tool is intended to be used to quickly map operational processes within activities, which can then help to categorise sources of tensions, while avoiding the specifics of individual cases. Our goal with this analysis was to evaluate student feedback to understand classes of tensions within activity sub triangles, which could them be used to inform cycle 3 by collating and presenting mirror data to share with cycle 3 participants via the exemplar prototype app.

Student anticipated project tensions	Sub-activity triangle AODM Mapping
Identifying when is personal time	 *Figure 4-7. Identifying when is personal time*
Not enough support from supervisor or [stakeholder]	 *Figure 4-7. Not enough support*

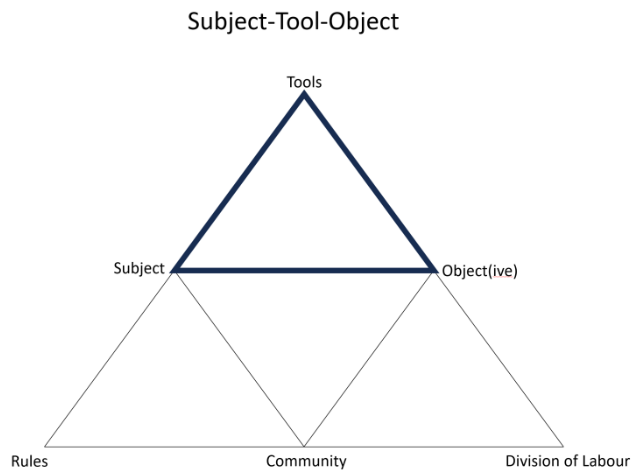
<table>
<tr>
<td>Virtual communication can be challenging, and we might encounter difficulties in terms of building and maintaining communication</td>
<td>


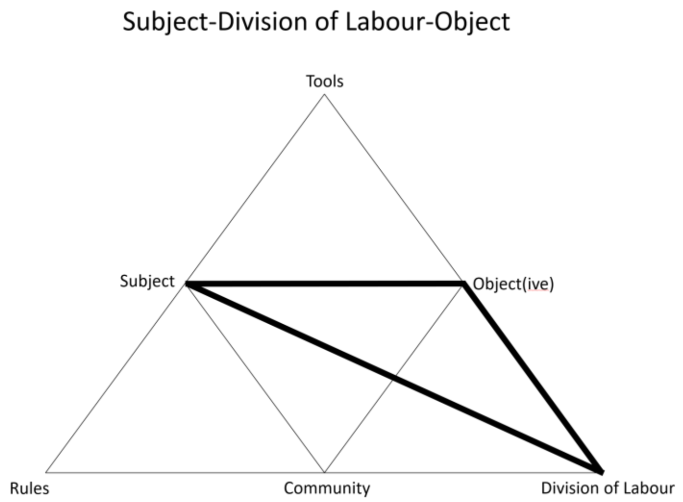
Figure 4-8. Virtual communication challenges
</td>
</tr>
<tr>
<td>Conflicts over preferences for certain roles</td>
<td>


Figure 4-8. Conflicts over preferences for certain roles
</td>
</tr>
</table>

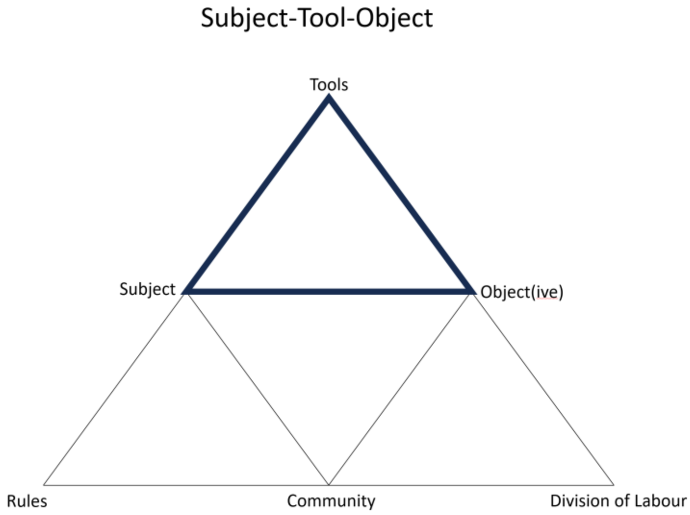
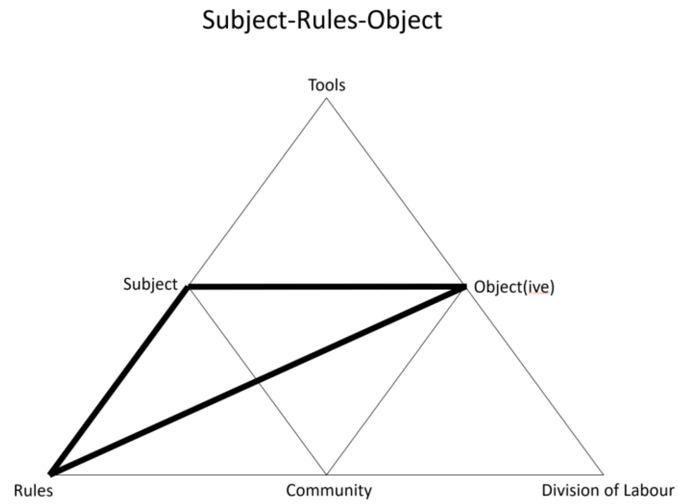
Hybrid communication	 *Figure 4-10. Hybrid communication tension*
Group communication encouraging positive and inclusive group dynamics	 *Figure 4-11. Challenges with group communication encouraging positive and inclusive group dynamics*

Table 4-7. Cycle 2 worksheet analysis. Sub-activity triangle AODM Mappings highlighting student identified tensions.

In summary, the AODM mappings above in table 4-7 show that our cycle 2 students were most concerned with issues relating to rules, expectations and social norms, followed by workload, team and team member capacity and the division of labour in their teams and with their project stakeholders. Table 4-8 below, collates our analysis of these student previewed tensions. The Subject-Rules-Object and Subject-Division of Labour-Object categories are clearly of greater concern to our novice hybrid transdisciplinary cohort than the other categories. Examples of rules contained a mixture of rules that were expected to be relevant, e.g. academic requirements, ethical guidelines, or rules proposed by teams help them in self-managing the teamwork, e.g. "be respectful of each other's time", "clear and open communication", as well as rules to improve team processes, e.g. “after a non-equal division of the work and it not being resolved internally, the supervisor is contacted”.

Subject, Rules, Object	21
Subject, Division of Labour, Object	15
Community, Division of Labour, Object	3
Community, Rules, Object	2
Unclear	1

Table 4-8. Summary of Cycle 2 Worksheet AODM Analysis

The list of tools generated by teams focused primarily on communications and production software tools, and these were useful insights that we later shared with cycle 3 participants in the form of mirror data in the cycle 3 intervention exemplar artefact tool which scaffolded the cycle 3 team discussions by helping students identify their own project concerns.

Heuristics updates from Cycle 2

Cycle 2 allowed us to add to our set of design heuristics through analysis of the focus group themes and student worksheets produced during the intervention. Since most teams did not manage to complete all sections of the worksheet, we concluded that our design was too complex for the allotted time of one class period. This was a valuable insight that directly influenced the format of our cycle 3 sessions.

Students generated insights for us in their worksheets regarding the challenges that they foresaw and the types of tools they expected to find useful. The worksheets contained eleven distinct roles that teams expected to adopt throughout their projects, with roles that manage communication with team members, programme staff and project stakeholders being mentioned by any teams that completed the section. Inequal division of labour was also mentioned as a perceived teamwork tension. Students’ awareness of the importance of communication and team roles indicates good support for our communication (Katzenbach and Smith, 1993) and division of labour (Salas, et al., 2013) related heuristics. Perceived intra-team communication needs also support our feedback related heuristic (LaFasto and Larson, 1989). Role related worksheet tensions included boundaries on personal time and balancing workload across the team, overlapping task roles, managing complexity of the project, and aligning the team when clashes occur. Each of these adds support to the literature-based heuristics mentioned. Communication tensions included the difficulties of communicating virtually and working in a multilingual team, each of which are addressed in our communication heuristics (Katzenbach and Smith, ibid), i.e. to be specific in communications, recognise and manage relative priorities and to employ a clear working approach.

Eighteen distinct tools were mentioned, covering communications, graphics, productivity, organization, research and hardware. Synchronous and asynchronous communication tools were mentioned in the worksheets (Teams, Zoom, WhatsApp, Slack, PowerPoint, Email) and these data were included in our content for the in-app Model/Vision and Mirror Data supporting information as part of our design for the exemplar tool used in the next cycle intervention.

Our analysis of the cycle 2 focus group confirmed our heuristic from cycle 1 that technology-mediated hybrid team onboarding is difficult for new users. Participants also highlighted three related themes that inform our next three user centred design heuristics, listed below;

- Remote teams experience reduced social presence and often miss social cues.
- Interface controls that represent analogues of social cues should not feel unnatural to users.
- Hybrid students feel disconnected from each other want to get to know one another.

This had implications for our study (RQ1) by emphasising the need to develop onboarding and hybrid team orientation supports. Our complete set of heuristics now covered twenty-three derived from the literature plus six that were drawn from participant feedback in the first two cycles. As this presented an infeasibly large number to work with in cycle 3, we followed the AODM eight-step questions to contextualise the ideal outcome for each heuristic as an approach to refining the set, which we describe in section 4.8.4 'Cycle 3 Focus Sessions'. The table below (table 4-9) is provided for the convenience of the reader to illustrate our original set of heuristics covering the previous design cycles and those heuristics that were drawn from the relevant literature in our review. Cycle 2 introduced three new heuristics (c2a, c2b, c2c) and no deletions were made during this cycle. Each item has a descriptive code which was useful both for our administration tasks in preparing the work and as a cross-reference code when identifying overlapping concepts. A granular explanation describing each heuristic and any overlapping constructs, can be found throughout Chapter 5 (See sections 5.4, 5.5 and 5.6).

Source	Code	Heuristic
User centred concerns		
Cycle 1	c1a	Don't assume users will recognise UI controls
	c1b	Team tools should provide detailed instructions
	c1c	XR onboarding is difficult for new users
Cycle 2	c2a	Remote teams experience reduced social presence and often miss social cues
	c2b	Interface controls that represent analogues of social cues should not feel unnatural to users
	c2c	Hybrid students want to get better acquainted will adopt strategies to do so
User experience		
Muller, et al., 1998	ux1	System Status, User Control and Freedom, Consistency and Relevancy, Error Recognition and Recovery, and Task and Work Support
Teamwork theories		
Tuckman, 1965;	th1	Tool should adapt to the users changing requirements
Inverardi & Tivoli, 2009		
LaFasto and Larson, 1989	th2	Support intra-team feedback
Salas, et al., 2013	th3	Support different roles and responsibilities
	th4	Support team mission objectives and norms
	th5	(consider) the environmental context
	th6	Foster team familiarity (to build affiliative associations)
Katzenbach and Smith, 1993	th7	Be specific in communications
	th8	Recognise and manage relative priorities
	th9	Employ a clear working approach
Team mental models		
Mohammed, et al., (2010)	tmm1	User-defined topics create mental representations of the key elements within a team's relevant environment that are shared across team members
DCog and DiCoT		
DCog (Hutchins, E., 1995)	dc1	Embodiment of information within the system
	dc2	Co-ordination between agents,
	dc3	The impact of set and setting (ecosystem) on the process taking place.
	dc4	Cognitive process is delimited by the functional relationships among the members
DiCoT (Blandford, A. & Furniss, D., 2006)	dc5	Physical Layout: Space and Cognition
	dc6	Physical Layout: Subtle Bodily Supports

	dc7	Physical Layout: Situation Awareness
	dc8	Information flow: Buffering
	dc9	Artefacts: Representation – Goal Parity
	dc10	Artefacts: Coordination of Resources
DiCoT extended (Webb, 2008)	dc11	Development of practice
	dc12	Development of practitioners

Table 4-9. Complete set of heuristics covering literature review and cycle 1&2 user-centred considerations.

With the set refined into a manageable size we could dedicate ourselves to the design of the Cycle 3 exemplar tool. While we did map all twenty-nine heuristics to design features, we describe our use of Mwanza's Technique for Mapping operational Processes above in this current section, which we used to refine and select testable heuristics for developing a simple web-app experience that could extend team members realities by providing qualitative real time sentiment feedback.

4.8 Cycle 3: An Activity Model to support the cohesiveness and effectiveness of hybrid transdisciplinary teams: A CHARM-EU Case study.

4.8.1 Introduction

During this cycle we refined our cycle 2 design to create a new learning intervention team activity where students worked with our prototype Transdisciplinary Teamwork Tool (TTT) in a hybrid classroom setting. Testing and evaluation between cycles 2 and 3 provided scope to refine the heuristics and redesign the prototype (RQ1a). AODM's eight-steps provided a culturally historical lens to contextualise student perceived tensions relating to the design features at the end of cycle 3 in our heuristic evaluations (RQ1b). The CHAT perspective recognises that teamwork involves multiple interacting activity systems, which is central to transdisciplinarity synthesis, but also true for any type of team, and our investigation of RQ1b to evaluate heuristics must be sensitive to the range of perspectives across the team. Figure 4-12 below describes this evolution from the cycle 2 paper-based prototype to the development of an exemplar software artefact that implemented the heuristics to test and evaluate them in cycle 3.

Figure 4-12. Cycle 3, prototype refinement / activity streamlining and cycle 3 heuristic evaluations.

4.8.2 Participant Selection

Cycle 3 participants were drawn from two active CHARM-EU cohorts, namely the ‘phase 1’ (i.e. semester 1, class of 2026) and the capstone phase (semester 3, class of 2025), where our intervention was delivered as part of learning content for the M.Sc. Programme.

Semester 1 group:
Ten teams engaged in the intervention activity. Thirty-six of forty-four students granted consent to include TTT data. Four engaged in focus sessions.

Capstone group:
Fourteen teams engaged in the intervention activity. Thirty-seven of fifty-two students granted consent to include TTT data. Seven engaged in focus sessions.

We worked with two individual gatekeepers for the separate cohorts to include our session at an early point in the semester. This allowed us to target newly formed teams for our study before workflows had been established within each team. Separate informed consent details were shared to each group and consent was gathered in sperate MS Forms sheets housed within our TCD MS Teams research site. Information was first shared with the capstone cohort in June of 2024 before their summer recess, and again one week prior to the study. Consent was shared with the first semester group as soon as their team had been formed during their orientation week, which was two weeks prior to their session. The researcher emphasised that they activity would not be assessed as part of coursework in their email invitation and reminded students of this again before beginning the intervention. Both groups were viewed similarly in terms of their aims and goals by the fact that they were students on the same M.Sc. programme built around transdisciplinary teamwork.

4.8.3 Intervention Design

Cycle 3 evolved directly from the cycle 2 intervention design but was also influenced by feedback from cycle 1. Our intervention during this cycle replaced our cycle 2 worksheet with our bespoke Transdisciplinary Teamwork Tool (TTT) to implement our heuristics in an exemplar artefact.

Heuristic Implementation Mappings

Our Cycle 1 heuristic that users often do not recognise UI controls prompted our design response to include in-app help and information and our implementation of this is described in the 'TTT Design' sub-section of the current chapter section. All of our Cycle 2 heuristics were implementable and included in the TTT design. The majority of our landmark Teamwork and Team Mental Model heuristics were also deemed to be implementable since these relate to activities involving feedback, which is a core function of any user interface and central to the design of our intervention.

Hutchins' (1965) D-Cog principles were split between two that could be implemented, i.e. co-ordination between agents, and cognitive process in role relationships, and two that were mapped to other heuristics in preparation for cycle 3 via an AODM analysis of the cycle 2 feedback. Each of Blandford and Furniss's (2005) DiCoT conceptual areas (i.e. organisation of work, information flow and artefacts) are represented within our set of heuristics, and although all of their principles have influenced our analyses, it was not feasible to map all principles directly to design heuristics as some describe actions beyond the scope of our design capacity. For example, the naturalness principle is informed by Norman's (1988; 1999) view that cognition is improved when the "form of the representation matches the properties of what it represents" (Blandford & Furniss, ibid), what Fitts & Seeger (1953) refer to as "stimulus–response compatibility", and while graphical fidelity has some impact in interpretation (Norman, 1988; 1999; Mohammad, 2010), we were less interested in the appropriateness of the graphical abstractions than the impact of sharing feedback that the emoticons enable within a team. The DiCoT naturalness principle is an important consideration, as indeed all the principles are, but it is not one that our study wanted to specifically design for since its purpose is to support an individual's understanding of an abstraction, whereas ours is to setup and stimulate moments of expansive team learning. The principles that were directly mapped to heuristics are italicised and marked with an asterisk in the lists below.

Physical organisation of work

Principles relating to the physical layout and organisation of work cover "things that can be physically heard, seen and accessed by individuals". This included to the arrangement of equipment and physical organisation of the ambulance control desk in Blandford and Furniss's original study. In the current research focusing on hybrid teamwork mediated by technology, the information architecture presented by a software tool or within a virtual space is an equally rich sources of information for supporting distributed cognition of a hybrid teamwork.

- Principle 1: *Space and Cognition**
- Principle 2: Perceptual Principle
- Principle 3: Naturalness Principle
- Principle 4: *Subtle Bodily Supports**
- Principle 5: *Situation Awareness**
- Principle 6: Horizon of Observation
- Principle 7: Arrangement of Equipment

Information flow

Information flow is both digital and analogue but primarily digital when it occurs as part of technology-mediated hybrid teamwork. In hybrid teams, there are many simultaneous information channels in concurrent use that must be managed by the team to balance their cognitive load. Buffering is the most essential to avoid information loss, and therefore important for transdisciplinary team synthesis where an overload of new ideas may be presented to team members. A shared notetaking tool or other transactive memory system would be a possible approach to buffering such information.

- Principle 8: Information Movement
- Principle 9: Information Transformation
- Principle 10: Information Hubs
- *Principle 11: Buffering**

- Principle 12: Communication Bandwidth
- Principle 13: Informal Communication
- Principle 14: Behavioural Trigger Factors

Artefacts

The “third important consideration within DC [DCog] is how artefacts are designed to support cognition”, (Blandford & Furniss, ibid). Our purpose is to propose that artefacts can be designed to support particular kinds of cognition and therefore we consider ‘Principle 15: Mediating artefact’ for each of our heuristics in our analysis. ‘Principle 16’ tells us that design features should purposefully scaffold user behaviour and each of the heuristics in our set speaks to this principle. The artefact model is a foundational concept in DCog in that it views the constituent actions of a distributed cognition being mediated via artefacts. The parallels with Activity Theory’s subject-tool-object relationship are evident and understanding the role of mediating artefacts can help us determine the success or limits of our design heuristics. Our approach has been to enquire whether the artefact enhances or constrains activity flow as part of a structured analysis, which we describe in our methodology chapter. Artefacts mediate cognitive processes by externalizing cognition and offloading mental tasks across other individuals and physical objects, but such meditation can also influence cognitive processes by structuring information and interactions. This prescriptive structure is a culturally historically determined factor that illustrates the connection between how we engage with a tool and activity theory’s concept or rules or norms shaping our understanding of how we should engage with tools. This is important because it emphasises that cognition does not just happen in the head, but as part of interactions between people, artefacts and the environment.

To support the development of student transdisciplinary team synthesis, we highlight the remaining two principles from the Artefacts theme in our collection of heuristics for their alignment with the types of tasks undertaken in the initial problem framing phase of transdisciplinary synthesis (Pohl, 2005) when transdisciplinary teams plan their methods of working together.

- Principle 15: Mediating Artefacts
- Principle 16: Creating Scaffolding
- Principle 17: *Representation – Goal Parity**
- Principle 18: *Coordination of Resources**

Additions by Webb (2008)

Webb (2008) extended Blandford & Furniss's principles to include Development of Practice and Development of Practitioner models. Both themes obviously relate to subjects that are best engaged with over time to understand their impact. Our study did not include longitudinal data which prevented us developing design responses more suited to a longer project. However, as educators we recognise the importance of Webb's contribution in the hopes we hold for our student's success. Apropos to this, transdisciplinarity is a skill that must be developed, and redeveloped continually due to the unique nature of each transdisciplinary team project, and we were eager to understand student views on this. We have therefore included both of Webb's principles within our heuristics for their importance regarding student's growth and learning.

***Operationalized as heuristics in our collection**

The following set of DiCoT principles were deemed most suited to operationalize and test within the scope of our project and we included each as heuristics in our collection.

- Physical Layout: Space and Cognition
- Physical Layout: Subtle Bodily Supports
- Physical Layout: Situation Awareness
- Information flow: Buffering
- Artefacts: Representation – Goal Parity
- Artefacts: Coordination of Resources

Integrating outputs from previous cycles

Cycle 3 was a streamlined evolution of cycle 2 wherein we aimed to test our refined set of heuristics in a hybrid team setting. This cycle reduced the complexity of the intervention team activity task in response to our cycle 2 findings. Cycle 2 outputs were drawn from our analysis of the student worksheets created in the intervention, researcher observations during the activity, and our analysis of the follow-up focus group data. This resulted in three heuristics being added. During cycle 2, student teams were tasked with identifying potential teamwork challenges as seen from their disciplinary perspectives. This set of challenges provided useful mirror data in a modal popup window to guide students by offering inspiration for their own team discussion topics. Additionally, a 'Model/Vision' information window included a tailored version of Mwanza eight-step model to suggest discussion prompts that could help to uncover teamwork tensions. This offered a streamlined approach to using Activity Systems analysis concepts in scaffolding their discussions without the need to spend time explaining Activity Theory to our students. Splitting the supporting information between independent Model/Vision and Mirror Data sections offered the additional benefit of supporting future work through a Change Laboratory study. We discuss the potential benefits of using this approach over a longer intervention in the future work section of the current study. Heuristics produced in cycle 2 recommend scaffolds for receival and transmission of social cues, as well as students desire to get to know their teams and these were each mapped to appropriate design features relating to the slides and emoticons sharing.

Refined intervention design

Cycle 3 refined the intervention activity used in cycle 2 to simplify the discussion activity while making it more participant centric. The AT elements are included as supporting guidance via model-vision and inspirational mirror-data pop-up windows. The intervention in this cycle facilitates giving and receiving of feedback relating to known and perceived team challenges, while maintaining a structured approach by requiring feedback from each team member. This addresses RQ1 by scaffolding an identified novice hybrid team transdisciplinary challenge. The full set of heuristics are represented (RQ1a) and a set of corresponding pre-determined evaluation questions were used to answer RQ1b by exploring participant feedback relating to each during our subsequent focus sessions.

Social Presence

Our intervention design in cycle 3 employs sharing of social cues to scaffold team discussions. As noted in our literature review chapter, we found forty-six definitions of Social Presence in the literature. Many of these are multi-dimensional and all overlap to some degree with our heuristics categories; i.e. teamwork, team cognition and our user-informed novice team onboarding heuristics outputted from our first two design cycles. During our preparations for the final design cycle, we reviewed the definitions and generated table 4-10 (below) to map each author's interpretation to a corresponding heuristic from our set. This was not the same as our heuristic mapping, since the design features had already been determined for each heuristic at that stage. However, we felt it important to connect our design with the social presence literature to better describe the connection between social cues, interpretation of shared sentiments, the reciprocal nature of on team cognition and its effect on building aligned and accurate team mental models.

Put simply, social presence improves engagement, engagement is theorised to lead to reflection and reflection is the key to expansive learning. We included the list in table 4-10 below for clarity.

Source	Dimension	Definition	Heuristic
Abdullah, 2004	Singular	Experience of others as real people	Remote teams experience reduced social presence and often miss social cues
Arbaugh, et al., 2008	Multi	Sense of group acceptance and integration	Hybrid students want to get to know each other.
Belderrain, 2006	Multi	Awareness of social protocols	Extensible via user defined topics
Bente, et al., 2004	Multi	Awareness of co-presence and engagement with others	Cognitive process is delimited by the functional relationships among the members
Biocca, et al., 2001a	Singular	Experience of engaging with something/someone/another	Support intra-team feedback
Biocca, Harms, & Burgoon, 2003; Gooch & Watts, 2015; Kehrwald, 2008	Multi	A meta-analysis presenting Social Presence as a literacy	Multifaceted.
Blascovich, et al., 2002	Singular	Experience of others as real people	Foster team familiarity (to build affiliative associations)
Cummings & Bailenson, 2016	Singular	Media capacity to support SP	Be specific in communications
Dikkers, et al., 2012	Multi	(1) Affective Association (AA); (2) Community Cohesion (CC); (3) Interaction Intensity (II); (4) Knowledge and Experience (KE); and (5) Instructor Involvement (IV)	Multifaceted.
Garrison, 2009	Multi	Sense of group acceptance and integration, plus self-actualization	Foster team familiarity (to build affiliative associations)
Garrison, et al., 2000	Singular	Self-actualization	Support different roles and responsibilities
Gibson, 1979	Singular	Sense of being in an environment	Support intra-team feedback.

Goffman, 1959	Singular	Experience of others as real people	Support intra-team feedback.
Gunawardena, 1995	Multi	Self-actualization, plus Experience of others as real people	Support different roles and responsibilities / Support intra-team feedback.
Gunawardena and Zittle, 1997	Singular	Experience of others as real people	Support intra-team feedback.
Hassanein and Head, 2007	Singular	Experience of others as real people	Support intra-team feedback.
Heeter, 1992	Singular	Experience of others as real people	Support intra-team feedback.
Jung, et al., 2002	Singular	Scaffolded learning interactions	Support team mission objectives and norms.
Kang, et al., 2007	Singular	Sense of group acceptance and integration	Foster team familiarity (to build affiliative associations)
Kim, 2011	Multi	Experience of others as real people, plus degree of affiliative associations	Support intra-team feedback / Foster team familiarity (to build affiliative associations)
Kozan and Richardson, 2014	Singular	Degree of affiliative associations	Foster team familiarity (to build affiliative associations)
Lee, 2004	Multi	Experience of others as real people, plus w.r.t, NPCs and objects	Support intra-team feedback / Embodiment of information within the system
Lombard & Ditton, 1997	Singular	Focused attention	Employ a clear working approach / Support different roles and responsibilities / Be specific in communications
Loomis, 1992	Singular	Sense of being in a remote environment	Support the building of mental representations of the key elements within a team's relevant environment that are shared across team members
McCreery et al., 2015	Singular	Social Presence as team development	Support different roles and responsibilities / Co-ordination between agents / Support intra-team feedback
Moreno and Mayer, 2004	Singular	Experience of others as real people	Support intra-team feedback
Ogara et al., 2014	Multi	Sense of group acceptance and integration	Support intra-team feedback
Palmer, 1995	Singular	Sense of presence in an interaction and awareness of the relationship that is creates	Support intra-team feedback / Foster team familiarity (to build affiliative associations)

Picciano, 2002	Multi	Sense of group acceptance and integration, plus ability to interact	Foster team familiarity (to build affiliative associations)
Remesal and Colomina, 2013	Multi	Sense of group acceptance and integration, plus scaffolded learning interactions	Foster team familiarity (to build affiliative associations) / Recognise and manage relative priorities
Rourke, et al., 2001	Singular	Self-actualization	Support different roles and responsibilities
Russo, 2000	Singular	Experience of others as real people	Support intra-team feedback
Sallnäs, 2005	Singular	Experience of others as real people	Support intra-team feedback
Shin, 2013	Multi	Experience of others as real people, plus degree of awareness of the ICT tool	Support intra-team feedback / Support the building of mental representations of the key elements within a team's relevant environment that are shared across team members
Short, et al., 1976	Multi	Experience of others as real people, plus degree of affiliative associations	Support intra-team feedback / Foster team familiarity (to build affiliative associations)
Slater & Wilbur, 1997	Singular	w.r.t, the media, capacity to support SP	Consider the environmental context / Support intra-team feedback
Sung and Mayer, 2012	Singular	Experience of others as real people	Support intra-team feedback
Swan and Shih, 2005	Singular	Degree of affiliative associations	Foster team familiarity (to build affiliative associations)
Tu, 2002a	Singular	Experience of others as real people	Support intra-team feedback
Tu and McIsaac, 2002	Singular	Experience of others as real people	Support intra-team feedback
Walther, 1992	Singular	Experience of others as real people	Support intra-team feedback
Whiteside, 2017	Singular	Social Presence as a literacy	Recognise and manage relative priorities
Yen and Tu, 2008	Singular	Experience of others as real people	Support intra-team feedback
Zhao, 2003	Singular	Shared co-presence	Support intra-team feedback

Table 4-10. Social presence definitions mapped to design features.

Table 4-11 below synthesises our review to group definitions. Heuristic mapping is included but with the addition on the design feature implementation of the heuristic in our cycle 3 intervention exemplar artefact.

Definition	Heuristic	Design Feature
Experience of others as real people	Live interactions	Live feedback
Sense of group acceptance and integration	Promote team identity and sense of membership	Team average avatar
Awareness of social protocols	Continuous feedback	Live feedback
Awareness of co-presence and engagement with others	Live interactions	Live feedback
Experience of engaging with something/someone/another	Live interactions	Live feedback
Self-actualization	Features to enable team members expression	User added topics
Sense of being in an environment	Common, shared experience	Live feedback and intervention design prompts
Social Presence as literacy	Opportunities for reflection	Intervention design
Scaffolded learning interactions	Opportunities for reflection	Intervention design
Focused attention	Live interactions and prompts	Live feedback and intervention design
Degree of affiliative associations	Promote sharing	Live feedback, team member details and team avatar
Creating connections to build community, applying content to authentic situations, integrating a careful mix of tools and media, leveraging reflective and interactive opportunities, providing early and continuous feedback, designing with assessment in mind, encouraging change in small increments.	Multi-dimensional	Live feedback, team member details, team avatar, user added topics and interventions session design
Shared co-presence	Live interactions	Live feedback

Table 4-11. Synthesis of Social Presence definitions mapped to heuristics and presented with our intervention design implementation features.

Reduced social presence was highlighted by participants in cycle 2 as a perceived difficulty with hybrid work, but with such a plurality of definitions, it is difficult to measure the concept. Approaches such as the Social Presence Behavioural Coding Scheme examine interactions (Hayes, Hughes and Bailenson, 2022), which would have been infeasible for us to do across all of the teams in our cohort as we did not oversee team meetings. "Researchers have explored the relationship between social presence and nonverbal synchrony, presenting the synchrony of turn taking behaviour as a potential measure of social presence" (Sun, et al., 2019, as cited in Hayes, Hughes and Bailenson, ibid) and we have looked for disclosures of similar behaviours during our focus group sessions. Additionally, we aimed to note any feedback that resonated with any of the categories of definition.

TTT User Journey

Before beginning our discussion of the TTT design and how our collection of heuristics was implemented in the app, it may be helpful to the reader to describe a brief user journey to understand the process that students went through when working with the TTT during the intervention sessions. As we describe below in the current section, (sub-section 'TTT Deployment'), the application was available to access via the web using an easy to remember domain name that presented a responsive web interface that could be accessed on any modern device such as a mobile phone or laptop. Figure 4.13 illustrates the initial login page that student saw when accessing the site. This login page asked for a first name and academic discipline, which were used to display information to peers on the team once they had logged on, while a drop-down option field of each team number allowed for easy self-grouping of students without the need to preconfigure teams in the database. This ensured reusability and a minimal data footprint. Following submission of the login form, students were redirected to the main interface which is shown in figure 4.14. This page displayed an screen that allowed students to enter their sentiment values per topic, while simultaneously seeing their peers' values for the same topics, and a team average per topic that was presented to stimulate conversation. Additionally, two pop-up modal help windows provided extra information and potential discussion points that had been generated by our Cycle 2 cohort feedback. Students were also free to add their own discussion topics, which were presented beneath the default topics in the same fashion. We now turn to an explanation of how each of our heuristics was used and implemented in our final TTT design.

TTT Design

The TTT implementation is an instantiation of our heuristics and one possible solution within the solution space of our second research question. The heuristics may be implemented in richer and more immersive media, and the resulting design will be contextual to that environment. Cycle 1 findings deemphasised fully immersive XR solutions for our cohorts and suggested that a simple web-application interface would best suit our use case, which limited the scope of possible design responses. The interface and features represent an instantiation of our design rules presented in a web-app format that was used as a companion application during our teamwork intervention activity. The TTT enriches team communication by offering an addition information channel, and the novelty that this provides may be a helpful catalyst for breakthroughs (Dahm, Rowan Byrne, Rogers, et al., 2021). The interface is fully responsive, meaning that it can be used on any kind of screen (i.e. a responsive, mobile first design) and its design applies modern web standards to facilitate easy integration into future computing paradigms such as fully immersive mixed reality experiences. Table 4-12 below illustrates the mapping of each heuristic support to our design implementation.

Source	**Reference**	**Heuristic**	**Corresponding design rule feature implementation**
UX			
Muller, et al., (1998)	ux1	System Status, User Control and Freedom, Consistency and Relevancy, Error Recognition and Recovery, and Task and Work Support	Collect participant UX feedback in focus sessions
Teamwork theories			
Tuckman, 1965; Inverardi & Tivoli, 2009	th1	Tool should adapt to the users changing requirements	User defined topics
LaFasto & Larson, (1989)	th2	Support intra-team feedback	User defined topics and live team members feedback
Salas, et al., (2013)	th3	Support different roles and responsibilities	All live feedback will be visible to every team member so that any (or every) member can lead the discussion.
	th4	Support team mission objectives and norms	Equated with design rule tmm1: Promote Shared team mental model building through scaffolded team

			interactions, i.e. intervention design and discussion topics.
	th5	(consider) the environmental context	Mobile first design
	th6	Foster team familiarity (to build affiliative associations)	Intervention design (explain your sentiment to your peers)
Katzenbach and Smith, (1993)	th7	Be specific in communications	Use multistep sliders to simplify the sharing of data
	th8	Recognise and manage relative priorities	Aggregated smiley feature to highlight issues and user added topics help the team to recognise relative priorities
	th9	Employ a clear working approach	Multistep sliders & user added topics
Team Mental Models			
Mohammed, et al., (2010)	tmm1	Scaffolds the key elements of the work within a team's relevant environment and share across team members	User added topics, intervention design rules (share and explain your sentiments) and synchronous live feedback to all team members
D-Cog			
Hutchins (1995)	dc1	Embodiment of information within the system	Live feedback
	dc2	Co-ordination between agents,	Live feedback & user added topics
	dc3	The impact of set and setting (ecosystem) on the process taking place.	Responsive, mobile first web design
	dc4	Cognitive process is delimited by the functional relationships among the members	Include live feedback on user defined topics to support asynchronous roles
DiCoT			
Blandford & Furniss (2006)	dc5	Physical Layout: Space and Cognition	Situate familiar content (PLO) as the first items "above the fold" (i.e. initially visible on the web-app page without the need for scrolling)
	dc6	Physical Layout: Subtle Bodily Supports	Responsive, mobile first web design
	dc7	Physical Layout: Situation Awareness	Scaffolded discussion topics: PLOs and learner defined

			team topic discussions as part of the intervention
	dc8	Information flow: Buffering	User defined topics
	dc9	Artefacts: Representation – Goal Parity	Live feedback & user defined topics
	dc10	Artefacts: Coordination of Resources	Team members are encouraged to discuss ways to overcome challenges that they see in the default topics and user added topics, in support of the Coordination of Resources principle.
Webb (2008)	dc11	Development of practice	Create opportunities for team member reflection through team feedback.
	dc12	Development of practitioners	Create opportunities for team member reflection through team feedback.
User centred considerations			
Griffin & Byrne	c1a	Don't assume users will recognise UI controls	Information from the instructor. In app help = Modal info windows
	c1b	Our tool should provide detailed instructions	Information from the instructor. In app help = Modal info windows
	c1c	XR onboarding is difficult for new users	Information from the instructor. In app help = Modal info windows
	c2a	Remote teams experience reduced social presence and often miss social cues.	Build in a clear, easy way to share cues
	c2b	Interface controls that represent analogues of social cues should not feel unnatural to users.	Use sliders for a recognisable and low effort UI
	c2c	Hybrid students want to get to know each other (not part of earlier set - later analysis)	Include team member details (profile data) to support team relationship building and a team average avatar to promote team alignment sentiment.

Table 4-12. XR novice hybrid transdisciplinary teamwork heuristic supports mapped to TTT design rule implementation.

Several implementation solutions were explored before settling on a TypeScript/React frontend and PHP/Laravel backend, with Postgres as our database tier. Our first implementation (PHP and MySQL) offered a good way to explore potential usage patterns and to anticipate any technical issue that this might present. During early testing it became clear that maintaining state for several team members at once would not be possible using PHP alone. We forked our PHP code and refactored it into a set of backend controllers for use within the Laravel PHP framework. Laravel is a free and open-source PHP-based web framework for building web applications based on a Model, View, Controller design pattern. Isolating our code as a set of controllers offered the advantage of allowing the framework to manage the security and other administrative aspects. Laravel provides caching options and an optimised way to interaction with the database tier, which adds up to improved performance and a better user experience. Once the backend functionality was isolated in this way, we needed to recreate our frontend code to present the tool to our learners. A design using the React framework with TypeScript for the rendering and Googles Material design framework for display of standardised interface elements including content boxes, layout grids, icons, buttons and typography. This also simplified the spawning of elements such as popup modal windows describing questions for the team to ask themselves (Model / Vision) and the inspirational mirror data generated by students during cycle 2. Figures 4-13 to 4-17 below, illustrate each screen of the TTT app implementation. Figure 4-14 illustrates functionality used by the students that exemplifies the heuristics. For example, team averages help members recognise and manage relative priorities, team mission objectives and norms and situational awareness relating to team capacities and goal parity by mediating the co-ordination between agents during the discussion activity. Feedback enables a clear working approach by being specific in communications via embodiment of information within the system, and user added topics control the information flow.

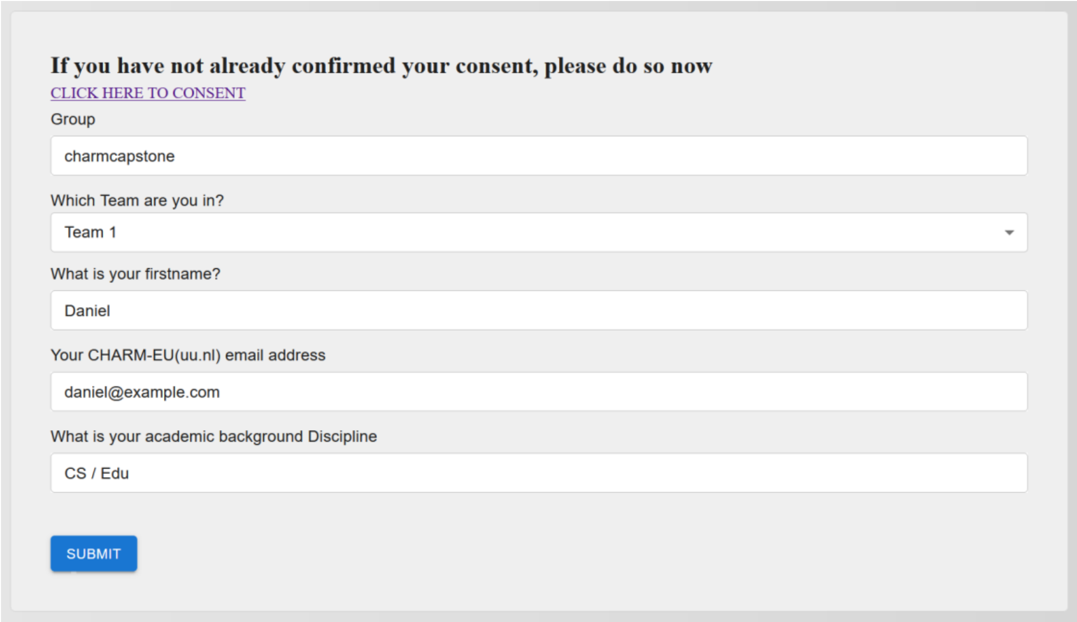


Figure 4-13. The TTT Login page.

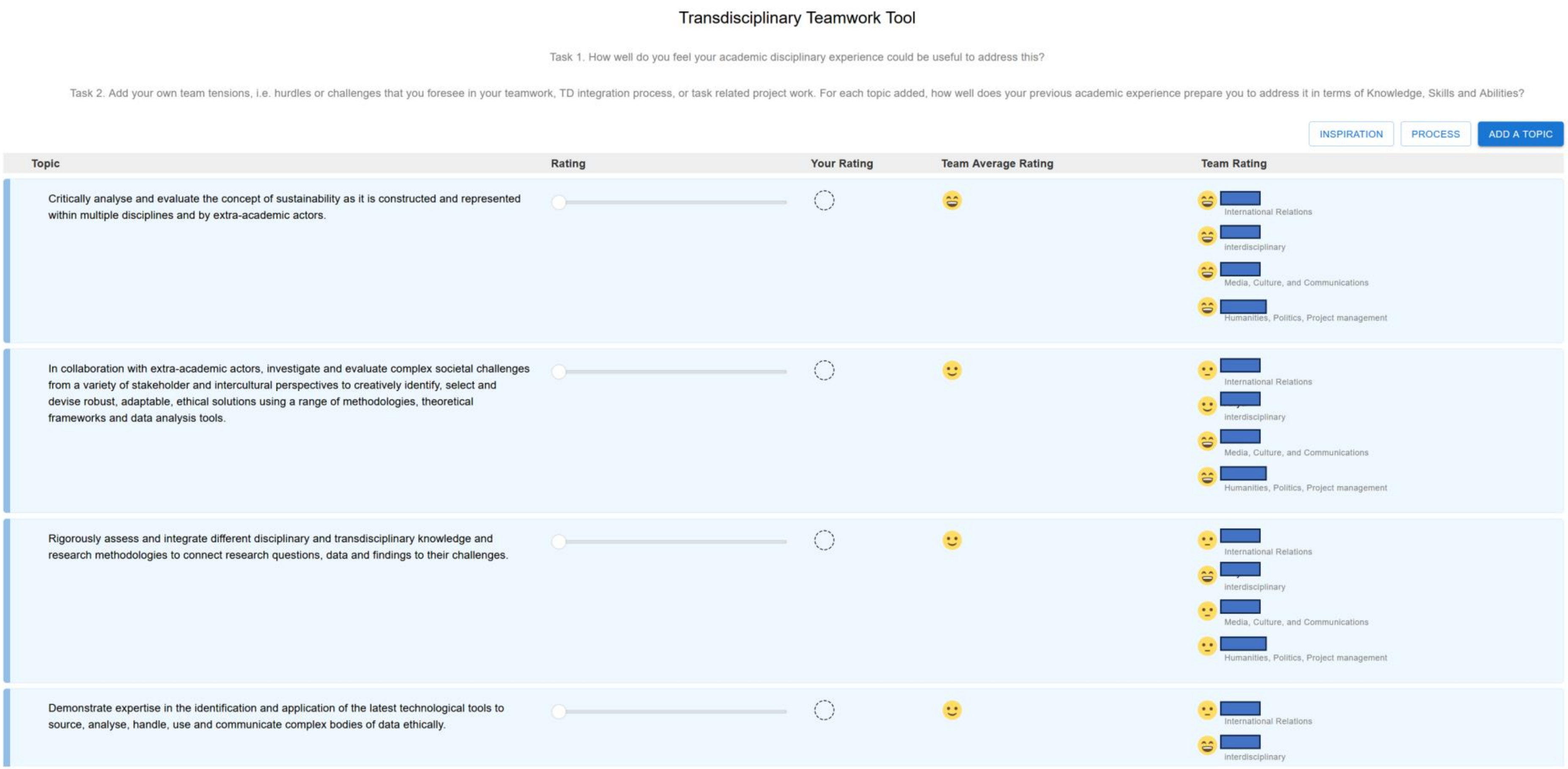


Figure 4-14. TTT Team Interface. Participant names obfuscated.

Figure 4-15. Close-up detail of an example discussion topic rating. Participant names obfuscated for privacy.

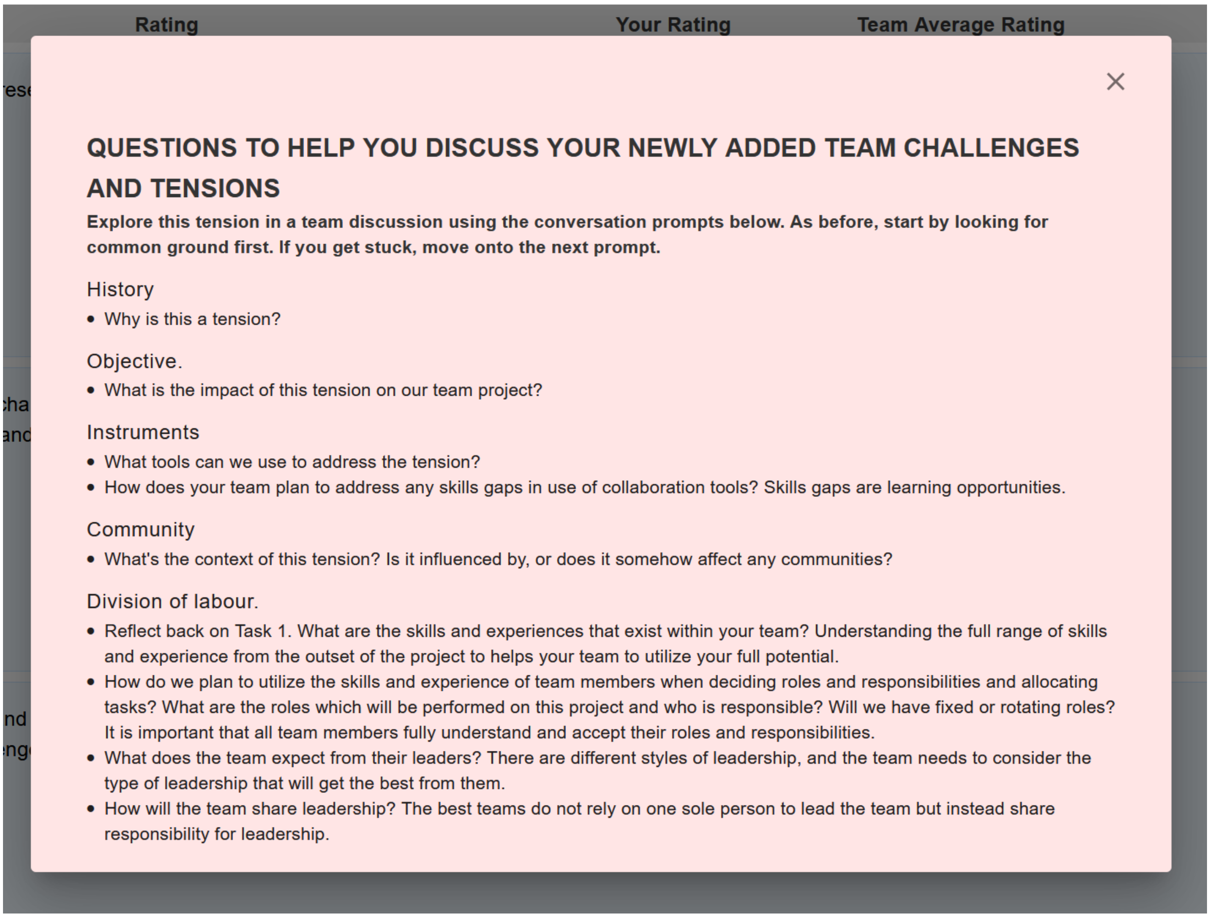


Figure 4-16. Popup modal window showing 'Process' (Model / Vision) information.

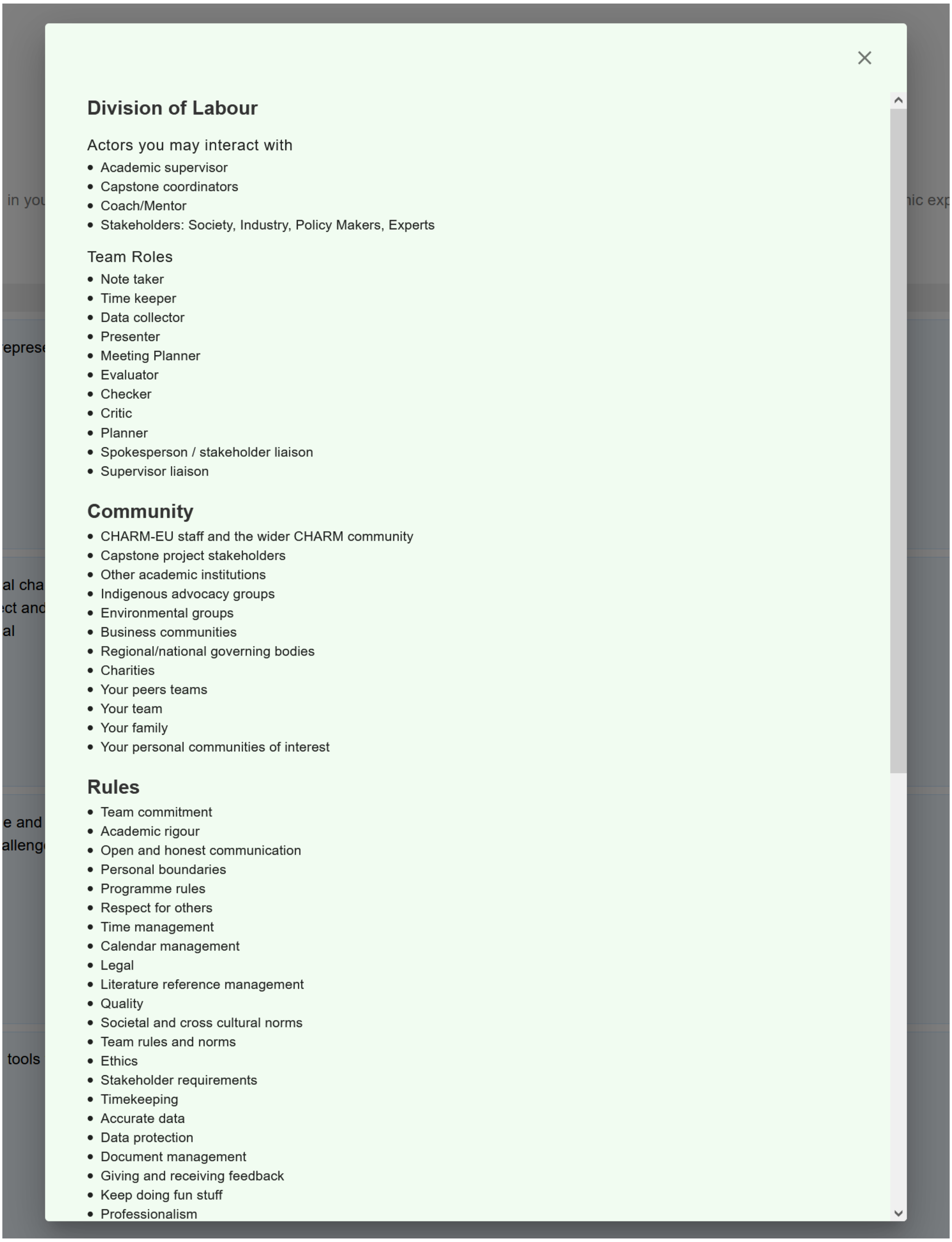


Figure 4-17. Popup modal window showing 'Inspiration' (Mirror data) information.

TTT Database Structure

Interested technical readers may review the SQL statements describing the TTT database schema, in Appendix 1.

TTT Deployment

Our frontend code is deployed on a free private repository in Vercel, which is a cloud infrastructure platform that supports easy scaling. This code does not interact with the database and only runs on each learner's device. Our backend code runs as a set of bespoke controller files in a Laravel instance on the Heroku platform (a backend deployment solution), again chosen for easy scalability, access control, alignment with our data protection requirements and the ability to separate the code from the data. Finally, the data itself that students generate is stored securely in a PostgreSQL database running on a server in the eu-west-1 Western Europe (Ireland) availability zone. This design ensures that data can only exist on the users' devices and our access-controlled database. There are no costs involved in the basic deployment with free tier accounts, however during our first session we reached the free tier usage cap and therefore opted to scale up our Vercel account tier to a basic paid version (nominal cost) to pre-empt any usage spikes in subsequent iterations of our intervention. This proved to be a sensible step as subsequent sessions did not hit the cap. For ease of access, we chose to make the app available via an easy to remember domain name, https://cientista.social, which hints at the social science nature of the tool. Cientista is the Portuguese word for scientist, which is memorable for our cohorts of mostly European CHARM-EU students. The word cientista also holds personal meaning for this researcher as it is my 'Capoeira appelido' or nickname with the 'Comunidade de Estudos e Pesquisas da Capoeira' (Community for the Study and Research of Capoeira). The top-level domain 'social' is unusual and therefore memorable, and we believe that its meaning fits the intended purpose of our tool well. Additionally, three example implementations of our heuristics (th5, th7 and dc6) may be seen in this choice. A web link is considerate of the environment context (Salas, et al., 2013) of hybrid teamwork. A URL that is short, memorable and easy to input, should offer a subtle body support (Hutchins 1995; Blandford and Furniss, 2006), and it allows us to be specific in our communication (Katzenbach and Smith, 1993) to our hybrid cohort.

App Usage Data

Software tools have the potential to produce massive amounts of telemetry and usage data. Direction, speed and frequency of movement, voice recordings, eye gaze targets and timings are just some of the data points that are currently being captured by vendors. We chose to avoid excessive tracking to protect our students and to reduce the processing demand on their devices. Accessing this information may be tempting but the current widespread practice of collection and sale to marketing companies sets a dangerous precedent for the exploitation of users. Furthermore, typical approaches to analysing this information are an extension of current web marketing practices which are notorious for making bad choices when it comes to ethical questions or the over-simplification of complex problems regarding race, gender, and other identity issues. Any use of personally identifiable data in a prototype application would obviously require further ethical approval and we preferred to avoid this kind of data entirely. The collection and use of these data would need to ensure that the user has full ownership and control over how and when the data are generated, which is beyond the scope of the current research. As discussed earlier, an analysis of inter-subjective experiences is best handled via qualitative methods and interview/focus group sessions have played an important role. Quantitative analysis of teamwork is not uncommon (Salas, et al., 2015), and Kerr and Chung (2012) successfully applied data-mining techniques to show patterns in teamwork. Some amount of quantitative data relating to teamwork and team process was useful, particularly when highlighting moments of mutual accommodation between teammates, however care must be taken to ensure that only the most appropriate data are collected and mined. The exploitation of user data is a fundamental failing of the current web ecosystem and any efforts that can help to prevent the same thing happening for XR should be promoted. The following principles guided the design of our database schema.

- Minimal data to identify students and support feedback to team members (firstname, student email address, academic discipline, team_id).
- Minimal data to describe user interactions with each topic (user_id, topic_id, rating, timestamp).
- Additionally, we included the teams list and topics list in our database for future flexibility, rather than the easier option of hard coding these into the app for the specific context.

We opted for an 'append only' approach to recording topic ratings with every score adjustment being recorded as a new database entry. This design automatically created a history of every student's interaction with each topic. The latest value for each student/topic combination was used as the sentiment value shown to teammates and included in the live team average calculation. Our simple design also allowed us to build a simple login solution that did not require maintaining individual user passwords. Students were quickly able to join their team by logging in with their group name (charmcapstone or charmphase1), email address and team number which was known to them in advance.

Usability

Data from cycle 1 indicated that our students initially struggled to handle the complexity of the interface elements for the 3D environment, with some even failing to recognise interface controls that we assumed to be evident, such as enabling one's microphone. Cycle 2 data supports our view that simple interfaces are the most useful when teams are dealing with a high degree of cognitive load such as trying to multitask in a new environment (e.g., in Mozilla Hubs; simultaneously talk, move and interact with objects in the space. E.g., in MS Teams, failing to keep up with a conversation thread, failing to find supplied learning materials).

Good usability allows a user to achieve their intended task more efficiently, with less errors and reduced cogitative load. Bad usability can ruin the productivity of a tool (Tufte, 2001). Really excellent usability is often overlooked by users as a well-designed interface allows the users to act in a more natural way, without the complexity of the application interfering in their intended task. It does this by leveraging the strengths of the human perceptual system (Tufte, ibid) to create interfaces that offer intuitive, memorable experiences that reduce the chance of user error.
Swan and Gabbard (2005) were among the first to attempt to assess the state of the art in mixed reality usability research. Others have continued the work, and Arindam, et al.'s extensive study in 2018 is recognised as the most recent large-scale effort. The study of usability within mixed reality is a broad field that encompasses typical human computer interaction and web-based usability topics such as navigation, performance, readability and cogitative load, as well as external factors such as hardware ergonomics. Our app addresses these requirements using the simplest of modern software inputs, the humble slider. Sliders are common across a wide variety of applications and can be easily interacted with on a similarly wide variety of devices and input styles (touch, mouse, VR wand, etc.). Sliders are common in 2D interfaces, and this translates easily into 3D where they are found in use within the menu systems of all current XR headsets. By using sliders, we have ensured that our design can be readily ported or otherwise integrated into future software environments.

4.8.4 Cycle 3 Focus Sessions

We use the term "focus session" in this section to include interviews, pair-interviews and small focus groups. We began each of these with a warmup round of eighteen questions from Ravitz et al's (2010)

21st century skills questionnaire. This helped students to relax into the session (Creswell, 1998; 2012) and allowed us to confirm how comfortable our students were with general ICT and transversal skills. In all but one case, every student answered positively to every question, with only one student mentioning they lacked prior experience of relating to making any kind of public presentation. The remainder of each session was equally structured and planned in accordance to a structured interview protocol listing the questions and notes on heuristics for the researchers reference. The decision to apply a more structured protocol in this cycle differed from the semi-structured approach taken in earlier cycles. This was a necessary consideration due to the less exploratory nature of cycle 3 and our aim to seek feedback on the heuristics. With a large collection of heuristics to examine, a structured format helped to maintain our focus and ensured the repeatable and consistent approach across the six focus sessions maintains coherence (Creswell, 2013).

In preparation for our sessions, we used the AODM eight-step questions as a guide to conceptualise the idealised outcome (Objective) for each design rule (Tool). This process aided reflection and helped us to recognise overlapping constructs in the outcomes. Of the design cycle set, we reasoned that the three rules from cycle 1 could be reduced to a single question for validation. Cycle 2 heuristics did not change (n=3). As our study did not include any longitudinal aspect, it was infeasible to develop software features in support of the 'Development of Practice' and 'Development of Practitioners' from our DiCoT heuristics (Webb, 2008) and we did not have design features from which to base our focus groups questions. We did want to explore these themes however and included follow-up questions whenever possible relating to students views regarding transitions from one activity system to another, i.e. previous modes of doing something versus their current experiences, or, current approaches and anticipated future outcomes (examples include previous teamwork experiences versus that experienced during the intervention, and, the impact that such approaches to teamwork might have on future teams). This reduced our literature set by two more heuristics. Our final UX related heuristic was not explicitly used but kept as a fall-back question to be asked if the subject came up during sessions.

An AODM analysis of the remaining topics for discussion identified seven questions focused on common design features. In the interest of time management we consolidated these into a related open question relating to said design feature, which give students scope to provide broader feedback and helped us to cover more ground during each session. This resulted in a final set of sixteen design rules and corresponding questions for the cycle 3 focus sessions.

Reviewing our heuristics

We reflected on each of the eight steps from the Mwanza AODM model, in the context of each one of our heuristics. The output of this process is illustrated per heuristic in the sections that follow.

Previous Cycle Heuristics

Cycles 1 and 2 produced three heuristics each (see table 4-13 below). Our AODM review indicated an overlapping theme from heuristic c1a with respect to c1b and c1c, and this prompted us to develop a single question to cover the cycle 1 heuristics in our cycle 3 focus sessions.

ID	Heuristic
Cycle 1 outputs	
c1a	Don't assume users will recognise UI controls
c1b	Our tool should provide detailed instructions
c1c	XR onboarding is difficult for new users
Cycle 2 outputs	
c2a	Remote teams experience reduced social presence and often miss social cues
c2b	Interface controls that represent analogues of social cues should not feel unnatural to users.
c2c	Hybrid students want to get to know each other.

Table 4-13. Cycle 1 and 2 heuristics informed by user centred concerns.

Heuristics from Cycle 1

Applying the AODM eight-steps suggested three potential tensions to us relating to this heuristic (figure 4-18).

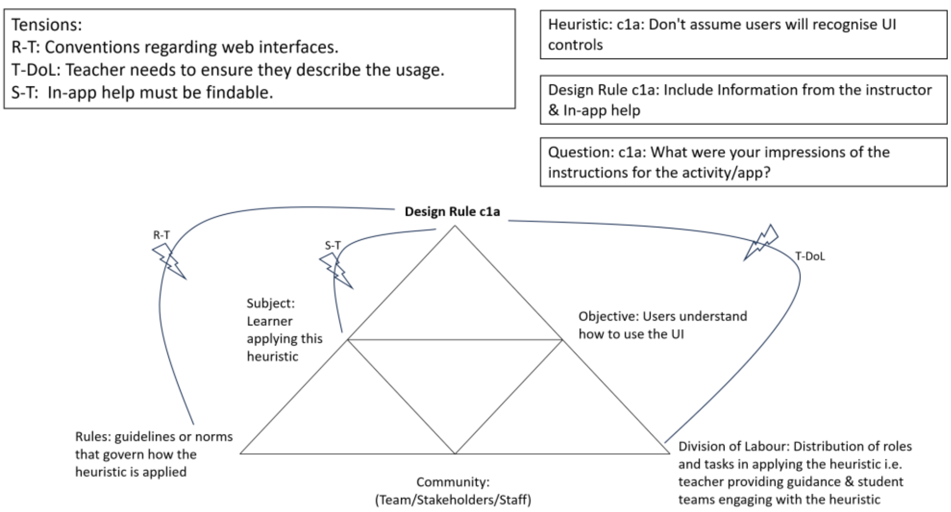


Figure 4-18. Heuristic c1a (Cycle 1), design rule/feature: Include information from the instructor and in-app help to guide usage.

Heuristics from Cycle 2

Our first cycle 2 heuristics holds that remote teams experience reduced social presence and often miss social cues, and our design rule response to this was to build in automatic sharing of social cues within our app interface via team member and team average sentiment emoticons for each discussion topic. Figure 4-54 illustrates the potential tensions with this first heuristic from cycle 2 which we identified when preparing for the cycle 3 focus group. Figures 4-19 and 4-21 illustrate the next three heuristics from this cycle. Our design rule implementations of the related heuristic are detailed in each figure.

Tensions:
S-T: Prior learning / XP can improve social presence.
R-T: Subjects need to express social cues in remote work.
T-DoL: Everyone needs to use the tool during the session.
C-T: Community membership may influence social presence sensitivity.

Heuristic: c2a: Remote teams experience reduced social presence and often miss social cues.

Design Rule c2a: Feature clear, easy way to share cues

Question: c2a: What did the emoticons make you feel about your teammates? What about the team average values?

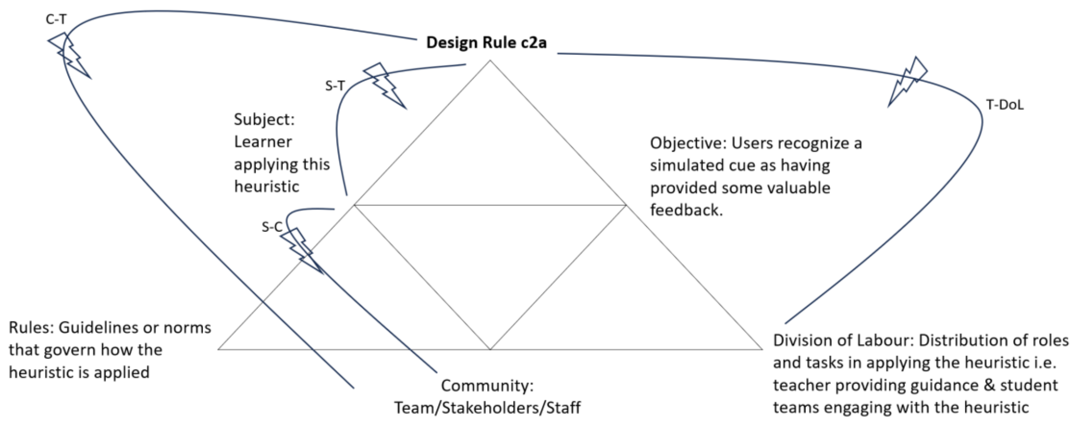


Figure 4-19. Heuristic c2a (Cycle 2), design rule/feature: Build in a clear, easy way to share cues.

Heuristic c2b (figure 4-20) addresses our cycle 2 finding that interface controls should not feel unnatural to users. In hybrid environments such as a team interaction, this leads to individual team members needing to split their focus between the teamwork activities and the teamwork tool. Our design response to this is to adopt best practices by employing simple sliders as analogues of the sentiment scale. Users can easily recognize that sliders represent a value on a scale since using a slider provides inherent feedback. A DiCoT framing of this aligns with Principle 2, i.e. the Perceptual Principle, based on affordances work by Norman (1988), which holds that “spatial representations provide more support for cognition than non-spatial ones provided that there is a clear mapping between the spatial layout of the representation and that which it represents”, (Blandford and Furniss, 2006). To further clarify their sentiment to teammates and to assist with transmission of social cues, each slider in our interface employed a live data binding to a corresponding emoticon smiley that is shared for all team members. Slider values were stepped at 20% intervals and updating the slider value automatically updated the emoticon state to reflect the change.

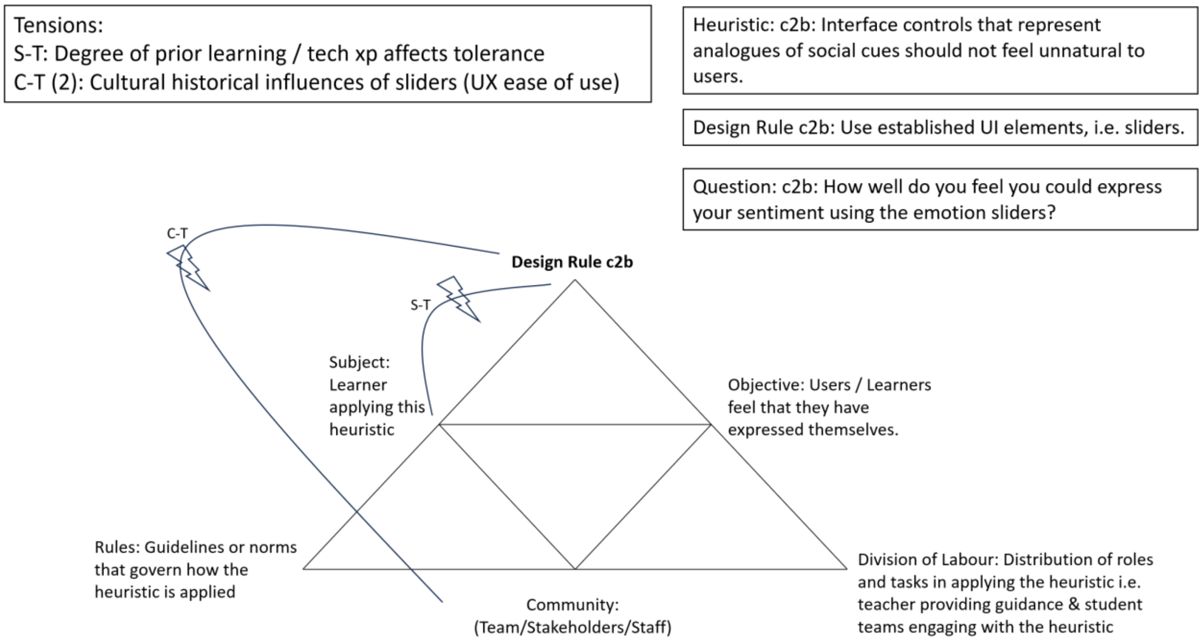


Figure 4-20. Heuristic c2b (Cycle 2), design rule/feature: Use sliders for a recognisable and low effort user interface.

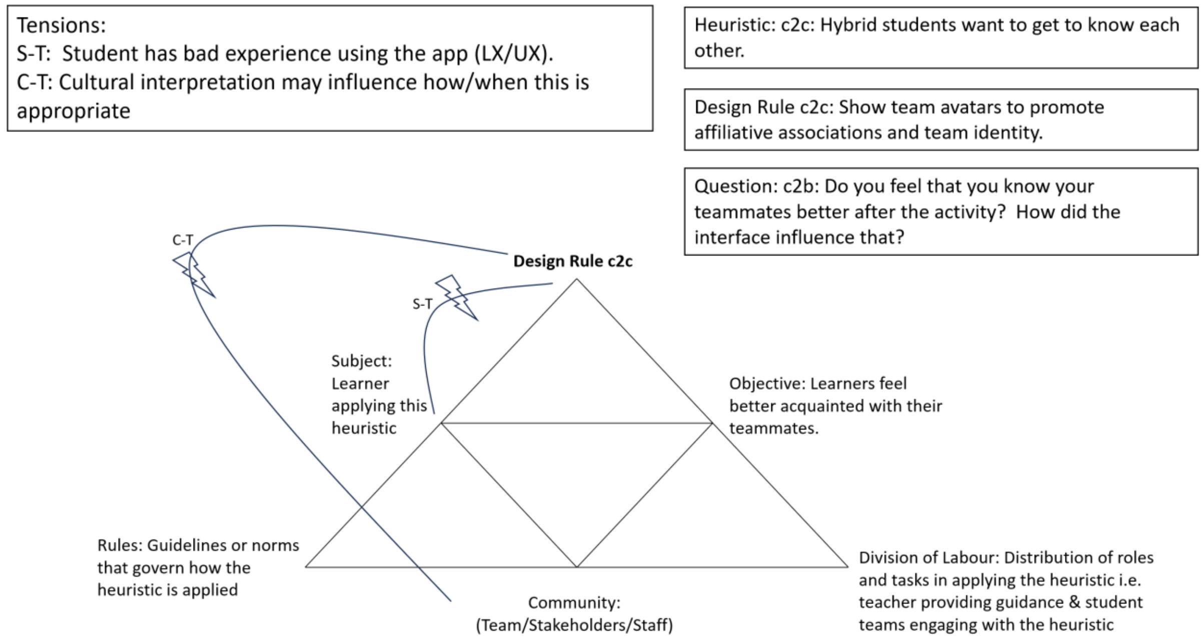


Figure 4-21. Heuristic c2c (Cycle 2), design rule/feature: Include team member details (profile data) to support team relationship building and a team average avatar to promote team alignment sentiment.

Heuristics from Literature

Teamwork theories

The following heuristics (table 4-14) are informed by the relevant teamwork theories in our conceptual framework and individual details are presented below for each. Each graphic represents the output of an AODM review based on asking Mwanza's (2002) eight-step to identify potential tensions and refine the associated focus session questions planned for the cycle 3 intervention. Shaded rows indicate those heuristics that were noted as overlapping with other themes during the AODM review. Tensions are labelled as arcs within each diagram that connect element of the Activity System triangles.

Source	Code	Heuristic
Tuckman, 1965; Inverardi & Tivoli, 2009	th1	Tool should adapt to the users changing requirements
LaFasto and Larson, 1989	th2	Support intra-team feedback
Salas, et al., 2013	th3	Support different roles and responsibilities
	th4	Support team mission objectives and norms
	th5	Consider the environmental context
	th6	Foster team familiarity (to build affiliative associations)
Katzenbach and Smith,1993	th7	Be specific in communications
	th8	Recognise and manage relative priorities

	th9	Employ a clear working approach

Table 4-14. Teamwork heuristics.

Figures 4-22 to 4-27 show potential tensions with our teamwork theory literature informed heuristics, which helped when preparing for the cycle 3 focus group questions. Heuristics inform the design rule and we developed the associated focus group questions by reflecting on the AODM steps and any tensions that were identified.

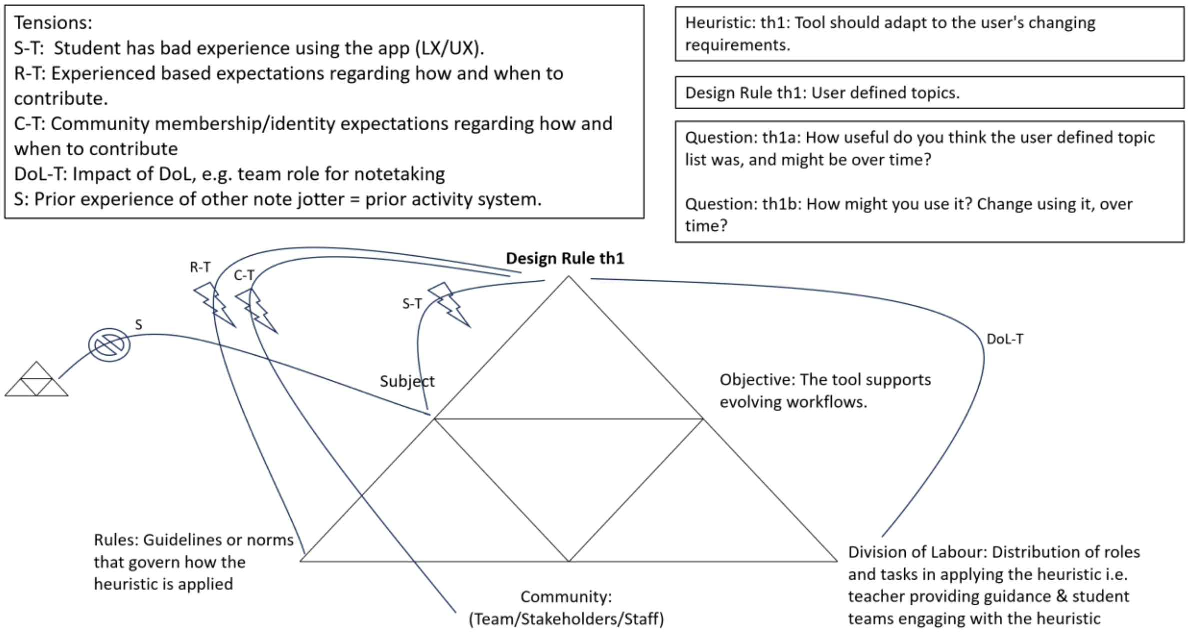


Figure 4-22. Heuristic th1 (Tuckman, 1965; Inverardi & Tivoli, 2009), design rule/feature: user defined topics to support changing team requirements. This includes four secondary tensions between elements, and one tertiary tension stemming from a prior activity system.

Tensions:
S-T: Student has bad experience using the app (LX/UX).
C-T: Expectations regarding feedback.
DoL-T: Members must all contribute

Heuristic: th2: Support intra-team feedback.

Design Rule th2: User defined topics and live team member feedback.

Question: th2a: How useful was the feedback.
Question: th2b: How might the topics be useful for feedback?

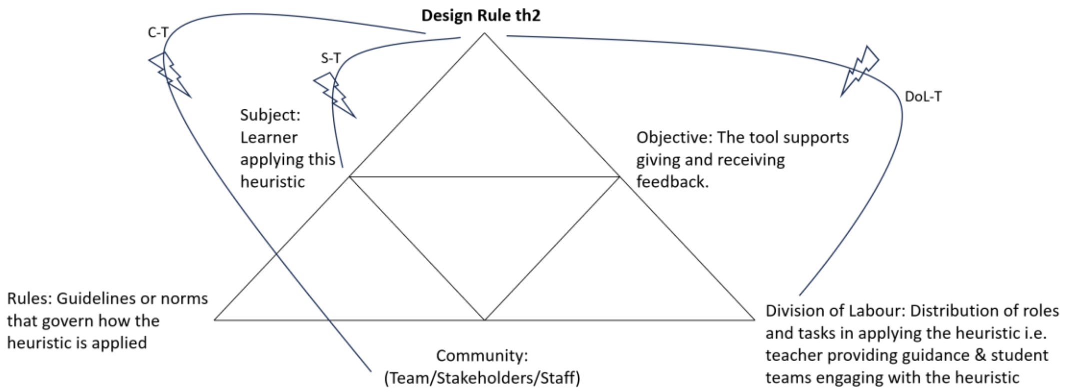


Figure 4-23. Heuristic th2 (LaFasto and Larson, 1989), design rule/feature: Include user defined topics and live feedback of team member sentiment to support intra-team feedback.

Tensions:
S-T: Student has bad experience using the app (LX/UX).
C-T: Expectations regarding feedback.
DoL-T: Members must all contribute
R-T: Programme requirements may mandate an approach

Heuristic: th3: Support different roles and responsibilities

Design Rule th3: User defined topics and live team member feedback.

Question: th3a: If you discussed the team suggested challenges, how did you organise the discussion?

Question: th3b: How could a session like this (this type of tool and activity) support you in different team roles?

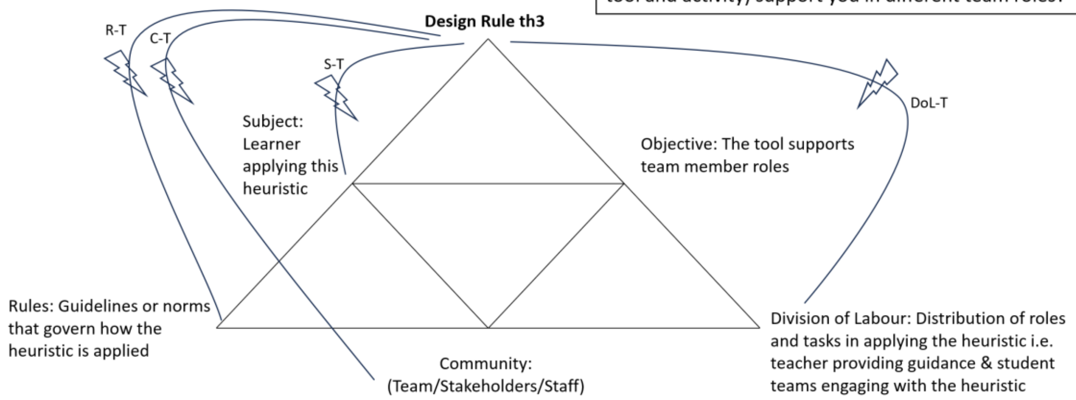


Figure 4-24. Heuristic th3 (Salas, et al., 2013), design rule/feature: Include user defined topics and live feedback of team member sentiment to support different roles and responsibilities.

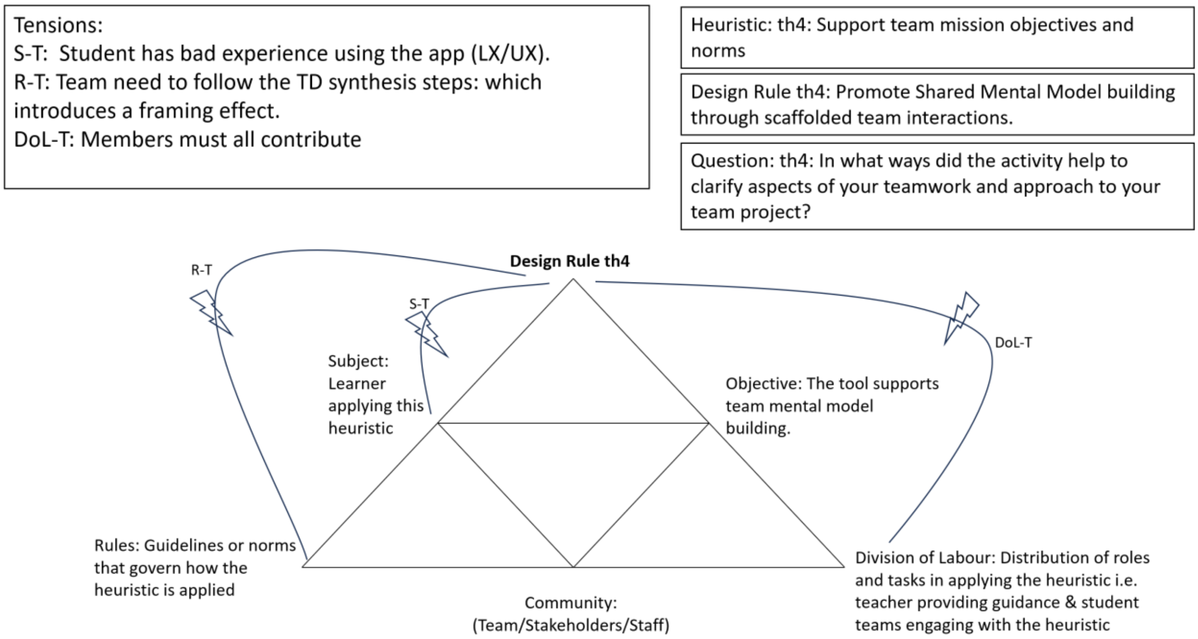


Figure 4-25. Heuristic th4 (Salas, et al., 2013), design rule/feature: Include user defined topics and live feedback of team member sentiment to clarify team mission objectives and norms.

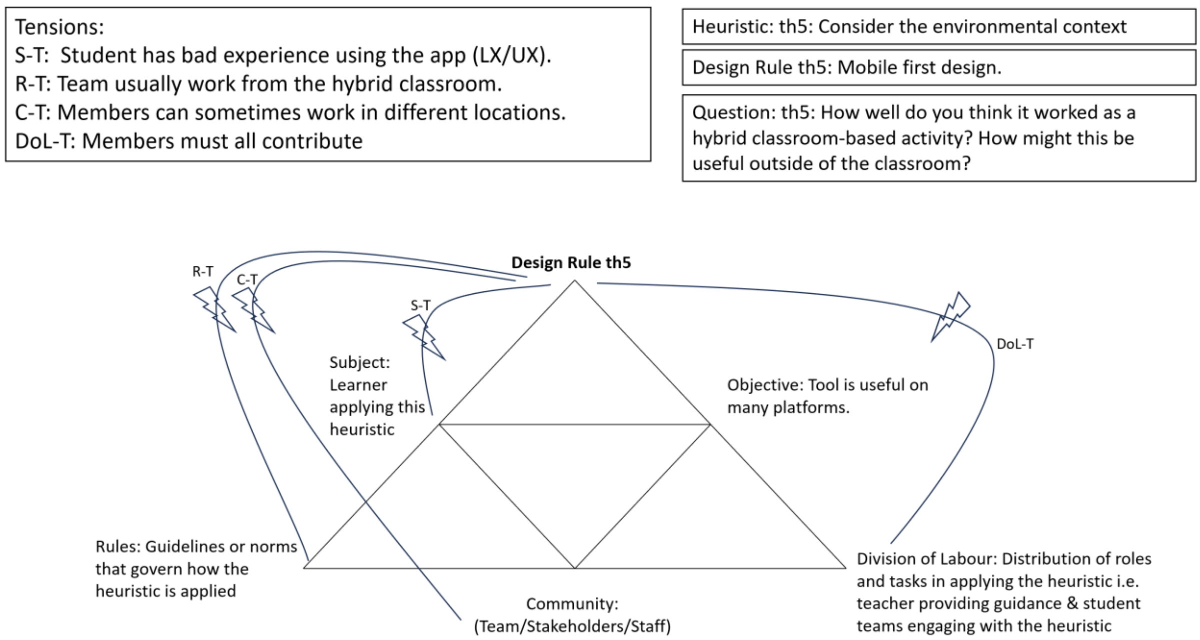


Figure 4-26. Heuristic th5 (Salas, et al., 2013), design rule/feature: Tools will use a responsive 'mobile first' design in consideration of the environmental context.

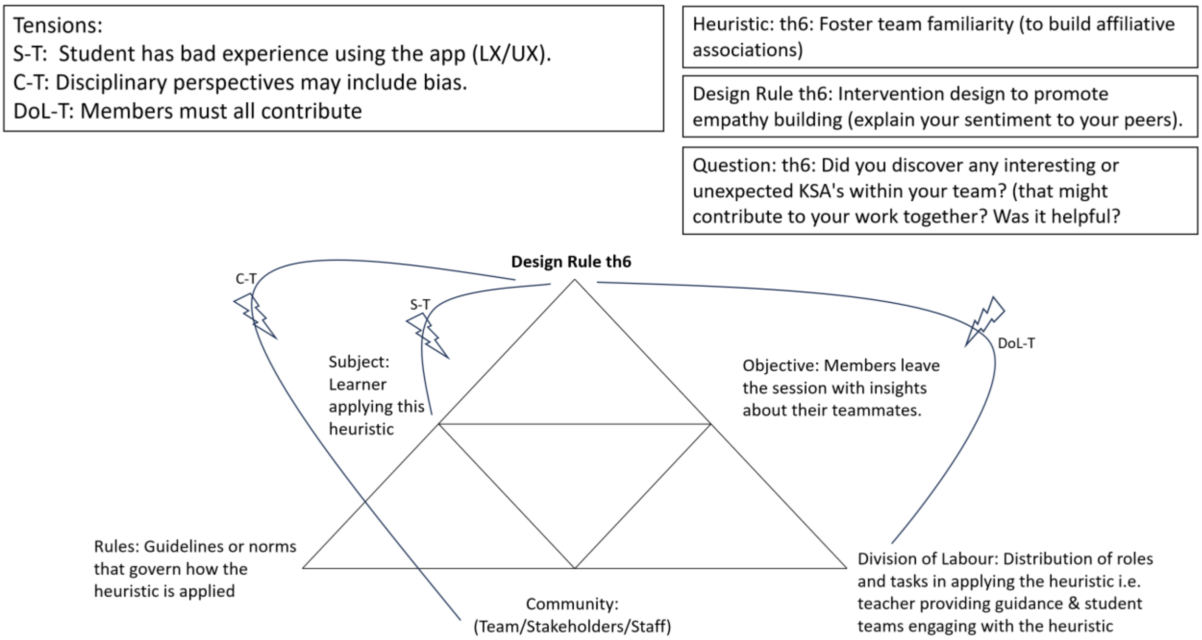


Figure 4-27. Heuristic th6 (Salas, et al., 2013), design rule/feature: Intervention design asks team members to explain their sentiment to peers, to foster team familiarity (i.e. and build affiliative associations).

Team mental models

We include our Team Mental Models heuristic (table 4-15) within the teamwork set and illustrate a potential tension with this in figure 4-28.

Source	Code	Heuristic
Mohammed, et al., (2010)	tmm1	User defined topics create mental representations of the key elements within a team's relevant environment that are shared across team members

Table 4-15. Team Mental Models heuristic.

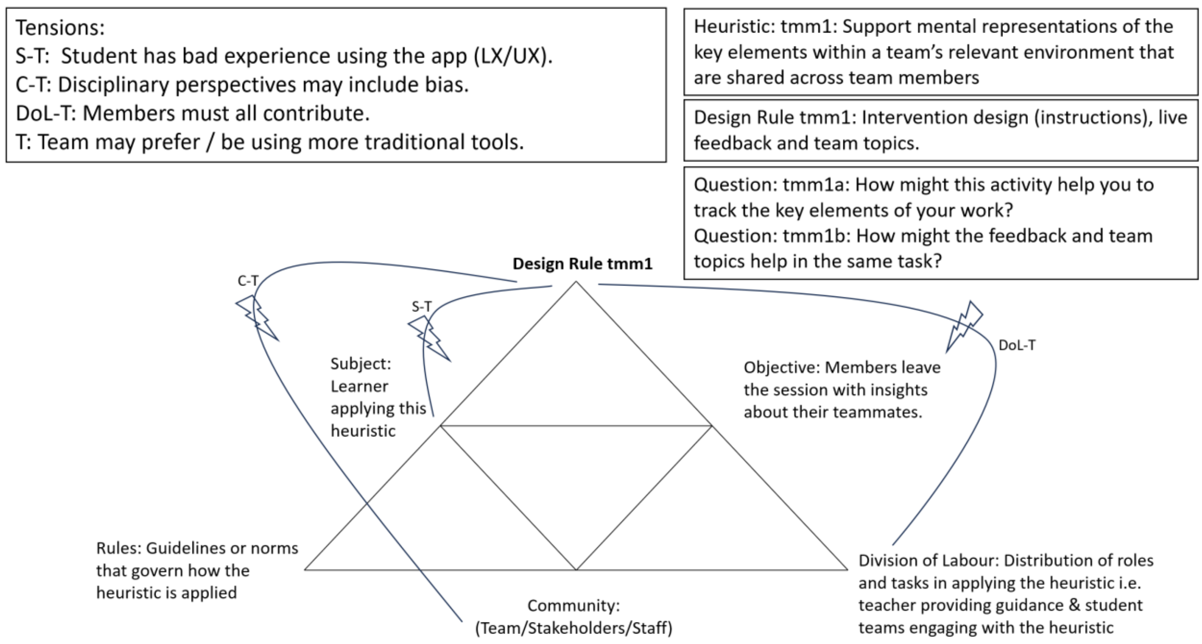


Figure 4-28. Heuristic tmm1 (Mohammed, et al., 2010), design rule/feature: User defined topics create mental representations of the key elements within a team's relevant environment that are shared across team members.

Distributed cognition

Source	Code	Heuristic
DCog (Hutchins, E., 1995)	dc1	Embodiment of information within the system
	dc2	Co-ordination between agents,
	dc3	The impact of set and setting (ecosystem) on the process taking place.
	dc4	Cognitive process is delimited by the functional relationships among the members
DiCoT (Blandford, A. & Furniss, D., 2006)	dc5	Physical Layout: Space and Cognition
	dc6	Physical Layout: Subtle Bodily Supports
	dc7	Physical Layout: Situation Awareness
	dc8	Information flow: Buffering
	dc9	Artefacts: Representation – Goal Parity
	dc10	Artefacts: Coordination of Resources
Webb (2008)	dc11	Development of practice
	dc12	Development of practitioners

Table 4-16. Distributed Cognition heuristics.

DCog and DiCoT principles (table 4-16 above) are collated into our Distributed Team Cognition category of heuristics and figures 4-29 to 4-36 illustrate potential tensions identified when preparing for the cycle 3 focus groups.

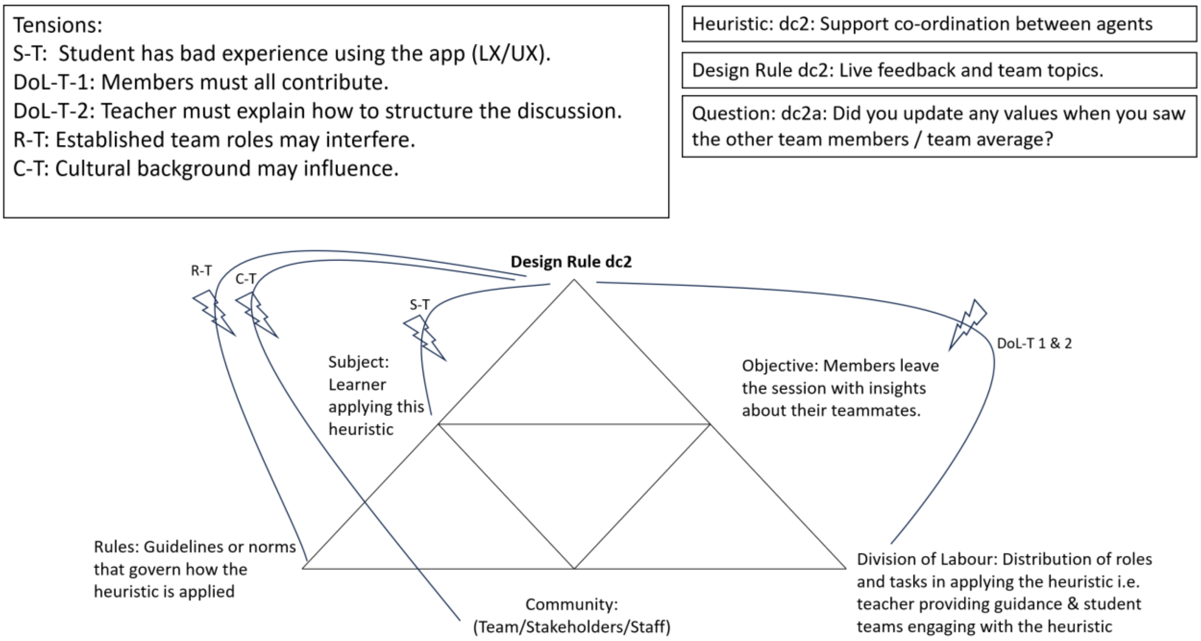


Figure 4-29. Heuristic dc2 (Hutchins, 1995), design rule/feature: Include live feedback and user defined topics to support co-ordination between agents.

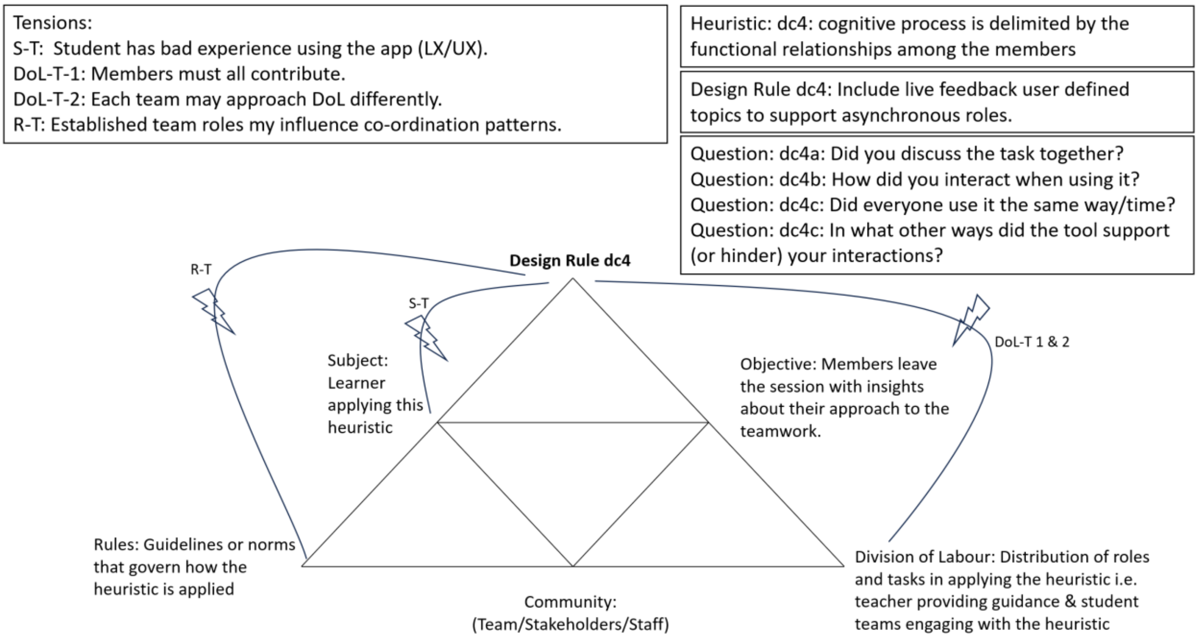


Figure 4-30. Heuristic dc4 (Hutchins, 1995), design rule/feature: Include live feedback user defined topics to support asynchronous roles. As CHARM-EU students do not have fixed team roles, we developed additional probing questions to better explore students perspectives relating to this heuristic.

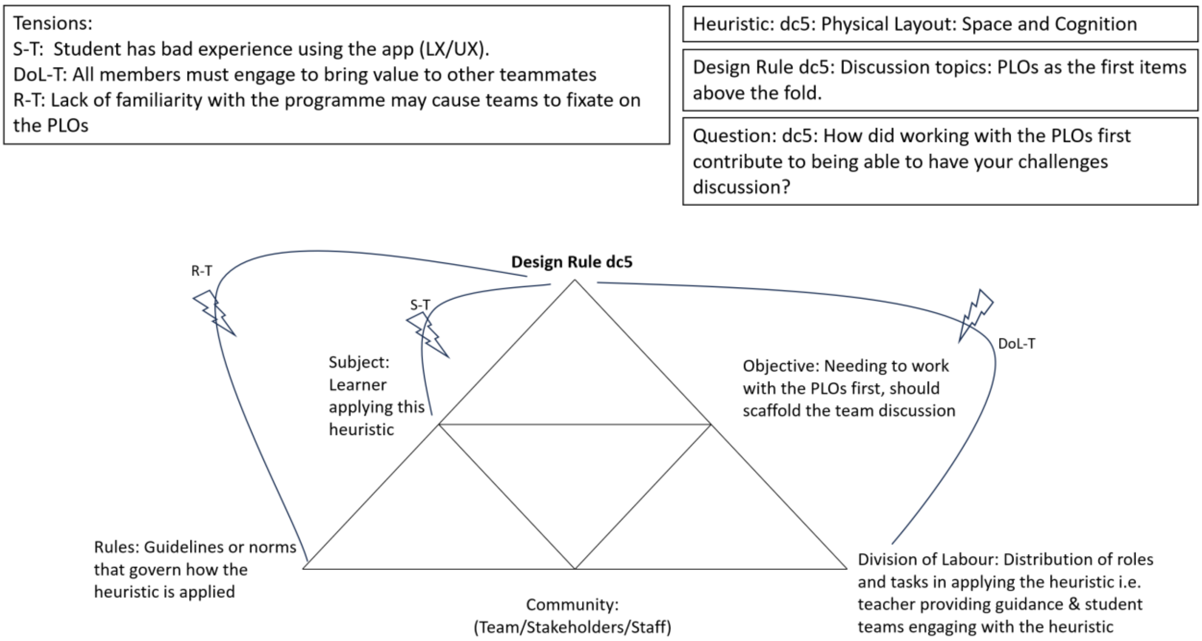


Figure 4-31. Heuristic dc5 (Blandford & Furniss, 2006), design rule/feature: PLOs as the first items above the fold support the Physical Layout: Space and Cognition principle.

Tensions:
S-T: Student has bad experience using the app (LX/UX).
DoL-T: All members must engage to bring value to other teammates
R-T: Lack of familiarity with the programme may cause teams to fixate on the PLOs

Heuristic: dc7: Physical Layout: Situation Awareness

Design Rule dc7: Scaffolded discussion topics: PLOs and learner defined team topic discussions are part of the intervention.

Question: dc7: How did the activity and tool structure help you to understand the aims of the discussion (i.e. to recognise and begin to conceptualise your team challenges).

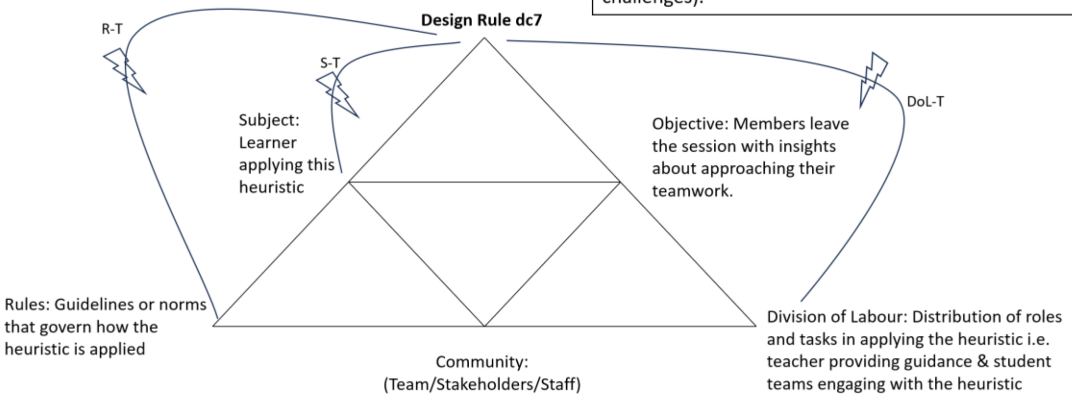


Figure 4-32. Heuristic dc7 (Blandford & Furniss, 2006), design rule/feature: PLOs as the first items above the fold support the Physical Layout: Space and Cognition principle.

Tensions:
T: Team topic design might not offer sufficient detail
S-T: Student has bad experience using the app (LX/UX).
DoL-T: More than one person must engage to bring value to other teammates
R-T: Expectations regarding meetings rules and netiquette

Heuristic: dc8: Information flow: Buffering

Design Rule dc8: Team topics can be queued

Question: dc8: Did topics get queued? How did you manage the queue?

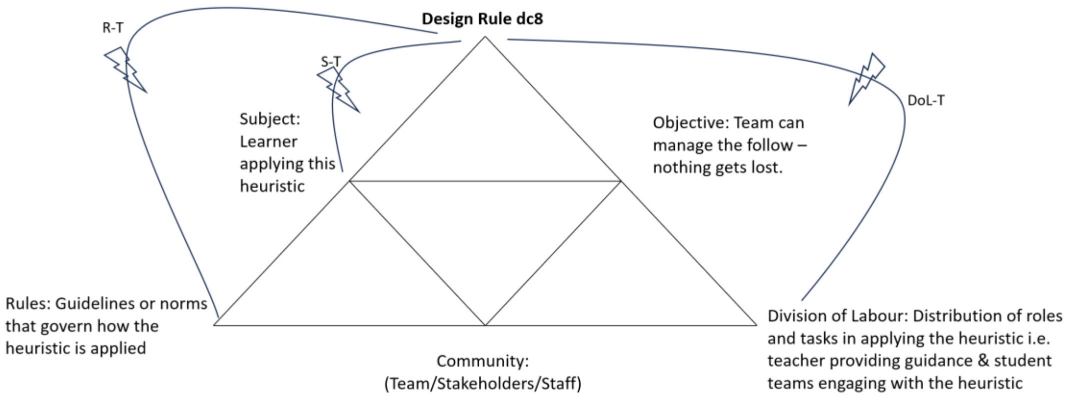


Figure 4-33. Heuristic dc8 (Blandford & Furniss, 2006), design rule/feature: Allow user added topics to be queued in support of the 'Information flow: Buffering' principle.

Tensions:
T: Team topic design might not offer sufficient detail
S-T: Student has bad experience using the app (LX/UX).
DoL-T: Everyone must engage to bring value to other teammates

Heuristic: dc9: Artefacts: Representation – Goal Parity

Design Rule dc9: Team discussion topics

Question: dc9: In what ways were your team clearer about your team project and teamwork goals following the activity?

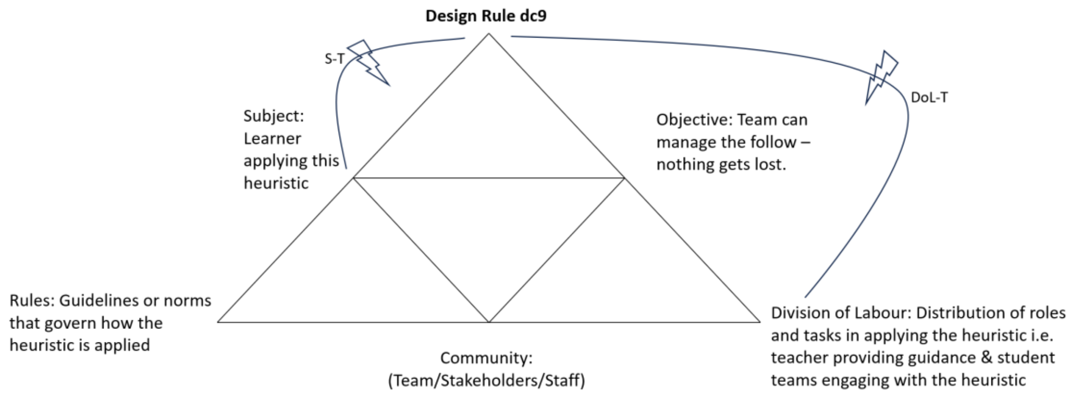


Figure 4-34. Heuristic dc9 (Blandford & Furniss, 2006), design rule/feature: Foster goal alignment via team mental model building using live team member feedback and user added topics.

Tensions:
T: Team topic design might not offer sufficient detail
S-T: Student has bad experience using the app (LX/UX).
DoL-T: Everyone must engage to bring value to other teammates
R-T: Programme rules might prescribe or influence their approach and focus

Heuristic: dc10: Artefacts: Coordination of Resources

Design Rule dc10: Team discussion topics

Question: dc10a: What aspects of planning did you discuss?
Question: dc10b: How did the activity and tool support that discussion?

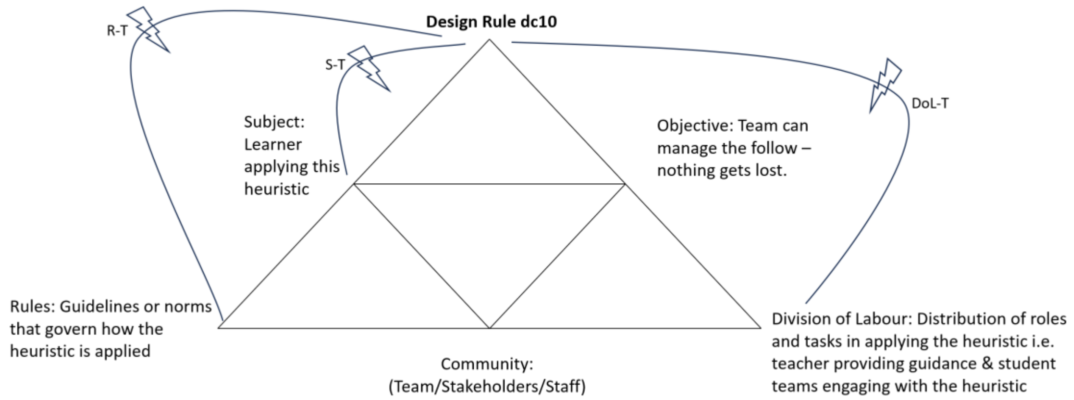


Figure 4-35. Heuristic dc10 (Blandford & Furniss, 2006), design rule/feature: Team members are encouraged to discuss ways to overcome challenges that they see in the default topics and user added topics, in support of the Coordination of Resources principle.

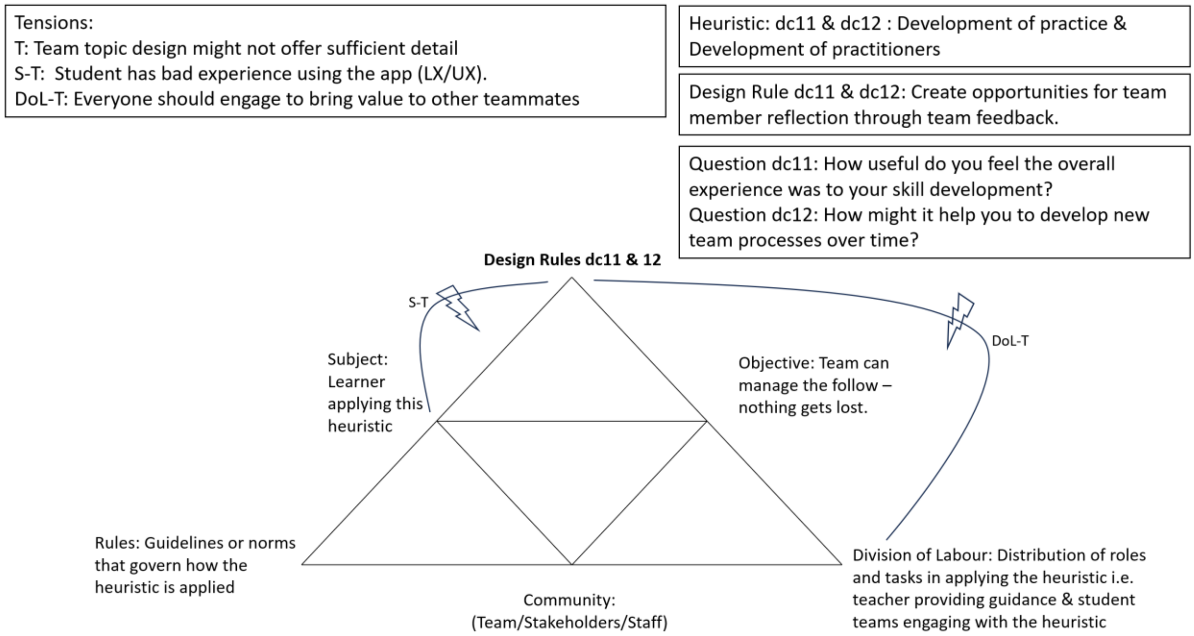


Figure 4-36. Heuristic dc11 and dc12 (Webb, 2008), design rule/feature: Create opportunities for team member reflection through team feedback, to support development of practice and development of practitioners.

As noted, heuristics dc11 and dc12 related to ongoing longitudinal development of team members practice and team process. We therefore did not directly test these topics in focus sessions due to the short duration of our intervention. Questions were developed however as useful topics to probe deeper if needed, and to help in considering overall student feedback that relates to ongoing personal and professional development regarding teamwork.

Relevance of UX and DiCoT development heuristics

Our UX heuristic (ux1) is broad, covering the wide set of user experienced related topics that are included in its title, “System status, user control and freedom, consistency and relevancy, error recognition and recovery, and task and work support”. The aim of this heuristic is to support the technical aspects, which is an important consideration in tool design but will vary depending on the implementation. Indirect feedback was therefore more useful when discussing this item and we noted instances of difficulties that students perceived with the technology in our analysis. Two further heuristics (dc11 & dc12) relate to longitudinal supports for the development of practitioners and practice, and these were not considered to be directly testable in a short study. We therefore opted to analyse any indirect feedback on these items also. Our remaining twenty heuristics from literature and six participant informed heuristics corresponded to design features that were implementable and therefore testable.

Focus session data

Cycle 3 generated 56 thousand words of student feedback split approximately evenly across both cohorts. As the structure of our cycle 3 sessions were considerably more rigid than previous two cycles, approximately 20% of this was information to students from the researchers as each question was asked and any necessary context described. After extracting this extra text we calculated approximately 45 thousand words over four group interviews and two individual interviews.

Focus session coding and themes

Cycle 3 followed the same coding process as cycle 2 with an initial inductive coding pass (summary in table 4-17 and details in table 4-18) followed by a deductive coding (table 4-19).

Cycle 3 Coding

Inductive Code	Cases	References
Teamwork scaffolds	6	59
Team Process Development	6	54
Communication	6	53
Reflection	6	52
Hybrid teamwork challenge	6	42
Team Health	6	39
Team Roles	6	31
Inclusion	5	30
Informal collaboration	6	27
Collaboration	6	22
Suggested Improvement	6	21
Project priorities	6	20
Team Values	5	19
Mutual accommodation	6	18
Personal disclosures	3	4
CONFIDENTIAL INFO	1	2

Table 4-17. A posteriori codebook (cycle 3, inductive).

Inductive Code	Description	Example quotes
Teamwork scaffolds	Descriptions of how the TTT implementation of the heuristics supported team orientation and set a basis for team affiliative associations to	"I feel like this was kind of a nice icebreaker into entering that territory without kind of being like, OK. Something's not right here. We need to, you know, it kind of opened the floor"

	develop empathy, perspective taking and team emotional security.	
Team Process Development	Examples of reflections on team capabilities to establish processes and protocols for transdisciplinary team project work that resulted from the learning intervention application of our heuristics.	“We talked about like what we could use as skills and we reflected [...]. We did a kind of a list of our skill right now and how to use them”
Communication	Illustrations of where the heuristics contributed to the comprehensibility of communications.	“…we kind of looked at that saying, oh, actually, you know what? That makes sense. And maybe we actually are doing better in that sense when we discussed it. And that's why they changed the value”
Reflection	TTT mediating artefact as a prompt for reflection.	“I kind of think maybe I should use a different standard and use their standard instead of kind of like the other people standard. So instead of my own standard because I think it would be like too subjective. So I think like the average helps in the sense that it will kind of help me better position myself in contrast to the others. For example, I think I'm better than this compared to my teammates or I'm worse at this compared to my teammates”
Hybrid teamwork challenge	Issues or problems with technology-mediated teamwork.	“sometimes, like, there's too many tools instead of just talking to each other” “sometimes it feels kind of awkward to communicate online” "...you're not able to fully understand or something is missing and you're trying to find information or we also have like a connection issue sometimes"
Team Health	Scaffolds for improving team health.	“that really opens the opportunity for us to very specifically gear the tool for our team because we do kind of know some of our weaknesses or strengths already, like even as a team”

		"how do we see each other and how do we collaborate better with each other" "The main thing is it opened doors for us to discuss things that maybe had been avoided up until that point."
Team Roles	Examples of practices or expectations relating to division of labour and team roles.	"oh, maybe we can collaborate like we both have this skill doing statistics that I didn't know about" "I think during the discussion part, my recollection is we all kind of took turns taking the lead" "Like if they need extra help, maybe because they've never done something like that, or if they already, let's say experts in in that area"
Inclusion	Examples of teams considering or practicing inclusion.	"the smileys were like quite interesting because like everyone had different like so it was nice to see like everyone's like perspective or and afterwards like talk about it like why did you choose this or that or" "Anyone who wanted to add something could add it" "for women, for example, we tend to downplay a little bit our skills and I think that sometimes we tend to score, put ourselves a little bit lower, so maybe a system where there was a little bit more of options would have allowed for scoring just a little bit higher for women for specifically"
Informal collaboration	Descriptions of unscripted team interactions.	"...it was more of a free flow kind of kind of conversation. It wasn't necessarily structured like and that's kind of always the setting of our meetings..."

Collaboration	Descriptions of how the team interacted to work on the TTT team activity.	"..go through like each section into like how we interpreted like we discussed them. How we feel about those et cetera, which then allows for some like extra conversation."
Suggested Improvement	Examples of improvements to the TTT or its application.	"I agree with it. Being earlier would have been more useful in this context." "maybe two or three times throughout the four months that we're here. I mean, could be helpful" "quite serious collaborative perspectives or issues, I feel like a numerical scale would feel more scientific or more serious" "a little bit more of options would have allowed for scoring just a little bit higher for women for specifically"
Project priorities	How the heuristics employed in the TTT helped to clarify project priorities for participants.	"I feel like if that wasn't in any of the questions then we would have added that something about time management or because that's been a big fear that we've been having related to our project " "at the start when you set out your, your goals and what you want to do and what's important to you as a group, as an individual and as a group. And then as the project and group. Work progresses. If maybe things are getting again, like maybe off topic going off track. It's a good point of reference to kind of bring everyone back"
Team Values	Examples of where the heuristics helped participants develop or express team values.	"everyone's coming from a different point of view. So it's more about how comfortable you are with the idea"

		"I also think that I got to know them a bit more, like more their backgrounds and their skills. What are they are good at? What they still want to improve or learn during the master"
Mutual accommodation	Descriptions of socially constructed meaning making and distributed team cognition producing a self-reflexive practice during the intervention activity.	"sometimes it made me think twice about it. I don't know if I adapted mine according to their response, but if I maybe I just looked at it very quickly, chose something if I saw they were like changing it or like thinking about it taking long, then I would be like ha, maybe I have to" "Oh, wow. OK. I think that in this part, we might have similar things because we have similar backgrounds, but they are rating each other higher. And I maybe we have a conversation about this. And maybe I'm like, oh, am I being too humble? Or is it like, I would question myself and like, I know only after questioning myself, I would change it" "for me it was more like, when I saw more of the emojis belonging to the lower scale and OK, I can admit this that I don't know as well." "For me it's more about like finding a common standard. So yeah, I will like value myself like rate myself a lot relative to the others" "Discussing it definitely changed my opinion on some of them because it would clarify or change the way that I interpreted the initial prompt"

Table 4-18. Cycle 3 inductive codes with descriptions and examples of quotes to which these were applied.

Source Literature	Theme	Deductive Code	Cases	References
Blandford and Furniss, 2006	Distributed Cognition of Teams (DiCoT)	Situation Awareness	6	75
Blandford and Furniss, 2006	Distributed Cognition of Teams (DiCoT)	Horizon of Observation	6	64
Green and Petre, 1996	Tools / Usability	Suitability of tools to tasks	6	63
Hutchins, 1995	Distributed Cognition (DCog)	Mental representations	6	59
LaFasto and Larson, 1989	Communication	Giving and receiving feedback	6	58
Salas, et al., 2013; Mohammed, 2010	Team cognition	Developing shared mental models	6	58
Katzenbach and Smith, 1993	Communication	Clarity of process	6	57
Blandford and Furniss, 2006	Distributed Cognition of Teams (DiCoT)	Naturalness Principle	6	51
Rubinstein, 1973; Vygotsky, 1978; Leontiev, 1981; Engeström, 2000	Activity Theory (Division of labour)	Work practices	6	42
Rubinstein, 1973; Vygotsky, 1978; Leontiev, 1981; Engeström, 2000	Activity Theory (Community)	Social-protocols	6	41
Betts, 2016; Ceballos,2016; Cortes, 2016; Hudelson, 2017; Hunter, 2016; Ravasz, 2016; Shanmugam, 2015; West, 2015	Tools / Usability	Timely feedback	6	40
Green and Petre, 1996	Tools / Usability	Usefulness of tools	6	38
Green and Petre, 1996	Tools / Usability	Clarity of intent	6	36
Blandford and Furniss, 2006	Distributed Cognition of Teams (DiCoT)	Perceptual Principle	6	28
Blandford and Furniss, 2006	Distributed Cognition of Teams (DiCoT)	Space and Cognition	6	28
Rosenfeld, et al., 2015	Tools / Usability	Tool design issues	5	26

Green and Petre, 1996	Tools / Usability	Threshold to usability	6	25
Katzenbach and Smith, 1993	Communication	Clarity of expression	5	23
Betts, 2016; Ceballos, 2016; Cortes, 2016; Hudelson, 2017; Hunter, 2016; Ravasz, 2016; West, 2015	Tools / Usability	Instructions and guidance	6	21
Green and Petre, 1996	Tools / Usability	Tool usage patterns	6	21
Betts, 2016; Hsu, 2016; Hunter, 2016	Tools / Usability	Appropriate use of abstractions	5	19
Green and Petre, 1996	Tools / Usability	Consequences of tool use	5	18
Inverardi & Tivoli, 2009	Project requirements	Evolving requirements	6	18
Green and Petre, 1996	Tools / Usability	Tool interaction	5	15
Blandford and Furniss, 2006	Distributed Cognition of Teams (DiCoT)	Arrangement of Equipment	6	14
Green and Petre, 1996	Tools / Usability	Ease of use	6	14
Green and Petre, 1996	Tools / Usability	Effort to change	5	13
Green and Petre, 1996	Tools / Usability	Onboarding of a tool	6	13
Green and Petre, 1996	Tools / Usability	Use of tool features	4	12
Ceballos, 2016; Hudelson, 2017; Korovkina, 2020; West, 2015	Tools / Usability	Controllers and Interface	4	11
Green and Petre, 1996	Tools / Usability	Working in multiple contexts	5	11
Green and Petre, 1996	Tools / Usability	Expected behaviour of a tool	5	10
Katzenbach and Smith, 1993	Organisation	Task Management	5	10
Myers, et al., 2000	Tools / Usability	Interacting with IT	4	10
Shanmugam, 2015; West, 2015	Tools / Usability	Display of textual information	5	8
Rubinstein, 1973; Vygotsky, 1978; Leontiev, 1981; Engeström, 2000	Activity Theory (Neighbouring activity systems)	External factor impact	3	7

Rubinstein, 1973; Vygotsky, 1978; Leontiev, 1981; Engeström, 2000	Activity Theory (Rules)	Methodologies	6	7
Green and Petre (1996)	Tools / Usability	Fluency with tools	4	7
Tuckman, 1965	Communication	Interpersonal clashes	3	7
Betts, 2016; Cortes, 2016; Hudelson, 2017; Hunter, 2016; Punchcut, 2016; Shanmugam 2015	Tools / Usability	Comfort and accessibility	4	6
Green and Petre, 1996	Tools / Usability	Effort to keep changing	3	6
Blandford and Furniss, 2006	Distributed Cognition of Teams (DiCoT)	Subtle Bodily Supports	2	2

Table 4-19. A priori codebook (cycle 3, deductive) sorted by code instances.

4.9 Conclusion

This chapter outlined the iterative design journey from the initial literature review through Cycles 1 and 2, showing how each phase contributed to the development and refinement of the heuristic set intended to support novice transdisciplinary students engaged in hybrid teamwork. Across these cycles, AODM (Mwanza, 2006) was used to guide design decisions and to shape the evolving heuristics in response to contextual feedback from participants, including the refinement of the focus-session questions. These activities deepened the connection between students' attitudes toward XR-mediated work and the requirements of hybrid transdisciplinary team activity. The work completed in Cycles 1 and 2 therefore established the consolidated heuristic set that forms the basis for the study's final evaluation.

In our next chapter (Chapter 5) we present our implementation and analysis of Cycle 3, where the full heuristic set is examined in detail and reviewed using the AODM process (see Section 3.5 for methodological background). Our use of iterative design cycles aligns with the principles of qualitative design-based research, recognising that meaning-making develops over time through repeated engagement with the problem space. Given the exploratory nature of investigating hybrid transdisciplinary teamwork, DBR provided a suitable methodological structure for guiding the development and refinement of the heuristics throughout the study.

5 Chapter 5. Cycle 3, Final heuristics analysis and findings

5.1 Introduction

Cycle 3 was based on an intervention activity including two cohorts of the CHARM-EU M.Sc. in Global Challenges for Sustainability. The intervention aimed to test our complete set of heuristics by working with student teams using our exemplar Transdisciplinary Teamwork Tool to structure team discussions. This cycle represented a final opportunity to refine our heuristics in support of RQ1a, and to test the heuristics to answer RQ1b. The interventions took place in a hybrid setting across the CHARM-EU hybrid classroom network. The researcher was based in the hybrid classroom at Trinity College Dublin where several of the local students were also attending class during each of three sessions. Remote students joined from the remote hybrid classroom locations or in some few cases individually from their home locations, to join the CHARM-EU MS Teams channels in their usual hybrid classroom environment. The intervention asked teams to engage in a team discussion using our exemplar software artefact tool to scaffold their conversation by providing sentiment feedback to peers for each discussion topic. Our feedback focus is informed by the tension areas that our Cycle 2 students identified and the need to scaffold such feedback was identified in our Cycle 1 participant responses. 'Giving and receiving feedback' is a 21st century skill (Ravitz, 2012). Feedback describes more than simply communicating, since it implies the development of listening, empathy and perspective taking skills. It is therefore distinct from the associated 21st century skill of Communication, which aligns more closely with the concept of communication literacy. Exercising the 21st century skill of giving and receiving feedback requires developing a theory of mind for both parties, to understand the perspectives of the other. Feedback can be formal or informal, formative or summative, and typically involves some degree of negotiation and reflection (Ravitz, ibid).

Design features of the tool were mapped to our set of theoretical and design informed heuristics, and a corresponding focus session question was formulated and refined by reflecting on concepts from third generation activity theory. Following the intervention, a series of six semi-structured focus sessions were conducted where we asked for participant views relating to each of our heuristics. Responses were coded using a codebook that had been developed as part of our literature review and the coding helped to uncover themes that informed a subsequent AODM descriptive analyses for each heuristic.

The purpose of this chapter is to examine our heuristics considering the cycle 3 data and identify any student perceived tensions with the TTT mediated team learning activity. Such tensions may indicate that heuristics require refinements, or that an implementation of the corresponding design rule feature was problematic and should be reconsidered. By identifying and analysing tensions we may reveal an appropriate design response to further refining the associated heuristic or design rule implementation.

In this chapter we again used the AODM toolkit to analyse the full collection of heuristics through the lens of cycle 3 participant qualitative feedback and time series quantitative data relating to the relevant heuristic. We have grouped heuristics by design cycle in the sections below, including the cycle zero literature review as the largest contributor to the collection. Creswell (2012) emphasizes the need of "connecting the dots" to describe the link between theory and empirical evidence and we have found the outputs of AODM's eight steps tell a story that helped us to describe such links by considering heuristics across design cycles to show the connection between theory by contextualising our design cycle data. This was described for the earlier cycles in the previous chapter, and for our final design cycle in this current final review chapter. AODM provided a method to apply a theoretical framing and thusly informed what to look for during our analysis of rich, contextual real-work data when producing and refining our heuristics.

As we have noted elsewhere, our collection is broad and requires a granular analysis to determine the potential of each heuristic. Our approach has been to undertake an AODM analysis for each as an vignette, which gave scope to cover the set of heuristics in the limited duration of focus groups sessions. Dolonen (2009) tells us that "the eight-step model is basically a direct mapping of components in Engeström's triangle into open ended questions or focus areas that is similar to the works of Korpela (1997) and Ottesen and Vennebo (2007)". As noted in our methodology chapter, traditionally the subject of an AODM framing is an actor with agency, and we describe our rationale for framing each heuristic as the subject, and the success of that heuristic as the objective or idealised outcome in our use of AODM discussion, section 3.4.3. This framing permits us to analyse student feedback to answer each question of the eight-step AODM model and highlight any associated tensions that the students perceived. Tensions may relate to the heuristics or their design rule implementation and may be rooted in the current activity or some other sub or parallel activity, but contextual student feedback helps to highlight potential limitations or success of the heuristic and "reducing the complexity of an activity system by making components more explicit", Dolonen (ibid), allows us to consider it more clearly. Our approach therefore has been to present each heuristic as an AODM vignette analysis where we examine student feedback in terms of the prominent themes encountered during the coding. AODM is applied to the feedback to conceptualise it in terms of third generation activity theory constructs and issues raised by students are framed as activity tensions. This provided a structured approach to evaluate our heuristics by exploring culturally historical tensions as a method to inform design refinements.

Three of our heuristics do not fit neatly into our analysis format and must be explained here before proceeding. The first of these relates to general user experience, ux1 (Muller, et al., 1998). It is included both as generally good advice for any kind of technology-mediated activity, but also provides a source of evaluative feedback to contextualize participant reported tensions if technical issues were encountered. Our implementation followed web development best practice regarding the coding and design however we were less interested in a technical UX evaluation of tool features and more concerned with any UX related impact on the learning experience. By contextualizing any usage difficulties, we could clarify potential conflations between the heuristics and design implementations, and building in feedback sources in this way aligns well with DBR recommendations to improve validity, (The Design-Based Research Collective, 2003). We therefore did not develop specific UX feature related questions and instead opted to gather student usability feedback across all features whenever it was offered. The other two heuristics dc11 and dc12 (Webb, 2008) that differ, relate to the development of practice and development of practitioners. As our study was not longitudinal, we did not implement features or develop questions for these topics and our discussions exclude the full AODM steps. However, we felt it important to include a commentary analysis of Webb's DiCoT additions for completeness which is based on general feedback relating to personal and professional development, and we address both at the end of this current chapter.

An AODM review of the remaining heuristics identified overlapping themes, as described in section 4.7 of our design process chapter. This allowed us to streamline the set of heuristics that we wanted to probe specifically during focus sessions with participants. Mapped items were therefore not included in the intervention design for cycle 3 focus sessions. Table below (5-1) outlines the complete set of heuristics and the mapping to sixteen for exploration during focus sessions (mapped and excluded items are shaded).

ID	Heuristic	Design Rule Response(s)	Cross Reference(s)	Focus Session Question
User centred considerations				
c1a	Don't assume users will recognise UI controls	Include information from the instructor and in-app help info windows	None	What were your impressions of the instructions for the activity/app?

c1b	Our tool should provide detailed instructions	Include information from the instructor and in-app help info windows	c1a	c1a
c1c	XR onboarding is difficult for new users	Include information from the instructor and in-app help info windows	c1a	c1a
c2a	Remote teams experience reduced social presence and often miss social cues	Build in a clear, easy way to share cues.	None	What did the emoticons make you feel about your team / teammates? What about the team average values?
c2b	Interface controls that represent analogues of social cues should not feel unnatural to users.	Use sliders for a recognisable and low effort UI.	None	How well do you feel you could express your sentiment using the emoticon sliders?
c2c	Hybrid students want to get to know each other.	Include team member details (profile data) to support team relationship building and a team average avatar to promote team alignment sentiment.	None	Do you feel that you know your teammates better after the activity? How did the interface influence/contribute to that?
Usability / User Experience (Muller, et al., 1998)				
ux1	System Status, User Control and Freedom, Consistency and Relevancy, Error Recognition and Recovery, and Task and Work Support	TTT Implementation	None	Instances of errors or usability feedback.
Teamwork Theories (Tuckman, 1965; Inverardi & Tivoli, 2009; LaFasto and Larson, 1989; Salas, et al., 2013; Katzenbach and Smith, 1993)				
th1	Tool should adapt to the users'	Include user defined topics.	None	How useful do you think the user defined

	changing requirements.			topic list was, and might be over time?
th2	Support intra-team feedback.	Include user defined topics and live team member feedback for each via an emoticon.	None	How useful did you find the feedback in general?
				How might the topics be useful for team feedback?
th3	Support different roles and responsibilities	All live feedback will be visible to every team member so that any (or every) member can lead the discussion.	None	If you discussed the team suggested challenges, how did you organise the discussion? How could a session like this (this type of tool and activity) support you in different team roles?
th4	Support team mission objectives and norms.	Promote Shared Mental Model building through scaffolded team interactions	tmm1	tmm1
th5	Consider the environmental context	Use a "Mobile First" design	None	How well do you think it worked as a hybrid classroom-based activity? How might this be useful outside of the classroom?
th6	Foster team familiarity (to build affiliative associations)	Intervention design (submit sentiment and explain it to teammates)	None	Did you discover any (interesting/unexpected) KSA's within your team that might contribute to your work together? Was that helpful?
th7	Be specific in communications	Use multistep sliders to simplify the sharing of data	c2b	c2b

th8	Recognise and manage relative priorities	An aggregated smiley feature can highlight issues to help the team to recognise relative priorities	c2b	c2b
th9	Employ a clear working approach	Multistep slider (for the PLOs and user defined topics)	c2b	c2b
Team Mental Models (Mohammed, et al., 2010)				
tmm1	Support the building of mental representations of the key elements within a team's relevant environment that are shared across team members	Intervention design rules (share and explain your sentiments) plus synchronous feedback to all team members	Some overlap with th4 (team mission objectives and norms)	th4
DCog (Hutchins, 1995)				
dc1	Embodiment of information within the system	Live Feedback	th2	th2
dc2	Co-ordination between agents,	Live Feedback & user defined topics	None	Did you update any values when you saw the other team members / team average?
dc3	(Consider) The impact of set and setting (ecosystem) on the process taking place.	A mobile first design.	th5	th5
dc4	Cognitive process is delimited by the functional relationships among the members	Include live feedback on user defined topics to support asynchronous roles	None	Did you discuss the task together? How did you interact when using it? Did you all use it the same way at the same time?

DiCoT (Blandford and Furniss, 2006)				
dc5	Physical Layout: Space and Cognition	PLOs as the first items "above the fold"	None	How did working with the PLOs first contribute to being able to have your challenges discussion?
dc6	Physical Layout: Subtle Bodily Supports	Mobile first design	th5	th5
dc7	Physical Layout: Situation Awareness	Scaffolded discussion topics: PLOs and learner defined team topic discussions as part of the intervention design.	None	How did the activity and tool structure help you to understand the aims of the discussion (i.e. to recognise and begin to conceptualise your team challenges)
dc8	Information flow: Buffering	User added topics enable discussion topic queues.	None	Did topics get queued? How did you manage the queue?
dc9	Artefacts: Representation – Goal Parity	Custom topics are intended to address the project goals.	Some alignment with tmm1 but discussed independently	In what ways were your team clearer about your team project and teamwork goals following the activity?
dc10	Artefacts: Coordination of Resources	The structured discussion process informs the team regarding each members competencies and task interest.	None	What aspects of planning did you discuss? How did the activity and tool support that discussion?
DiCoT extensions (Webb, 2008)				
dc11	Development of practice			
dc12	Development of practitioners			

Table 5-1. Heuristics mapped to design features with thematic overlaps and excluded items highlighted

5.2 AODM Steps

Our heuristic categories address different thematic areas which makes a unified analysis of the full set impractical. We therefore analysed each heuristic individually (or as heuristic clusters where consolidation was employed). Applying AODM allowed us to contextualise our students feedback to highlight culturally historical team tensions that inform our evaluation of the heuristics when answering RQ1b, which improves external validity by surfacing tensions from multiple team members relating to the range of heuristics. Each of our analyses follows the eight steps of Mwanza's (2002) Activity Orientated Design Method with a repeating format that the improves coherence of the study (Creswell, 2013) and is based on three tables and a narrative. The first table in each of the analyses outlines the heuristic, its design rule response, and any cross references if the heuristic is thematically linked to another item. This table also includes the associated focus session question to explore the students views regarding said heuristic and its implementation in our exemplar Transdisciplinary Teamwork Tool. The second table in each section describes the themes and codes that have emerged from a qualitative analysis as described in our methodology. This is grouped by focus session and codes are presented in the order that they were applied during the analysis. The third table in each section is a summary of the AODM analysis. Finally, each section also includes a narrative description where the narrative is also structured to follow the eight steps of the model. Culturally historical tensions, or third generation activity "systemic contradictions" are illustrated with supporting additional notation from Bligh and Flood's (2015) Change Laboratory Toolkit to illustrate culturally historical activity systems tensions, i.e. either parallel, competing, or prior versions of the activity, which Mwanza did not include the original AODM study.

The Mwanza eight-steps and questions are listed below as a reminder for the reader.

1. Activity of Interest (what sort of activity are we interested in?)
2. Objective (why is the activity taking place?)
3. Subjects (who is involved in carrying out the activity?)
4. Tools (by what means are the subjects carrying out this activity?)
5. Rules and Regulations (are there any cultural norms, rules or regulations governing the performance of this activity?)
6. Division of Labour (who is responsible for what, when carrying out this activity and how are the roles organised?)
7. Community (what is the environment in what the activity is carried out?)
8. Outcome (what is the desired outcome from carrying out this activity?)

5.3 How to read AODM analyses.

Here the AODM analysis format that is used throughout this chapter is described. A repeating vignette format is employed to describe each heuristic in the light of the cycle 3 data, to allow for a granular treatment of each heuristic, and a consistent approach that supports replicability and improves clarity and interpretability. We have noted in our methodology that we align the heuristic in the place of 'subject', and the ideal outcome of the heuristic as the 'objective'. Our rationale, described in chapter 3 (section 3.5.3), frames heuristics as intent to action, which enables compatibility with traditional action orientated Activity Theory perspectives. Each analysis includes three tables and a narrative section in a repeating pattern that bolsters the reliability of our study. The first table for each heuristic describes the heuristic, its design rule response implementation in the TTT and the associated focus session question used to explore the heuristic during the cycle 3 focus sessions. Following the introductory details in the first table, a second table in each section describes the deductive and inductive qualitative codes applied to participant responses on comments for the heuristic in question, per case. Codes are listed as they were encountered, to indicate the flow of that part of the discussion and the breath of related concepts that were discussed. Deductive codes specifically relating to the theme of the heuristic being analysed are presented in bold text to distinguish them from the other, contextually related codes and improve coherence by emphasising the connection between data and theory, and the language used in the narrative segment applies the phrasing of the qualitative codes relating to major themes, to further clarify the link. Each analysis then includes a third table summarizing our AODM analysis, which follows the Mwanza (2006) AODM toolkit's eight-step questions. A more detailed text then follows this table to describe the analysis in greater depth and key references to the AODM steps are highlighted using bold text. The steps are occasionally presented out of sequence to improve readability. This textual description follows the same eight-step format to ensure a consistent approach in our discussion of each heuristic.

5.4 Cycle 0, heuristics from literature.

While the insights from our first two design cycles produced interesting heuristics that relate to perspectives of our CHARM-EU students, a broader set of heuristics was drawn from our conceptual framework. We refer to these theory-based heuristics as 'heuristics from literature' in the current text and examine them as a single collection here. Social presence theory has influenced our thinking during our study although, as discussed, there are a plurality of definitions in the literature that complicate any discussion or measurement of social presence. We consolidated these definitions by identifying overlapping concepts and produced a reduced set of social presence heuristics to cover the many associated themes in the literature. Once mapped, we realised that any design response to social presence would cover the same types of design features that we were already developing for our heuristics. We therefore did not develop specific questions to explore social presence and instead chose to examine our participant responses for each design rule through a social presence lens. Our other theory-based heuristics are drawn from teamwork theories, team mental models, foundational distributed cognition theory and distributed cognition of team's theory.

5.4.1 Usability / user experience

User experience, heuristic 1 (ux1).

ID	Heuristic	Design Rule Response(s)	Cross Reference(s)	Focus Session Question(s)
ux1	System Status, User Control and Freedom, Consistency and Relevancy, Error Recognition and Recovery, and Task and Work Support	Emoticons displaying user status. Free to add topics. A mobile first design.	None	All feedback of UX issues is relevant.

Table 5-2. Heuristic ux1 overview.

Related themes (uncoded)

High level details of this heuristic are presented in table 5-14. We understood that usability problems could potentially derail the other elements of our study and therefore took steps to address this by applying best practices for a mobile first, responsive design using Google's Material Design framework and the MUI library of interface elements to render our interface. This would provide a similar interaction experience for whatever type of device our students chose to use for the intervention activity, although our focus session participants all used laptops for the sessions and therefore did not have difference interaction experiences. We return to this point in the feedback of heuristic th5 when discussing the hybrid experience.

During our first iteration of the intervention (semester 1 cohort) our tool encountered a database limit that prevented students from completing the full activity. We probed during focus sessions to understand how students handled the failure and received encouraging feedback where some students managed to share screens to extend the horizon of observation for their peers regarding the overall team sentiment levels. We return to this point in our discussion of heuristics th1 (user defined topics) and dc6 (understanding the aims) when considering themes relating to clarity of intent, clarity of process, situational awareness and extending the horizon of observation.

We received feedback from a mature student relating to the use of emoticons to address serious topics such as sentiment about academic project work. This represents a usability concern for the student in question regarding the suitability of the tool to the task and the appropriateness of the abstractions used in the interface. These topics have been covered above in our discussion of emoticons relating to heuristic c2a.

The final UX issue that we noted relates to our choice to use a simple five-point scale in our interface rather than the more typical seven-point Likert scale. A focus session participant highlighted some research indicating females' propensity to underestimate their abilities and mentioned that a longer scale would be a helpful to avoid central tendency bias and aid with clarity regarding edge cases sentiment values. This topic was addressed above in our discussion of heuristic c2b which relates to the degree of possible expressivity.

5.4.2 Teamwork theory heuristics

Our conceptual framework highlighted Tuckman (1965), Inverardi & Tivoli (2009), LaFasto and Larson (1989), Salas et al. (2013), Katzenbach and Smith (1993) as landmark teamwork literature. From these, we produced nine heuristics relevant to distributed teamwork. As with previous heuristics, three tables describe our approach (5-15 to 5-17).

5.4.2.1 Teamwork theories, heuristic 1 (th1)

ID	Heuristic	Design Rule Response(s)	Cross Reference(s)	Focus Session Question(s)
th1	Tool should adapt to the users' changing requirements.	Include user defined topics.	None	How useful do you think the user defined topic list was, and might be over time?

Table 5-3. Heuristic th1 overview.

Case	Related deductive codes	Related inductive codes

Case 1 (Capstone Focus Session 1)	Interpersonal clashes, Mental representations, **Work practices**.	Collaboration, Communication, Reflection, Team health, Team process development.
Case 2 (Capstone Focus Session 2)	Clarity of process, **Suitability of tools to tasks**, Tool design issues, Tool interactions, **Use of tool features**, Working in multiple contexts, Situation awareness.	Project priorities, Communication, Team health, Hybrid teamwork challenge.
Case 3 (Capstone Focus Session 3)	Instructions and guidance, Suitability of tools to tasks, Threshold to usability, Tool design issues, Task management, Tool usage patterns, **Work practices**, Working in multiple contexts, **Clarity of intent**, Usefulness of tools.	Team process development, Teamwork scaffolds, Communication, Team health.
Case 4 (Phase 1 Interview 1)	Social-protocols, **Suitability of tools to tasks**, Clarity of intent, Mental representations, Threshold to usability, Timely feedback, **Clarity of process**, Consequences of tool use, Developing shared mental models, **Giving and receiving feedback,** Tool usage patterns.	CONFIDENTIAL INFO, Inclusion, Personal disclosures.
Case 5 (Phase 1 Interview 2)	Developing shared mental models, **Situation awareness, Clarity of expression, Clarity of intent, Evolving requirements, Timely feedback**, Tool usage patterns.	Communication, Reflection, Team process development, Project priorities.
Case 6 (Phase 1 Focus Session 1)	**Clarity of intent, clarity of process, Developing shared mental models, Evolving requirements, Perceptual principle, Situation awareness**, Task management, **Timely feedback**, Work practices, **Effort to keep changing**, Giving and receiving feedback, Methodologies, Naturalness principle, Social-protocols.	Communication, Collaboration, Hybrid teamwork challenge, Project priorities, Reflection, Team health, Team process development, Team values, Teamwork scaffolds.

Table 5-4. Heuristic th1 codes and themes.

AODM Analysis

Step	Definition	Details
Activity of Interest	(what sort of activity are we interested in?)	Support teams changing requirements.
Objective	(why is the activity taking place?)	Teams needs change and develop as the teammates through the Tuckman model phases. Tool should adapt to the users'

		changing requirements for each stage of the model.
Subjects	(who is involved in carrying out the activity?)	First semester students, Capstone students, CHARM-EU teaching staff, The researchers.
Tools	(by what means are the subjects carrying out this activity?)	Scaffolded discussion using the exemplar artefact tool. This included a default set of topics for the CHARM-EU programme learning outcomes, plus the ability for team members to add their own team discussion topics.
Rules and Regulations	(are there any cultural norms, rules or regulations governing the performance of this activity?)	We asked students to first consider the PLOs and discuss these together before adding new discussion topics.
Division of Labour	(who is responsible for what, when carrying out this activity and how are the roles organised?)	Although the design is intended to reduce the need for specific roles or any individual administrative effort for a team leader, there is evidence of some learners adopting a leadership role where they were the only, or one of few team members to add topics.
Community	(what is the environment in what the activity is carried out?)	Hybrid sessions (n=2) and Co-located session (n=1)
Outcome	(what is the desired outcome from carrying out this activity?)	Students added their own topics and reported finding this to be a useful feature that would benefit their teamwork.

Table 5-5. Heuristic th1 AODM summary.

AODM discussion of findings (heuristic th1)

The **activity of interest** in this heuristic begins with Tuckman's (1965) view and is supported by Inverardi & Tivoli (2009), that teams' needs will change over time, we developed the heuristic that our tool should be flexible so that it could support these changing requirements. Our design response **objective** was to include a feature that gave our student **subjects** the facility to add custom topics to their teams in-app topic list. The **tool** was also preloaded with a default set of topics and our activity **rules** asked to collectively (i.e. **division of labour**) discuss and once complete, they were then encouraged to move on to add their own challenge discussion topics. As our cohorts are part of the CHARM-EU master's **community**, the default list was composed of the seven CHARM-EU master's programme learning outcomes as well as the top four concerns reported by student teams during our cycle 2 Cultural Historical Activity Theory framing of team challenges. These challenges were included as mirror-data prompts to help our cycle 3 students understand the type of challenges that we wanted them to focus on in their own teamwork discussions. The default set of topics are listed below for the convenience of the reader.

CHARM-EU M.Sc PLO's

- Critically analyse and evaluate the concept of sustainability as it is constructed and represented within multiple disciplines and by extra-academic actors.
- In collaboration with extra-academic actors, investigate and evaluate complex societal challenges from a variety of stakeholder and intercultural perspectives to creatively identify, select and devise robust, adaptable, ethical solutions using a range of methodologies, theoretical frameworks and data analysis tools.
- Rigorously assess and integrate different disciplinary and transdisciplinary knowledge and research methodologies to connect research questions, data and findings to their challenges.
- Demonstrate expertise in the identification and application of the latest technological tools to source, analyse, handle, use and communicate complex bodies of data ethically.
- Formulate an advanced understanding of transdisciplinarity and demonstrate expertise in the facilitative, communicative and collaborative skills to support its practice, ensure a reflexive outlook and interpret and connect different disciplinary languages and intercultural perspectives to complex challenges.
- Acquire advanced competency within a range of transversal skills such as communication, teamwork, problem solving, creative thinking, entrepreneurialism, innovation, digital skills and a life-long learning disposition.
- Communicate effectively on complex issues that aim for behavioural change, interpreting and connecting complex challenges to diverse stakeholder, disciplinary and intercultural perspectives that encompass global and European citizenship.

Student perceived challenges with hybrid transdisciplinary teamwork, (produced in cycle 2)

- Teamwork and team roles
- Working with stakeholders and the wider community
- Project rules and expectations

- Collaboration and productivity tools and processes

This heuristic aims to support teams changing requirements by providing a mechanism to share sentiment on bespoke topics, while providing a transactive memory of these topics for reference during the session or at any future team engagements. Mixed **outcomes** were found which we attribute to some practical differences between sessions. While all our capstone teams managed to add their own topics for discussion, the novice cohort experienced a technical failure of the database connection during their first session and did not manage to complete the full activity. We conducted a second session with this cohort where two teams managed to add several of their own topics although they did not spend much time discussing these. Their peers in the other teams did not move beyond the PLO discussions. The disjointed format of conducting the activity over two sessions is a likely contributing factor here that meant students gave less attention to the rules and regulations (i.e. instructions) for the activity. A verbal reminder was given to all teams by the researcher via the Microsoft Teams group channel asking them to remember to add some topics and it is possible that the other remote classrooms failed to hear this reminder since members of the two teams who added their own topics happened to be located within the local Trinity College classroom with the researcher. We can describe this in terms of a secondary CHAT tension between the rules and the subjects, (see figure 5-3 below).

Our capstone group generated a considerably longer list of perceived challenges however we needed to exclude a number of these suggestions due to withheld consent from some participants (n=7, i.e. a 28% reduction). Both sets of challenges are listed verbatim below and we interpret the wide variety of perceived challenges that were raised and discussed by teams as indicative support for their awareness of evolving project requirements.

First semester student perceived challenges with hybrid transdisciplinary teamwork, cycle 3.

- Challenges in teamwork
- Personality Clashes relating to work styles
- Communication Styles
- Communicating through conflict
- Team roles
- Ethics and privacy
- Task division
- Graphic skills

Capstone student perceived challenges with hybrid transdisciplinary teamwork, cycle 3.

- Scientific Research
- Be able to use tools or methods to narrow down a highly complex problem into concrete and therefore actionable sub problems
- Keeping track of data and keeping analysis themes and points collaboratively together
- Sustainability
- Ability to use newfangled communications tools
- Expectation vs time
- Ability to effectively communicate ideas and processes in clear and simple terms to ensure every member of the team and relevant stakeholders are on the same page.
- Methodology
- Conflict management
- Climate Physics
- Too critical and long discussion which leads to less effective Collaborative decision making
- Innovative Brainstorming
- Engage in peer-to-peer feedback to learn from, and contribute to, each other`s work.
- Patience
- Taking initiatives
- Dealing with uncertainty
- How to move beyond our disciplinary research methods and integrate them
- Visual Design
- Political involvement and dissemination of knowledge (what parties / recipients / stakeholders do we involve)
- Ensures an even distribution of work amongst team members and ensures all member's perspectives are incorporated.
- Communication
- Choosing and using the appropriate software to manage data - it is sometimes assumed that everyone knows how to do this.
- Presenting, communicating and visualizing data in a way that is understandable and usable by your co-researchers/ stakeholders involved in the project

We identified an additional secondary tension between our rules and the tool design that relates to a disclosure of a personal circumstance by one of our first semester students. This student mentioned raising a challenge within their team discussion that they did not feel comfortable adding to the list. It is reassuring to hear that the team did indeed conduct a discussion on what they felt to be an important topic which might otherwise have affected their team organization, and this is a valuable outcome in terms of team health, team values and clarity of process regarding any additional scaffolds needed to support their teamwork and team process development. However, the sensitive nature of the disclosure and the justifiable unwillingness of the student to formally record the topic in the tool represents a tension between the activity rules and the subject in our design, which would have frustrated these students' efforts to reach the objective if they had not been open to discussing the details in-camera.

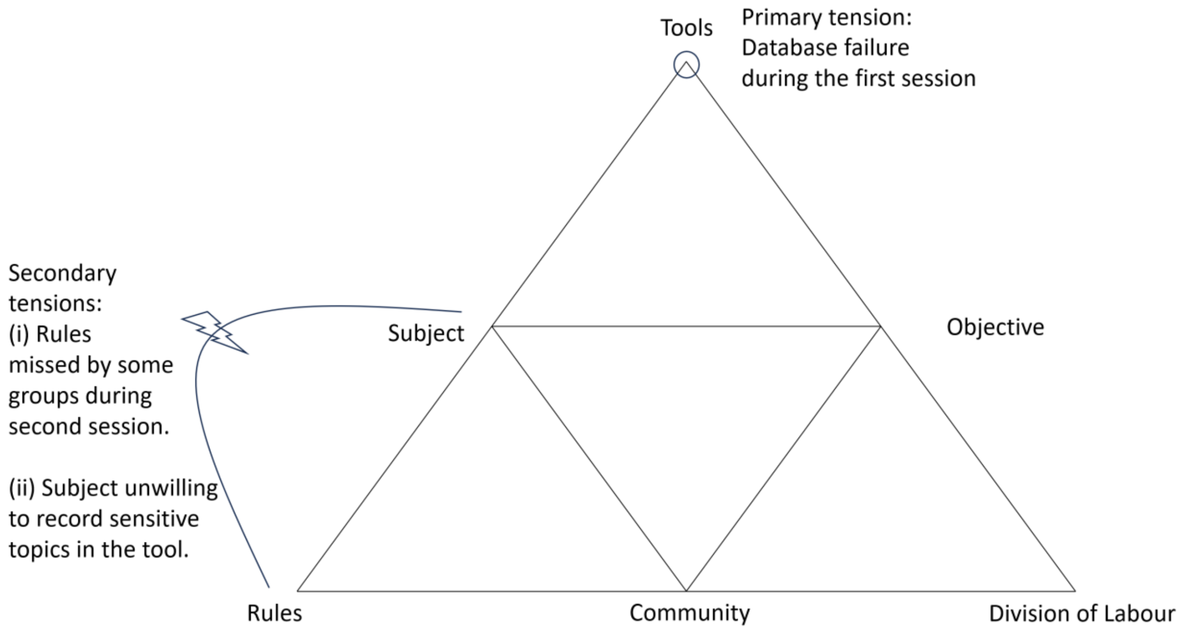


Figure 5-1. Heuristic th1 tensions. One primary tool tension and two secondary tensions.

When we asked how the students felt their topic lists might develop over a longer project, we received answers that mostly related to maintaining clarity of intent regarding their project priorities and task management.

"something that tracks the progress"

While we would not recommend our exemplar artefact be used to manage serious workloads, it is encouraging to observe students thinking about how they might need to course correct if the work begins to diverge from project priorities. This highlights students recognizing the need for development of practice, which we address in overview later in heuristic dc11 (development of practice). Case 3 offered some encouraging feedback regarding how the tool could be useful for defusing tensions that might emerge over time, by allowing the team to easily raise difficulties that they would be uncomfortable doing in a regular team meeting session. In a more established team or a team working over a longer period, the team leader might need to prompt the team to tackle such issues. This additional duty can be seen as a secondary tension between the division of labour and the activity objective within possible earlier versions of the activity, but which can be defused by our approach of scaffolding team growth.

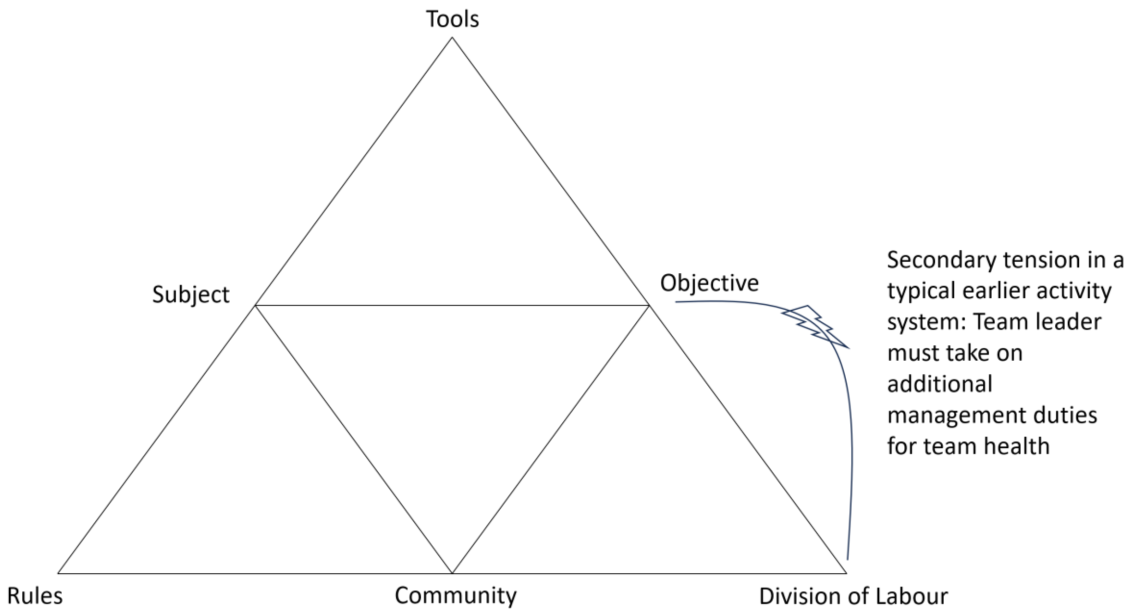


Figure 5-2. Heuristic th1 defuses a potential tension rooted in earlier practice.

5.4.2.2 Teamwork theories, heuristic 2 (th2).

LaFasto and Larson (1989), view feedback as a crucial factor affecting the success of teams. Our second teamwork heuristic (th2) therefore proposes that applications designed to support any kind of team should include mechanisms for intra-team feedback but especially so in distributed teams where there are less opportunities to give feedback. Both the user defined topics and the team member emoticons offered suitable design approaches to support this heuristic, and a two-part probing question was used in the focus group to ensure that the topic could be examined in depth. Full details are presented across tables 5-18 to 5-20.

ID	Heuristic	Design Rule Response(s)	Cross Reference	Focus Session Question(s)
th2	Support intra-team feedback.	Include user defined topics and live team member feedback for each via an emoticon.	None	How useful did you find the feedback in general? How might the topics be useful for team feedback?

Table 5-6. Heuristic th2 overview.

Case	Related deductive codes	Related inductive codes
Case 1 (Capstone Focus Session 1)	Effort to change, **Giving and receiving feedback**, Mental representations, Social-protocols.	Mutual accommodation, Reflection.
Case 2 (Capstone Focus Session 2)	**Clarity of process, Situation awareness**, Fluency with tools, **Giving and receiving feedback**, Naturalness principle, Suitability of tools to tasks, Threshold to usability, Expected behaviour of a tool.	Mutual accommodation, Informal collaboration, Collaboration, Team values.
Case 3 (Capstone Focus Session 3)	Appropriate use of abstractions, **Clarity of expression, Clarity of intent**, Controllers and interface, **Developing shared mental models, Giving and receiving feedback**, Mental representations, Perceptual principle, **Situation awareness**, **Space and cognition**, Suitability of tools to tasks, Usefulness of tools.	Inclusion, Personal disclosures, Reflection, Team health, Teamwork scaffolds.
Case 4 (Phase 1 Interview 1)	**Clarity of intent, Clarity of process, Developing shared mental models, Giving and receiving feedback,** External factor impact, Naturalness principle, **Social-protocols**, Work practices.	Project priorities, Team process development, Teamwork scaffolds, Team health, Collaboration, Hybrid teamwork challenge, Inclusion, Team roles, Team values.
Case 5 (Phase 1 Interview 2)	**Clarity of expression, Clarity of intent, Mental representations, Naturalness principle, Situation awareness.**	Communication, Inclusion, collaboration, Hybrid teamwork challenge.
Case 6 (Phase 1 Focus Session 1)	**Clarity of expression, Clarity of process, Developing shared mental models, Giving and receiving feedback**, Mental representations, Perceptual principle, **Situation awareness**, Task management, Timely feedback, Work practices.	Hybrid teamwork challenge, Team process development, Team roles, Communication, Teamwork scaffolds, Reflection, Team values.

Table 5-7. Heuristic th2 codes and themes.

AODM Analysis

Step	Definition	Details
Activity of Interest	(what sort of activity are we interested in?)	Supporting intra-team feedback.
Objective	(why is the activity taking place?)	Team members should feel that they are able to contribute clearly and understand feedback from their peers.
Subjects	(who is involved in carrying out the activity?)	First semester students, Capstone students, CHARM-EU teaching staff, The researchers.
Tools	(by what means are the subjects carrying out this activity?)	The primary purpose of our exemplar artefact is to facilitate intra team feedback via the interface element.
Rules and Regulations	(are there any cultural norms, rules or regulations governing the performance of this activity?)	Students were asked to openly discuss their sentiments and explain their view to team mates for each discussion topic.
Division of Labour	(who is responsible for what, when carrying out this activity and how are the roles organised?)	Focus session data indicates that most teams approach the sharing of feedback informally, although there are some examples of round-robin approaches or of leadership orientated individuals prompting their teammates.
Community	(what is the environment in what the activity is carried out?)	Hybrid sessions (n=2) and Co-located session (n=1)
Outcome	(what is the desired outcome from carrying out this activity?)	Objective and outcomes align well, and students reported that they did feel that their communication improved as a result of using the tool during the activity.

Table 5-8. Heuristic th2 AODM summary.

AODM discussion of findings (heuristic th2)

Our second teamwork-based heuristic **activity of interest** is to scaffold intra-team feedback with a view towards prompting group reflection and team alignment of shared mental models for each of the activity discussion topics. The literature indicates that feedback is an important factor for team health and that it can extend the situation awareness of team members in recognizing the scope of their team competencies. Our **objective** was to prepare our students to begin thinking about their team transdisciplinary synthesis by helping them to recognize that peers from diverse disciplinary backgrounds would have differing views regarding how prepared they felt to engage with the topics during the master's programme. Activity **rules** encouraged students to explore any differences that they encountered in the tool mediated feedback by discussing which aspects of their academic disciplinary backgrounds contributed to their sentiments. Both the in-app feedback and the team discussion can be viewed as mediating **tools** that modify the subject-object relationship. All team members were expected to engage with an equal **division of labour** although some examples of distributed leadership are apparent with team members taking on encouraging roles to progress the discussions. Community and or cultural influence (**community/rules**) were anticipated to have an impact on willingness to share but this was not encountered in the data. We hypothesized that any reported instances of mutual accommodation by team members would support a socially distributed cognition of teams' perspective that exposure to peers' feedback could be helpful for the team members to conceptualize each topic by reflecting on it from multiple perspectives. Regarding **outcomes**, feedback showed that students valued the reassurance that the feedback gave them regarding each of the topics and knowing their teammates skills balanced their own when they had uncertainties.

"can take a little bit of pressure off yourself. Like if you specifically are not really confident about your skills or about your [] research knowledge or stuff like that"

Embedding the feedback into the interface acts as a visual cue to team members that serves to remind them of their peers sentiment during the activity. This aligns with the DiCoT (Blandford and Furniss, 2008) perceptual principle and builds on Normans (1988; 1999) claim that spatial representations of information offer better supports for cognition than non-spatial information. Our exemplar tool displayed this team feedback in the user interface by sharing team member sentiment for each topic via a corresponding live feedback emoticon for each team member and our activity rule that team members should explore any differences is intended as the scaffold that promotes the necessary level of reflection required to establish this type of social cognition across the team.

Focus sessions showed evidence that being able to see peers' sentiments and hearing their explanations prompted instances of mutual accommodation within teams such that team members reflected on their own sentiments before adjusting their feedback accordingly. Different reasons were given to explain this. The first reason was well supported across cases and relates to students reflecting more deeply upon seeing their peers' views, and using this feedback as a scaffold for evaluating the quality of their own initial sentiment levels. This suggests that a valuable expansion of learning took place for these students, which we view as a positive outcome. Two students also mentioned that they wanted to more closely align with their teammates sentiments rather than appearing to be overly confident in front of their newly acquainted peers. This outcome may have resulted from the students not paying enough attention to the activity rules and a future implementation of the intervention would therefore need to place extra emphasis on the requirement for students to be truthful in the sentiment scores that they share. Following this line of reasoning, we might interpret this effect as a tension between the subject and the rules.

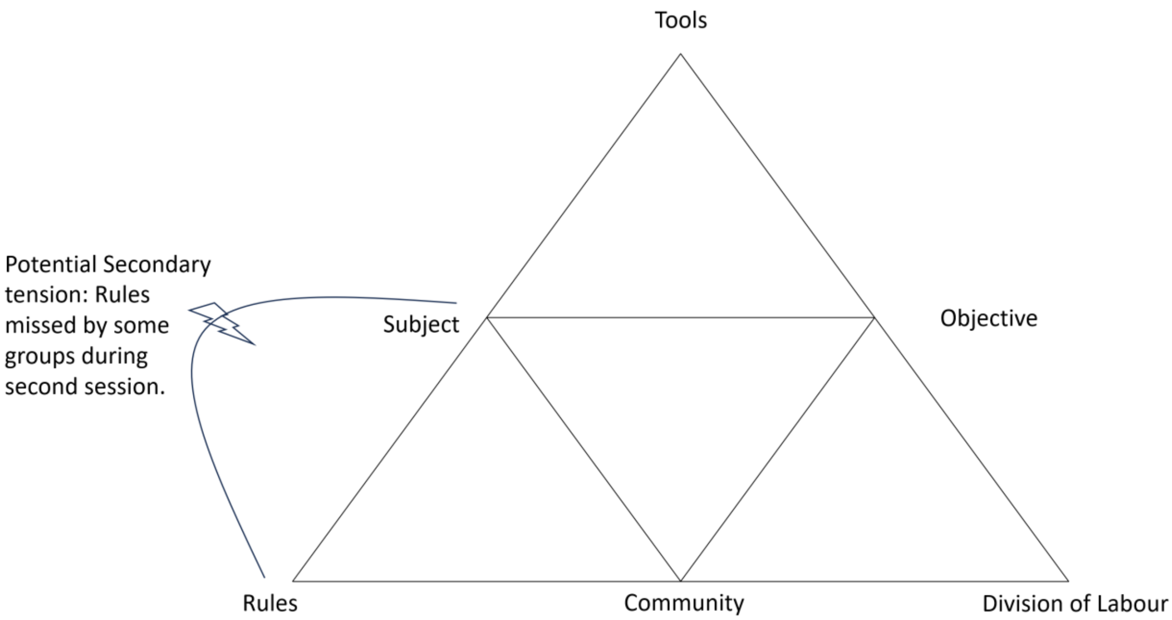


Figure 5-3. Heuristic th2 tension between rules and subject.

An alternative interpretation might consider possible cultural impact and community membership affecting the students' expectations about how to behave in groups, which we would classify as a tension between rules and community.

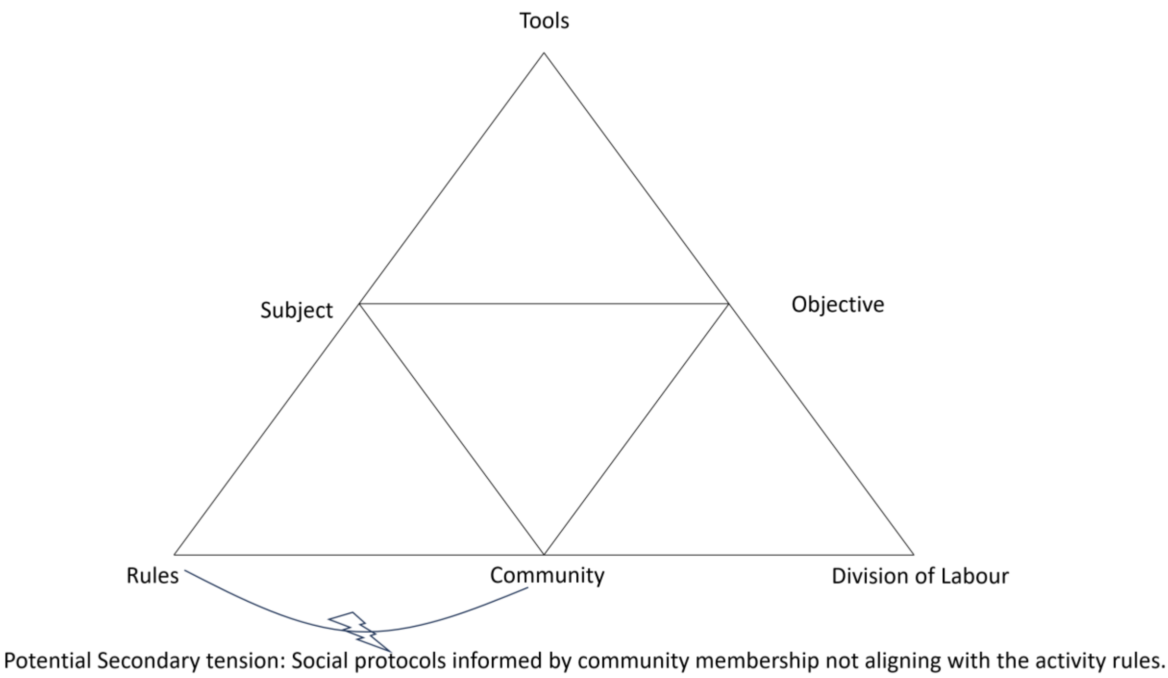


Figure 5-4. Heuristic th2, alternative interpretation of tension.

Other factors such as personality characteristics or team emotional security may have influenced the dynamics, although a full investigation of these themes is beyond the scope of the current research and represents a limitation of our study which we discuss in our final chapter.

Perhaps the most impactful benefit of team feedback is project course correction, if it is offered and acknowledged.

"I think it basically provided talking points that we weren't really speaking about because we were talking about the group work specifically. So, I suppose this was more in the kind of psychological factors."

Such types of feedback can be off-putting if framed incorrectly and the impact of this is that difficult topics can often be left unaddressed in novice teams. The TTT intervention aimed to scaffold difficult team communications via heuristic th2 and participant feedback indicated that students found this to be beneficial to their teamwork.

5.4.2.3 Teamwork theories, heuristic 3 (th3).

Tables 5-21 to 5-23 detail our analysis of heuristic th3.

ID	Heuristic	Design Rule Response(s)	Cross Reference	Focus Session Question(s)
th3	Support different roles and responsibilities	All live feedback will be visible to every team member so that any (or every) member can lead the discussion.	None	If you discussed the team suggested challenges, how did you organise the discussion? How could a session like this (this type of tool and activity) support you in different team roles?

Table 5-9. Heuristic th3 overview.

Case	Related deductive codes	Related inductive codes
Case 1 (Capstone Focus Session 1)	**Effort to change**, Naturalness principle, Social-protocols, **Threshold to usability, Work practices**, Appropriateness of abstractions, Controllers and interface, Expected behaviour of a tool, Perceptual principle, Tool design issues.	Communication, Team health, Team process development, Team values, Suggested improvements, Teamwork scaffolds.
Case 2 (Capstone Focus Session 2)	**Suitability of tools to tasks**, Tool design issues, Clarity of process, Effort to change, **Threshold to usability**, Timely feedback.	Suggested improvement, Team process development, Team roles, Teamwork scaffolds, Collaboration.
Case 3 (Capstone Focus Session 3)	**Work practices, Clarity of expression, Clarity of intent**, Controllers and interface, Developing shared mental models, **Mental representations, Methodologies, Naturalness principle**, Tool design issues.	Informal collaboration, Communication, Reflection, Team process development, Teamwork scaffolds.
Case 4 (Phase 1 Interview 1)	**Social-protocols**, Task management, **Work practices**, Ease of use, Instructions and guidance, Situation Awareness, Threshold to usability, Tool design issues, Tool interactions, Usefulness of tools, Clarity of process, Developing shared mental models, **Effort to keep changing**, **Giving and**	Informal collaboration, Inclusion, Suggested improvement, Collaboration, Communication, Team process development, Team roles.

	receiving feedback, Suitability of tools to tasks, Timely feedback, Tool usage patterns, **Work practices**.	
Case 5 (Phase 1 Interview 2)	**Naturalness principle, Social-protocols, Giving and receiving feedback, Situation awareness**, Space and cognition, Suitability of tools to tasks, tool usage patterns, Usefulness of tools.	Inclusion, Team roles, Hybrid teamwork challenge, Informal collaboration, Suggested improvement, Team health, Team values, Teamwork scaffolds.
Case 6 (Phase 1 Focus Session 1)	Developing shared mental models, Social-protocols, **Giving and receiving feedback, Naturalness principle, Work practices**, Clarity of expression, Consequences of tool use.	Communication, Informal collaboration, Team process development, Team roles, Hybrid teamwork challenges, Inclusion, Team health, Team values, Collaboration, Teamwork scaffolds.

Table 5-10. Heuristic th3 codes and themes.

AODM Analysis

Step	Definition	Details
Activity of Interest	(what sort of activity are we interested in?)	Support different roles and responsibilities across teams
Objective	(why is the activity taking place?)	To provide a flexible experience that would support any team member in any role. Particularly those students that wanted to adopt a leadership role.
Subjects	(who is involved in carrying out the activity?)	First semester students, Capstone students, CHARM-EU teaching staff, The researchers.
Tools	(by what means are the subjects carrying out this activity?)	It was important for our artefact to provide the same user experience to all students, to offer maximum flexibility in how the teams chose to use the tool.
Rules and Regulations	(are there any cultural norms, rules or regulations governing the performance of this activity?)	Students were free to use the tool as they wished after they had input their sentiment scores. We asked them to add their own topics also.

Division of Labour	(who is responsible for what, when carrying out this activity and how are the roles organised?)	Some evidence of individuals adopting a leadership stance by being one of few to add topics.
Community	(what is the environment in what the activity is carried out?)	Hybrid sessions (n=2) and Co-located session (n=1)
Outcome	(what is the desired outcome from carrying out this activity?)	No specific roles adopted beyond prompting others for feedback and some general administrative suggestions. When asked about other potential role supports, the feedback focused on the user added topics potential for supporting project management related tasks.

Table 5-11. Heuristic th3 AODM summary.

AODM discussion of findings (heuristic th3)

Salas et al. (2013) informed our next four teamwork-based heuristics. The **activity of interest** for the first heuristic from this group (th3) reflects the importance of supporting different roles and responsibilities within teams to balance the division of labour and allow each team member focus on what they do best. We knew that team roles would need to be flexible since CHARM-EU student teams often swap roles over time and can adopted either fixed, rotating, or distributed leadership models of teamwork. The **objective** of this heuristic is therefore to support different team roles while recognizing the practical constraint of needing to offer flexibility to the teams (**subjects**) to support their preferred teamwork approach. Our design response to this heuristic was to provide the same live feedback in the **tool** for every team member so that any, or every, member could lead the topic discussions if they wished (**division of labour**). This had the added benefit of aligning with any cultural norms, social-protocols or other kinds of undisclosed **rules** that might influence team members chosen approach or willingness to display leadership during the activity. **Community** membership or influence was not impactful in this case. Our instructions to students before the activity covered this topic by highlighting that the teams should work in a natural way that they found most comfortable, while still encouraging each member to contribute to the discussion and share the rational for their sentiments and this was welcome information for the capstone cohort who had already been working together for four weeks prior to the intervention. Our first semester students were less well established and had not yet adopted any kind of work practices, but their feedback indicates that some teams had already recognized peers displaying leadership skills.

“there's always like one person who's a bit more like dominant”

One participant highlighted the benefit of our approach for helping the less dominant team members to contribute without feeling uncomfortable by mediating the conversation. They offered a suggestion to enhance this potential by including additional nudges to the user.

“but obviously having to be careful in the sense that you're not putting people under pressure either. If they're not comfortable to, to speak. So in terms of the tool, I think it might be good maybe to place some like maybe some nudges like, is there someone comfortable to speak on this for example, or if there's a certain topic that someone is a bit more confident on or more interested in?”

The only **rules** relevant to this heuristic asked that each student contribute equally during the activity. In terms of activity **outcomes** for this heuristic, we noted a difference between each cohort. The more mature capstone teams reported less benefit from the activity in terms of establishing team roles and each group gave the same reason that they had already become well acquainted during the previous year of the master’s programme, and while working as a team during the first four weeks of their capstone project. Teamwork practices were well established by the capstone students, and they reported that the effort to adopt new practices was not seen as worthwhile at this stage. This is surprising since the teams would likely shift or rotate some roles or duties later during their projects, but with only four weeks elapsed, the effort to change from newly established practices so early in the project may have been seen as a barrier to getting on with the work. We understood from our literature review that the timing of the activity would be sensitive, and that timely feedback represented a threshold to usability. This was confirmed by our first semester students who regarded the session as a useful team orientation activity to scaffold the team in establishing team roles and developing aligned shared mental models of how they planned to undertake their teamwork.

5.4.2.4 Teamwork theories, heuristic 4 (th4).

ID	Heuristic	Design Rule Response(s)	Cross Reference	Focus Session Question(s)
th4	Support team mission objectives and norms.	Promote Shared Mental Model building through	tmm1	tmm1

		scaffolded team interactions		

Table 5-12. Heuristic th4 overview.

Heuristic th4 (table 5-24) relates to establishing team mission objectives and norms. Following our AODM review we noted a conceptual overlap between this heuristic and our heuristic relating to team mental models. Briefly recapped, we argue that Salas et al.'s (2013) concepts of team mission objectives and norms equate with Mohammed et al.'s (2010) concept a team mental model based on the representations of key elements of a team's work. That is to say, the team mental model we wish to promote is that of transdisciplinary synthesis. This requires the establishment of team mission objectives and norms before a meaningful integration of disciplinary perspectives can begin. We consolidated heuristics th4 and tmm1 into one question for the focus sessions and discuss both together later in this chapter (see heuristic tmm1 for details).

5.4.2.5 Teamwork theories, heuristic 5 (th5).

Teamwork theory th5 is described over tables 5-25 to 5-27.

ID	Heuristic	Design Rule Response(s)	Cross Reference	Focus Session Question(s)
th5	Consider the environmental context	Use a "Mobile First" design	none	How well do you think it worked as a hybrid classroom-based activity? How might this be useful outside of the classroom?

Table 5-13. Heuristic th5 overview.

Case	Related deductive codes	Related inductive codes
Case 1 (Capstone Focus Session 1)	**Arrangement of equipment, Giving and receiving feedback**, Onboarding of a tool, **Perceptual principle**, Suitability of tools tasks, Tool interactions, Use of tool features.	Communication, Hybrid teamwork challenge, Teamwork scaffolds.
Case 2 (Capstone Focus Session 2)	**Arrangement of equipment**, Expected behaviour of a tool, **Giving and receiving feedback, Situation awareness, Space and cognition**, Threshold to usability.	Collaboration.

Case 3 (Capstone Focus Session 3)	Ease of use, **Giving and receiving feedback**, Suitability of tools to tasks, Work practices, **Arrangement of equipment**, Comfort and accessibility, Controllers and interface, Effort to change, **Horizon of observation**, Mental representations, **Perceptual principle, Situation awareness, Space and cognition, Subtle body supports**, Tool design issues.	Hybrid teamwork challenge.
Case 4 (Phase 1 Interview 1)	**Arrangement of equipment**, Threshold to usability, Tool interaction, **Working in multiple contexts**, Clarity of process, Effort to keep changing, **Evolving requirements, Horizon of observation**, Interacting with IT, **Naturalness principle**, Suitability of tools to tasks, Clarity of expression, Comfort and accessibility, **Display of textual information**, Effort to change, Expected behaviour of a tool, **Situation awareness, Space and cognition**, **Ease of use, Tool usage pattern**.	Hybrid teamwork challenge, Informal collaboration.
Case 5 (Phase 1 Interview 2)	**Arrangement of equipment, Ease of use, Naturalness principle, Space and cognition**, Suitability of tools to tasks, Tool usage patterns, Tool interaction, **Comfort and accessibility**, Effort to change, Expected behaviour of a tool, Fluency with a tool, Interacting with IT, Perceptual principle, **Subtle body supports**, Work practice, **Working in multiple contexts**.	Hybrid teamwork challenge, Informal collaboration, Communication, Inclusion, Team roles.
Case 6 (Phase 1 Focus Session 1)	**Arrangement of equipment, Comfort and accessibility**, Interacting with IT, tool interaction, Work practices, Suitability of tools to tasks, **Threshold to usability, Instructions and guidance, Naturalness principle, Social-protocols**, Tool usage patterns.	Hybrid teamwork challenge, Team process development.

Table 5-14. Heuristic th5 codes and themes.

AODM Analysis

Step	Definition	Details
Activity of Interest	(what sort of activity are we interested in?)	Understanding the environmental context to see what potential usage patterns and modalities can be supported.
Objective	(why is the activity taking place?)	To support students in their hybrid teamwork, regardless of the type of device they chose to use.
Subjects	(who is involved in carrying out the activity?)	First semester students, Capstone students, CHARM-EU teaching staff, The researchers.
Tools	(by what means are the subjects carrying out this activity?)	We adopted a mobile first design approach in our exemplar artefact.
Rules and Regulations	(are there any cultural norms, rules or regulations governing the performance of this activity?)	Students were asked to use their own devices.
Division of Labour	(who is responsible for what, when carrying out this activity and how are the roles organised?)	A student reported observing a teammates suing a mobile phone for data entry and looking in on a peers later screen for the discussion. No other division of labour is evident, likely due to the rule asking students to each use their own device.
Community	(what is the environment in what the activity is carried out?)	Hybrid sessions (n=2) and Co-located session (n=1)
Outcome	(what is the desired outcome from carrying out this activity?)	No mobile users took part in our focus sessions, so it is difficult to comment directly on the mobile first implementation. All teams both co-located and hybrid, were able to engage in the activity successfully, which supports this heuristic

		although as noted earlier, students spent some time finding a location to make their calls which delayed the start. The CHARM-EU hybrid classroom approach asked students to bring their own devices, so it is likely that most students were working in a familiar computing context.

Table 5-15. Heuristic th5 AODM summary.

AODM discussion of findings (heuristic th5)

Salas, et al. (2013) suggest that the context of where teamwork takes place can profoundly influence team performance outcomes and this frames the **activity of interest** for heuristics th5. Their work identifies stressful, distributed, and multicultural contexts as the type of factors that can affect teamwork, and each of these contexts can be found in the type of hybrid teamwork encountered on the CHARM-EU master's programme. Students on the programme (**subjects**) can work remotely or be co-located. They can connect to class activities using their own laptops or mobile phones or more typically join via one of the CHARM-EU hybrid classrooms using either team "pods" that support a single team around a single screen, or as part of the full class using the larger classroom screen and ambient audio system, and these diverse **tools** lead to differing experiences regarding the horizon of observation that can impact situational awareness. The **objective** of our next teamwork-based heuristic (th5) is therefore to recognize that students are affected by these factors and to attempt to address this by offering as flexible an experience as possible. One design rule could not hope to cover all possible contexts, and we therefore concluded that a suitable design response to this heuristic was to adopt a "mobile first" interface to support as wide a variety of devices and interactions as possible. This was achieved in our exemplar application using Google's Material Design framework and the MUI library of user interface elements to ensure that our tool could be used on any 2D device. Our approach helps to isolate the front-end styling from our application code, which provides a clean separation of the front and back-end elements, and this futureproofs for easy integration into more complex computing environments such as mixed reality. Indeed, the implementation can already integrate easily into contemporary XR environments as a floating web panel, thanks to this adherence to current web standards.

No specific **rules** applied, and **community** was not mentioned in feedback, however a **division of labour** is apparent with some device sharing taking place in our co-located capstone group.

Concerning **outcomes**, it is unfortunate that we did not have an opportunity to gather direct student feedback regarding the mobile first approach since each of our focus session participants connected using their laptops, which meant that each worked in a similar context. A future study could build on this work to include students working across a wider variety of device types, which would provide richer data to evaluate the heuristic. We did however receive an indirect account of a teammate that connected using their mobile phone. In this case the team were partially co-located, and the student noted that although their team each worked on their own devices, the mobile user chose to look at their local peers screens during the discussion part of the activity, i.e. when not entering data.

“people in Barcelona one laptop and the people in the Utrecht like another one, but like everyone was connected in a call all the time”

We would classify this as a preference for a subtle body support that improved the accessibility of the activity and helped the student work more comfortably with their co-located peers. Our instructions for the activity asked each student to connect using their own device. This is common practice in CHARM-EU for in class activities however students often double up at a single device if an activity supports it or if there is some technical issue with an individual device. Our capstone students, who were fully co-located, reported that they were initially confused as to why they each needed to use a device even when working in the same physical space and one individual reported that some members of their team were reluctant to enter data since they felt that observing others doing so was sufficient. This informal division of labour, which is contextually determined by the situation, could be considered as a tension between the subjects and the activity rules, which stems from the earlier activity system of their typical teamwork sessions and typical practices as student members of the CHARM-EU community. It is gratifying to note however that our tool defused this tension since the student in question followed up by saying that once they noticed the different emoticons of their peers appearing on the screen, they understood the purpose of individual devices and found this feature to be an enjoyable motivation to fully engage with the session using their own laptops. Overcoming this earlier tension is a positive outcome since it means that each student contributed their sentiment values and thusly received the full benefit of working through the learning material during the session, which may not always be the case during CHARM-EU teamwork-based activities due to the existing practice of screen sharing during sessions requiring individuals to interact.

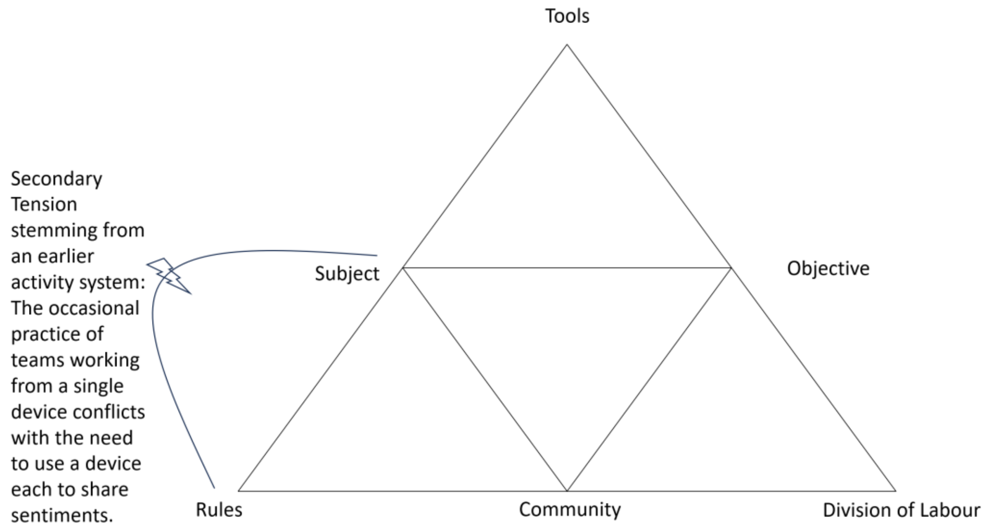


Figure 5-5. Heuristic th5 secondary tension between rules and subject.

An alternative interpretation that considers the cultural historical significance of tensions between a prior practice and a new approach might characterize this data as a tertiary tension between an old and new model, that is, the general approach used in CHARM-EU versus the specific rules defining the interaction in our intervention. Feedback received from our participants highlighted the uniqueness of our approach stating that they had never engaged in such types of team discussions in the past which supports this view.

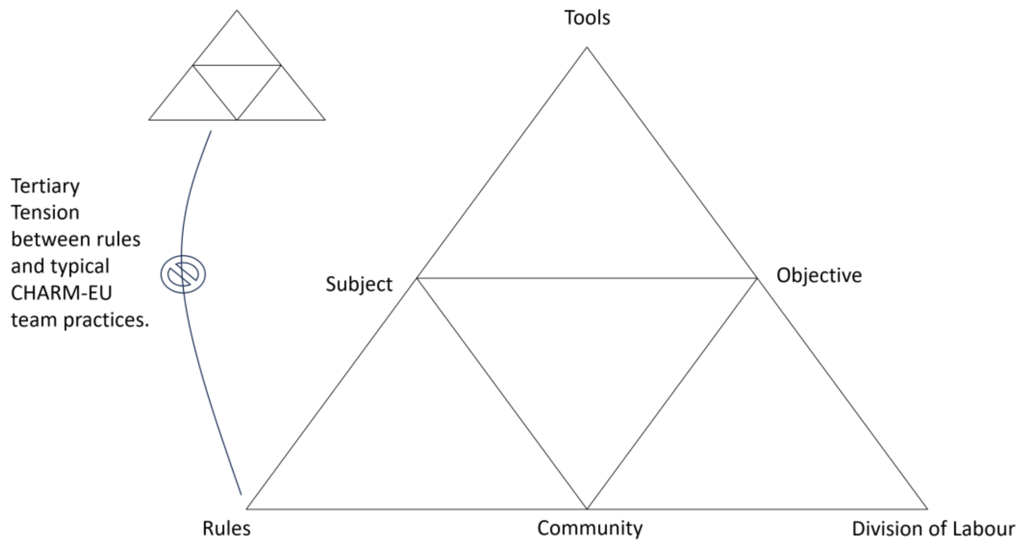


Figure 5-6. Heuristic th5 3rd generation AT interpretation showing tertiary tension between different versions of the same activity system (old vs. new).

5.4.2.6 *Teamwork theories, heuristic 6 (th6).*

Tables 5-28 to 5-30 detail our analysis of heuristic th6.

ID	Heuristic	Design Rule Response(s)	Cross Reference	Focus Session Question(s)
th6	Foster team familiarity (to build affiliative associations)	Intervention design (submit sentiment and explain it to teammates)	None	Did you discover any (interesting/unexpected) KSA's within your team that might contribute to your work together? Was that helpful?

Table 5-16. Heuristic th6 overview.

Case	Related deductive codes	Related inductive codes
Case 1 (Capstone Focus Session 1)	Clarity of process, **Developing shared mental models**, Fluency with tools, **Situation awareness, Timely feedback**, Usefulness of tools, Work practices.	Collaboration, Communication, Informal collaboration, Personal disclosures, Team process development, Team roles, Teamwork scaffolds.
Case 2 (Capstone Focus Session 2)	**Giving and receiving feedback, Timely feedback.**	Teamwork scaffolds.
Case 3 (Capstone Focus Session 3)	**Clarity of intent, Developing shared mental models, Giving and receiving feedback**, Mental representations, Perceptual principle, **Situation awareness**, Social-protocols, Space and cognition.	Reflection, Team process development.
Case 4 (Phase 1 Interview 1)	**Developing shared mental models**, Mental representations, **Situation awareness**, Clarity of process, Perceptual principle, **Situation awareness, Suitability of tools to tasks,** Work practices, **Giving and receiving feedback**.	Communication, Teamwork scaffolds, Reflection, Team health, Team roles, Inclusion.
Case 5 (Phase 1 Interview 2)	**Timely feedback.**	Team roles.
Case 6 (Phase 1 Focus session 1)	**Developing shared mental models, Giving and receiving feedback**, Mental representations, **Situation awareness**, **Timely feedback**, Consequences of tool use, **Naturalness principle**.	Inclusion, Team health, Teamwork scaffolds, Reflection, Team roles.

Table 5-17. Heuristic th6 codes and themes

AODM Analysis

Step	Definition	Details
Activity of Interest	(what sort of activity are we interested in?)	Foster team familiarity (to build affiliative associations)
Objective	(why is the activity taking place?)	Build intra-team familiarity that extends the situation awareness for team members regarding their team competencies and capabilities.
Subjects	(who is involved in carrying out the activity?)	First semester students, Capstone students, CHARM-EU teaching staff, The researchers.
Tools	(by what means are the subjects carrying out this activity?)	The exemplar tool displayed limited profile data for each students.
Rules and Regulations	(are there any cultural norms, rules or regulations governing the performance of this activity?)	We asked students to add their names and academic background when logging onto the tool.
Division of Labour	(who is responsible for what, when carrying out this activity and how are the roles organised?)	A division of labour is not evident although our focus session data suggests that some students directed their sessions by prompting feedback from peers and conducting the session in their group.
Community	(what is the environment in what the activity is carried out?)	Hybrid sessions (n=2) and Co-located session (n=1)
Outcome	(what is the desired outcome from carrying out this activity?)	One capstone group did not report any surprise insights regarding their peers capabilities but all felt that they were closer after the experience. First semester students reported very positive experiences and new knowledge about their peers thanks to their interactions during the activity.

Table 5-18. Heuristic th6 AODM summary.

AODM discussion of findings (heuristic th6)

This heuristic's **area of interest** is informed by Salas, et al. (2013) and relates to the importance of building team familiarity and affiliative associates between team members. They consider good team relationships to be a positive influencer of team health and suggest that building friendships or "affiliative associations" within teams is a common occurrence that supports teamwork. Measurement of affiliative associations can be conflated by factors such as personality characteristics or cultural background and we therefore chose to focus on whether students managed to develop any insights about their peers as an indicator for the impact of this heuristic. Our **objective** with this heuristic was to help students become better acquainted with their new teammates to establish a basis for good team relations and we made a point to clarify to our focus session participants that they should only discuss insights that related to knowledge, skills and abilities of teammates to avoid any potential disclosure of sensitive information. We expected that the first semester group would benefit more from this aspect of the activity in comparison to our capstone cohort due to the capstone students already knowing one another somewhat from other CHARM-EU programme activities and the findings support this. The exemplar **tool** mediated the sentiment sharing and the activity instructions (**rule**) asked students to explain the rationale for their sentiment scores with their teams during the discussions. Emoticons of each members sentiment scores were intended to scaffold the discussions by acting as a transactive memory support and visual reminder to help team members to stay focused when engaging in the topic discussions. This approach aligns with media richness theory's (Daft and Lengel, 1986) stance that information received over multiple channels can be more readily understood, and with Norman's (1988; 1999) view regarding spatial representations of information. The rules and regulations for this heuristic included the instructions given at the start of class, where the teams were asked to explore any differences in sentiment scores to reveal team capacity and capabilities by developing insights regarding their situational awareness and mental representations of other team members background experiences. We expected that extrinsic **rules** and regulations relating to cultural norms and willingness to share might also impact the success of this heuristic, however no instances of this were noted in the participant responses. Once again, most teams adopted an informal round-robin **division of labour** to share of their sentiment explanations. **Outcomes** from the focus session feedback indicates that this informal division of labour was not discussed by the teams but instead seems to have happened naturally, aside a few individuals who adopted a leadership role by prompting responses from their teammates.

Participants in five out of the six focus sessions agreed that they had developed insights regarding their peers backgrounds and competencies from engaging in the activity. One participant told us that their team had spent time reflecting together on the group’s repertoire of competencies and that this experience later helped them to identify potential connections that would be helpful for their work together.

“maybe the connections came a bit later […] not with this activity yet but later on, we dig deeper to the topic right and really then we could more like utilize our individual backgrounds and experiences”

Negative emoticons were seen to be more motivating to the team from focus session 3, where a participant mentioned that seeing negative sentiments prompted them to discuss the item more deeply and understand their teammates.

"most of them are positive, so the negative faces […] were the outliers […] we probed more deeply into those"

Negative sentiment indicates a potential hurdle, and our students were eager to discuss this during the intervention. This is an interesting outcome that shows how willing the students were in supporting their peers.

5.4.2.7 Teamwork theories, heuristics 7, 8 and 9 (th7, th8 and th9).

Teamwork heuristics th7, th8 and th9 are detail below over two tables (5-31 and 5-32)

ID	Heuristic	Design Rule Response(s)	Cross Reference	Focus Session Question(s)
th7	Be specific in communications	Use multistep sliders to simplify the sharing of data	c2b	c2b
th8	Recognise and manage relative priorities	An aggregated smiley feature can highlight issues to help the team to recognise relative priorities	c2b	c2b
th9	Employ a clear working approach	Multistep slider (for the PLOs and user defined topics)	c2b	c2b

Table 5-19. Heuristics th7, th8 & th9 overview.

AODM Analysis

Step	Definition	Details
Activity of Interest	(what sort of activity are we interested in?)	Supporting clear intra-team communication regarding the expression of team member sentiment.
Objective	(why is the activity taking place?)	To help students be specific in their communication. help students be specific in their communication. To help students recognise issues that the team consider to be important. To help students employ a clear working approach.
Subjects	(who is involved in carrying out the activity?)	First semester students, Capstone students, CHARM-EU teaching staff, The researchers.
Tools	(by what means are the subjects carrying out this activity?)	The exemplar app employed a five-point stepped slider and corresponding emoticons for each step.
Rules and Regulations	(are there any cultural norms, rules or regulations governing the performance of this activity?)	Students each needed to enter their sentiment score.
Division of Labour	(who is responsible for what, when carrying out this activity and how are the roles organised?)	Each team member must contribute equally by adding their own sentiment values before engaging in a team discussion to explain the rationale behind their inputs.
Community	(what is the environment in what the activity is carried out?)	Hybrid sessions (n=2) and Co-located session (n=1). Students ability to recognise emoticons states may vary, possibly by cultural background and/or prior experience of using emojis.
Outcome	(what is the desired outcome from carrying out this activity?)	Students feel that they can clearly express their sentiments and gauge other teammates sentiments for each topic.

Table 5-20. Heuristic th7, th8, th9 AODM summary.

AODM Discussion of findings (heuristic th7, th8, th9)

Our next three heuristics were drawn from the work of Katzenbach and Smith, (1993) who relate team performance and wellbeing to the quality of communications between team members. These heuristics relate to, being specific in communications, recognising and managing relative priorities and employing a clear working approach. Our earlier review of these topics identified overlapping concepts with heuristic c2b, i.e. “Interface controls that represent analogues of social cues should not feel unnatural to users”. Our focus session question for these concepts asked, how well do you feel you could express your sentiment using the emoticon sliders? The tool included animated avatars for each topic discussion point, and these were stepped over a five-point scale. We asked our students to give their sentiment values for each discussion topic using the associated slider interface. The focus session participants reported that they were generally able to express themselves well and understand the information from their peers. However, we did receive feedback from students in two groups who initially struggled to recognise the emoticons at each end of the scale, with one student questioning whether the dissatisfied emoticons represented anger. A larger sample would help to clarify whether this was due to a poor choice of icons or the student’s ability to recognise emoticons states, possibly influenced by cultural background and/or prior experience of using emojis. These students suggested a review of the emoticons, but also confirmed that they were able to understand the meaning after considering for a moment. Overall, the support is good for this heuristic despite some reservations for these students regarding the implementation in our exemplar artefact tool.

5.4.3 Team mental models

5.4.3.1 Team mental models (tmm1).

We include our team mental model heuristic within our teamwork category but present it separately here for clarity. Details are include in tables 5-33 to 5-35.

ID	Heuristic	Design Rule Response(s)	Cross Reference	Focus Session Question(s)
tmm1	Support the building of mental representations of the key elements within a team’s relevant environment that	Intervention design rules (share and explain your sentiments) plus synchronous feedback to all team members	Some overlap with th4 (team mission objectives and norms)	How might this activity help you to track the key elements of your work?

	are shared across team members			

Table 5-21. Heuristic tmm1 overview.

Case	Related deductive codes	Related inductive codes
Case 1 (Capstone Focus Session 1)	**Appropriate use of abstractions, Situation awareness,** Suitability of tools to tasks, Usefulness of tools, **Clarity of purpose, Developing shared mental models**, Evolving requirements, **Methodologies**, Perceptual principle, **Situation awareness**, Space and cognition, **Task management, Timely feedback, Tool usage patterns, Work practices**.	Project priorities, Communication, Reflection, Suggested improvement, Team health, Team process development, Teamwork scaffolds, Mutual accommodation.
Case 2 (Capstone Focus Session 2)	**Evolving requirements**, Suitability of tools to tasks, **Effort to change**, **Situation awareness**, Tool design issues, **Timely feedback, Work practices**.	Team process development, Team roles, Suggested improvement, Teamwork scaffolds.
Case 3 (Capstone Focus Session 3)	**MISSED QUESTION***	**MISSED QUESTION***
Case 4 (Phase 1 Interview 1)	**Clarity of intent, Clarity of process, Developing shared mental models, Evolving requirements, Giving and receiving feedback**, Interpersonal clashes, Situation awareness, Social-protocols, Space and cognition, **Timely feedback, Tool usage patterns, Usefulness of tools, Work practices.**	Project priorities, Communication, Hybrid teamwork challenge, Reflection, Suggested improvement, Team health, Team process development, Team values, Teamwork scaffolds.
Case 5 (Phase 1 Interview 2)	**Clarity of process, Developing shared mental models, Evolving requirements, Methodologies**, Perceptual principle, **Situation awareness**, Space and cognition, Suitability of tools to tasks, Timely feedback, Tool usage patterns, Use of tool features, **Usefulness of tools, Work practices.**	Communication, Reflection, Team health, Team process development, Team values, Teamwork scaffolds.
Case 6 (Phase 1 Focus session 1)	**Clarity of expression, Clarity of process, Developing shared mental models**, Interpersonal clashes, Naturalness principle, Perceptual principle, **Situation awareness**, Social-protocols, **Suitability of tools to tasks, Timely feedback.**	Communication, Inclusion, Reflection, Team health, Team process development, Team roles, Teamwork scaffolds.

*Table 5-22. Heuristic tmm1 codes and themes. *Note, this question was not asked of capstone group 3 due to a methodological oversight by the researcher.*

AODM Analysis

Step	Definition	Details
Activity of Interest	(what sort of activity are we interested in?)	Investigate potential to support team mental model building
Objective	(why is the activity taking place?)	Support the teams in their planning needs by beginning to think about the key elements of their team capabilities.
Subjects	(who is involved in carrying out the activity?)	First semester students, Capstone students, CHARM-EU teaching staff, The researchers.
Tools	(by what means are the subjects carrying out this activity?)	Students were free to use the tool however they wished and were later questioned about how they might use it for project planning. User added topics can support planning and most responses to the question of team planning relate to such items.
Rules and Regulations	(are there any cultural norms, rules or regulations governing the performance of this activity?)	No specific relating to how students should use the tool although we anticipated some culturally historical reasons why other types of planning tools might be preferred (i.e. familiarity and features). Students were encouraged to actively share the rationale for their sentiments.
Division of Labour	(who is responsible for what, when carrying out this activity and how are the roles organised?)	Some students adopted a note taking role by adding topics to their team list.
Community	(what is the environment in what the activity is carried out?)	Hybrid sessions (n=2) and Co-located session (n=1)
Outcome	(what is the desired outcome from carrying out this activity?)	The limited features of our tool were not expected to be useful for planning, but we instead wanted to see evidence of questioning and sharing practice taking place and to see if students would recognise the value of this approach for their project planning needs. There was some limited support for this in student feedback.

Table 5-23. Heuristic tmm1 AODM summary.

AODM discussion of findings (heuristic tmm1)

The **activity of interest** for our heuristic relating to team mental models (tmm1) is informed by Mohammed et al. who defined a team mental model as "mental representations of the key elements within a team's relevant environment that are shared across team members", (Mohammed, et al., 2010), and heuristic tmm1's **objective** is to scaffold such representations via the tool and intervention. Our focus group preparation identified an overlapping concept with that of our fourth teamwork heuristic (th4) which builds on Salas et al.'s (2013) work in supporting team mission objectives and norms. Team mission objectives and norms are central themes when it comes to building a transdisciplinary team synthesis since the norms determine the integrative approach. This was examined during the focus session by asking students how the experience might help them to track key elements in their work, which is the basis for informing and building a team mental model for their team project. A shared mental model for team planning is the template for how that team will function together and this clearly requires considerably more planning and discussion than we aimed to cover during our intervention. Students were not specifically asked to discuss their team planning during the activity however we anticipated that some teams would begin to think about how their disciplines should eventually interact and then consequently begin to think about some related goals for their project. This would prime them to consider the appropriate division of labour for the skills possessed.

The **tool and rules** might be seen as complementing each other in our analysis of this heuristic as we are interested in the potential of team planning to promote refection and improve situation awareness within team members. Our exemplar artifact supports this kind of group reflection by acting as a focus for discussion topics that is visible to all team members. The rule that most influences the objective in this heuristic is the requirement for teams to discuss openly and share insights or other relevant background information to explain their sentiments. This rule establishes the process for team interactions. We noted several examples of individuals adopting a shared leadership role by interjecting with their suggested team discussion topics, however our participants generally reported that the **division of labour** was informal and unstructured regarding any planning topics raised during their discussions.

Here we have another example of **community** influencing the set of rules at play within the activity system relating to this heuristic. The heterogeneous nature of transdisciplinary teamwork implies that some students would have greater experience of project planning due to their specific academic backgrounds. This represents a culturally historical community effect that influences each team to varying degrees, for example, with science and business students more readily considering project planning at an early stage of their teamwork by adopting the cultural norms associated with their disciplinary praxis. However, contrary to this theme we also encountered instance of participants reporting that the desire to learn new techniques can also be motivating to take on new roles.

"the person who maybe has the background in that enjoys doing stuff like that and that. What they want to do? [...] Or on the flip side to that, like a person […] maybe wants to look at the more theoretical framework who maybe haven't (sic) done something like that before and wants to, you know, learn more about that"

Feedback and **outcomes** for this heuristic were positive, especially regarding the activity approach to generating reflections and identifying team capacity. When asked about any potential benefits of the activity that might assist with team planning, participants did not report seeing much value in this aspect of the exemplar tool, but did mention improved familiarity with the CHARM-EU programme learning outcomes as being helpful. Overall, the process was well received for prompting reflection and intra-team enquiry. The benefit to team decision making was specifically noted, with a focus on occasional exploring of a problem space rather than as a regular practice. The student that raised this point suggested that once or twice per month would be the upper limit to usefulness, with sessions aimed at setting personal and team goals that would help the team align through improved clarity of process. Such an approach was also noted as potentially useful for highlighting negative group sentiment for issues before it could have an adverse effect or derail future efforts. When asked directly about possible planning benefits, one student mentioned potential uses of user added feedback as a type of informal process and progress tracker, where teams could do ongoing check-ins to see if they still felt themselves to be aligned on any of their recorded topics.

"it helps keep on track because it helps, like organizing it a little bit and like, actually see it, not just like, think about"

"good to keep track of the process or the progress for example"

Another student mentioned that seeing the scales for their teammate's sentiment values helped them to recognise skills gaps in their team which lead them to understand and manage their expectations about the team capacity regarding their project.

"being able to see everybody's scale and level of that scale, I think it definitely somehow managed expectations"

5.4.4 Distributed cognition heuristics (DCog)

Our four DCog informed heuristics are drawn from the seminal work of Hutchins, (1965). These are the first heuristics in our Distributed Team Cognition category.

5.4.4.1 Distributed cognition, heuristic 1 (dc1).

Heuristic dc1 was identified as an overlapping theme of teamwork heuristic 2 as described in our design process chapter, i.e. regarding the usefulness of feedback during the session. Details are included here as a reminder in table 5-36.

ID	Heuristic	Design Rule Response(s)	Cross Reference(s)	Focus Session Question(s)
dc1	Embodiment of information within the system	Live Feedback	th2	th2

Table 5-24. Heuristic dc1 overview.

5.4.4.2 Distributed cognition, heuristic 2 (dc2).

Our analysis of the co-ordination between agents heuristic is detailed over tables 5-37 to 5-39.

ID	Heuristic	Design Rule Response(s)	Cross Reference(s)	Focus Session Question(s)
dc2	Co-ordination between agents	Live Feedback & user defined topics		Did you update any values when you saw the other team members / team average?

Table 5-25. Heuristic dc2 overview.

Case	Related deductive codes	Related inductive codes
Case 1 (Capstone Focus Session 1)	Appropriateness of abstractions, **Clarity of intent**, **Mental representations**, Naturalness principle, **Space and cognition**, Use of tool features.	Mutual accommodation, Reflection.
Case 2 (Capstone Focus Session 2)	Consequences of tool use, **Giving and receiving feedback, Situation awareness**, Social-protocols, Tool design issues, Use of tool features, Appropriateness of abstractions, **Clarity of expression**, Controllers and interface, **Mental representations**, Naturalness principle, Perceptual principle, Tool usage patterns.	Collaboration, Mutual accommodation, Reflection, Team health, Team process development.

Case 3 (Capstone Focus Session 3)	**Clarity of process**, Developing shared mental models, Giving and receiving feedback, **Mental representations**, **Situation awareness**, Social-protocols.	Mutual accommodation, Reflection, Communication, Inclusion, Team process development, Teamwork scaffolds.
Case 4 (Phase 1 Interview 1)	**Clarity of intent**, Consequences of tool use, Developing shared mental models, **Giving and receiving feedback**, Interpersonal clashes, **Mental representations**, Naturalness principle, Social-protocols, Work practices, Suitability of tools to tasks, Usefulness of tools.	Team health, Team roles.
Case 5 (Phase 1 Interview 2)	**Clarity of expression, Clarity of process**, Consequences of tool use, Developing shared mental models, **Mental representations**, Perceptual principle, **Situation awareness**, Social-protocols, **Space and cognition**.	Mutual accommodation, reflection.
Case 6 (Phase 1 Focus session 1)	**Clarity of expression, Clarity of intent**, Consequences of tool use, Developing shared mental models**, Giving and receiving feedback, Mental representations**, Perceptual principle, **Situation awareness**, Social-protocols, Timely feedback, Work practices, **Clarity of process**, Naturalness principle.	Hybrid teamwork challenge, Inclusion, Mutual accommodation, Reflection, Team health, Team values, Teamwork scaffolds.

Table 5-26. Heuristic dc2 codes and themes.

AODM Analysis

Step	Definition	Details
Activity of Interest	(what sort of activity are we interested in?)	Scaffolding co-ordination between agents by sharing live sentiment scores of all team members
Objective	(why is the activity taking place?)	Promoting team reflection is theorised to support team mental model building.
Subjects	(who is involved in carrying out the activity?)	First semester students, Capstone students, CHARM-EU teaching staff, The researchers.

Tools	(by what means are the subjects carrying out this activity?)	Live Feedback & user defined topics act to scaffold the team discussion.
Rules and Regulations	(are there any cultural norms, rules or regulations governing the performance of this activity?)	The activity instructions asked students to adjust their sentiment scores as required during the discussions.
Division of Labour	(who is responsible for what, when carrying out this activity and how are the roles organised?)	All team members engaged equally.
Community	(what is the environment in what the activity is carried out?)	Hybrid sessions (n=2) and Co-located session (n=1)
Outcome	(what is the desired outcome from carrying out this activity?)	Evidence of mutual accommodation as a result of reflection during the discussion.

Table 5-27. Heuristic dc2 AODM summary.

AODM discussion of findings (heuristic dc2)

The **activity of interest** for heuristic dc2 relates to supporting transdisciplinary teamwork synthesis by prompting intra-team reflection, with the **objective** of improving co-ordination between team members through the giving and receiving of feedback via our exemplar **tool** that improves situational awareness and helps to clarify team purpose. There are several benefits to such an effect, including team bonding, team mental model building, increased team familiarity and improving team member situation awareness regarding team competencies, and our participant **subjects** reported examples for each of these effects. However, prompting reflection is perhaps the most interesting and impactful effect for transdisciplinary student teams who are attempting to develop their transdisciplinary team synthesis approach. Students were given the **rule** to reflect on their own scores during the discussion and update their values as needed. **Community** membership has the potential to influence participant behaviour for such as task, particularly for community of practice and community of interest memberships that help to build experience. It is also likely that other factors such as gender gap confidence, individual confidence or experience levels, and Big Five personality factors like high extraversion or high neuroticism may also influence mutual accommodation, however these aspects are beyond the scope of the current research, and we discuss these in our limitations.

The visual feedback of each team members sentiment values within the exemplar artefact was intended as a scaffold for reflection by revealing peer sentiment values to each team member. This visual reminder build on DiCoT's space and cognition principle by acting as a transactive memory system that can regulate the information flow of the teams cogitative system, since it can be reviewed as needed throughout the activity. Seeing one's peers sentiments should therefore prompt reflections and we expected to see a large degree of mutual accommodation of sentiment scores during the activity. Mutual accommodation was evident and widely reported by our participants, which indicates that the feedback did extend the teams cognitive system. Hutchins (ibid) DCog theory explains this interaction on three levels, i) cognitive processes are distributed across members of a social group, ii) they involve coordination between internal (material) and external (environmental) structures, and iii) they can be distributed through time such that they modify the outcome of later events. The heuristic scaffolds a reciprocal **division of labour** by mediating the team interactions.

The **outcome** of qualitative feedback analysis indicates that many students modified their sentiment values upon seeing their peers' values change. One participant explained their reflective process for us to show how they reassessed their sentiment level before deciding to stick with the original value.

"…we might have similar things because we have similar backgrounds, but they are rating each other higher. And I maybe we have a conversation about this. And maybe I'm like, oh, am I being too humble? Or is it like, I would question myself and like, I know only after questioning myself, I would change it. Sometimes I would be like no, OK. I think that this is still fair."

Different reasons were given when we asked our participant if they had updated any of their own values after seeing other team members and team average values. Firstly, to set a positive tone with their peers.

"yes, there was second guessing. I would say for sure and also basically not trying to have a pessimistic view. You know, not trying to set the tone of pessimistic kind of path"

Secondly, participants reported changing their sentiment values after reflecting on how closely aligned they were with their teammates either as a way of recalibrating their own sentiments, or in one case, to better align themselves with their group.

"I definitely think there were cases where people maybe had been a little bit too self-critical initially and then once they actually talked it out with their team, they possibly realised that they had been, you know, human nature, sometimes is we can be harder on ourselves."

"I changed it first to align a bit with the group and second after discussing I change it too because I felt like my first idea were (sic) wrong and I didn't really understood (sic) the question, so I needed to update it."

The situation of recalibrating is positive. Projecting unfounded positivity or conforming to a group mean can both create an echo chamber or groupthink effect, and care would need to be taken to highlight this to participants in any future iterations of the activity. One student (case3) mentioned team peers struggling to understand a particular topic and that the group spent time to tease out the meaning of the topic, which we view as positive inclusion of all team members and a good sign of a healthy team environment. The student mentioned that this extended discussion helped them to see the topic from multiple perspective and that this prompted them to adjust their sentiments.

Time series sentiment data

During the intervention our students generated time series data while interacting with the exemplar tool. We were most interested in any data indicating mutual accommodation of participant sentiment between team peers during the team's discussions and both qualitative and quantitative data shows support for this topic. Our quantitative data also revealed usage patterns that was confirmed in student focus session feedback. We wanted to plot this data to show a moment-by-moment state of each team's values per topic. As consent was not received from all our students, we could not generate this data for any individual full team. Nonetheless, our student teams generated a considerable volume of sentiment data during the activity. Each chart below plots the scores for all consenting team members, of a topic, within a team. It is unsurprising to note that for the first few discussion topics, many of the charts show that students experimented with the interface as there is a considerable degree of noise in the data where students are clearly examining the emoticons for each sentiment level. While this means that we possibly did not capture good data for the initial set of topics, it is encouraging to see that our students were eager to explore the TTT app. Instances of mutual accommodation were noted and although it is impossible to know what specific discussion points or comments may have prompted these sentiment changes, the data represents evidence of individual reflection taking place during the discussions, and this is supported by our focus session feedback. See figures below for details.

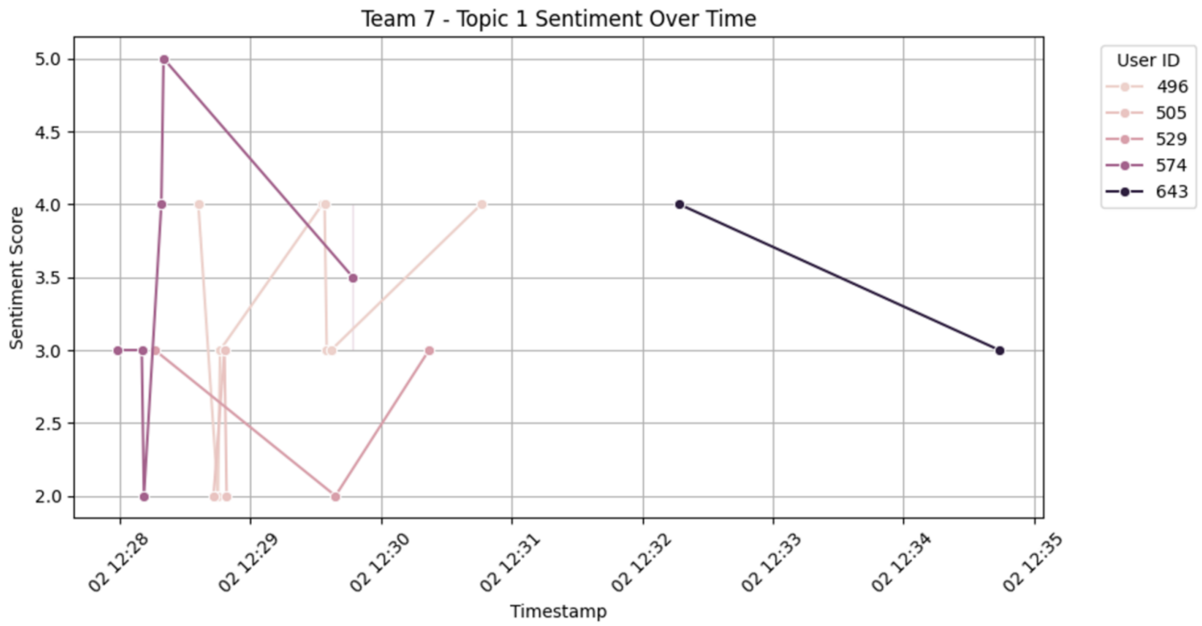


Figure 5-7. Example of a team adding multiple data points over a short period. This is explained by the students exploring the interface during topic 1. There is also indication of negative and positive accommodation taking place with two students re-evaluating up and two re-evaluating down.

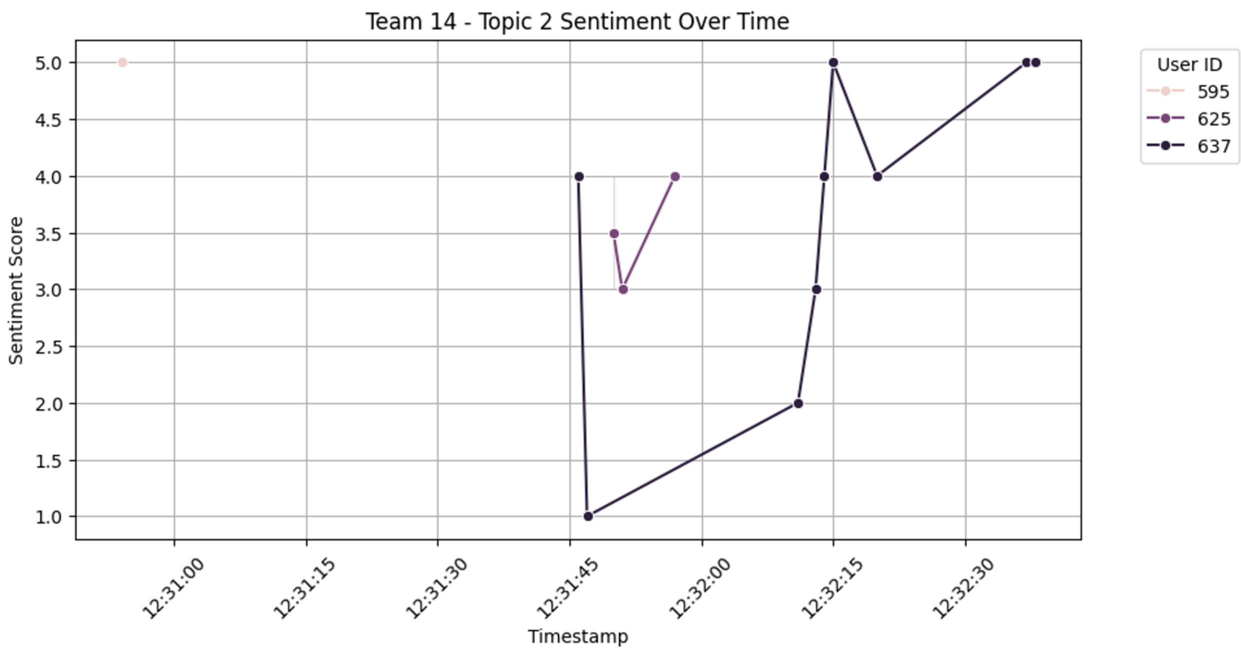


Figure 5-8. Example of time series student sentiment scores as potential indicator of positive mutual accommodation for two of three students in this team.

5.4.4.3 Distributed cognition, heuristic 3 (dc3).

ID	Heuristic	Design Rule Response(s)	Cross Reference	Focus Session Question(s)
dc3	(Consider) The impact of set and setting (ecosystem) on the process taking place.	A mobile first design.	th5	th5

Table 5-28. Heuristic dc3 overview.

Heuristic dc3 (table 5-40) considers the impact of set and setting (ecosystem) on the process taking place. Our preparation for focus session design identified this as overlapping with heuristic th5 ("consider the environmental context") and both items were therefore addressed together during the focus sessions. Although CHARM-EU students generally have the same or similar experiences of conducting their work, we could not hope to anticipate all possible working environments where our students might connect with their teams. For this reason, we chose to address this heuristic with the design rule of adopting a mobile first design in our exemplar artefact. Unfortunately, our focus session participants all worked with laptops and therefore did not have different technology experiences during the intervention. However, we noted that some of our co-located students reported an example of a peer that did use a mobile phone for data input but also looked in on a teammates larger screen during the discussion part of the activity. The convenience of a nearby large screen is an obvious attraction and perhaps unsurprising that the student in question chose to look at it, although it is encouraging to note that they did manage to interact well using their mobile phone for the inputs. Convenient access to a peer's screen represents a subtle body support that extended the horizon of observation for the student in question. It would be wrong however to expect all distributed learners to be able to access such facilities in all situations and a mobile first design approach is recognized as the best solution for the wide variety of computing devices currently in use.

5.4.4.4 *Distributed cognition, heuristic 4 (dc4).*

Tables 5-41 to5-43 detail our analysis of heuristic dc4.

ID	Heuristic	Design Rule Response(s)	Cross Reference(s)	Focus Session Question(s)
dc4	Cognitive process is delimited by the functional relationships among the members	Include live feedback on user defined topics to support asynchronous roles	None	Did you discuss the task together? How did you interact when using it? Did you all use it the same way at the same time?

Table 5-29. Heuristic dc4 overview.

Case	Related deductive codes	Related inductive codes
Case 1 (Capstone Focus Session 1)	**Clarity of process**, **Naturalness principle**, Threshold to usability, **Work practices**.	Hybrid teamwork challenge, Informal collaboration.
Case 2 (Capstone Focus Session 2)	**Clarity of intent**, Horizon of observation, Instructions and guidance, **Naturalness principle**, Onboarding of a tool, Space and cognition, Threshold to usability, Tool design issues, **Working in multiple contexts**.	Communication, Hybrid teamwork challenge, Informal collaboration.
Case 3 (Capstone Focus Session 3)	**Giving and receiving feedback**, Social-protocols, **Task management, Work practices**.	Collaboration, Informal collaboration, Team process development, Team roles.
Case 4 (Phase 1 Interview 1)	**Developing shared mental models, Giving and receiving feedback**, **Mental representations**, **Situation awareness**, Space and cognition, Timely feedback.	Communication, Informal collaboration, Mutual accommodation, Reflection, Team process development, Teamwork scaffolds.
Case 5 (Phase 1 Interview 2)	**Giving and receiving feedback**.	Informal collaboration.
Case 6 (Phase 1 Focus session 1)	**Developing shared mental models**, **Giving and receiving feedback**, **Mental representations**, **Naturalness principle, Situation**	Communication, Mutual accommodation, Reflection, Collaboration, Hybrid teamwork challenge, Project priorities, Team process

	awareness, Threshold to usability, Usefulness of tools, **Clarity of process**, Perceptual principle, Social-protocols, Space and cognition, Tool design issues, Tool interaction, Tool usage patterns, **Work practices**, Working in multiple contexts.	development, Team roles, Team values, Teamwork scaffolds.

Table 5-30. Heuristic dc4 codes and themes.

AODM Analysis

Step	Definition	Details
Activity of Interest	(what sort of activity are we interested in?)	To address this heuristic, we included live feedback for user defined topics to support asynchronous roles.
Objective	(why is the activity taking place?)	Although CHARM-EU students do not have mandated team roles, they frequently develop work patterns that favour a division of labour. The objective is to support asynchronous roles.
Subjects	(who is involved in carrying out the activity?)	First semester students, Capstone students, CHARM-EU teaching staff, The researchers.
Tools	(by what means are the subjects carrying out this activity?)	In app live feedback of each team members sentiments per topic.
Rules and Regulations	(are there any cultural norms, rules or regulations governing the performance of this activity?)	No additional rules were introduced, and teams were asked to conduct their session as they would normally do for any team meeting.
Division of Labour	(who is responsible for what, when carrying out this activity and how are the roles organised?)	The division of labour was not mandated but we expected some individuals to be more engaged than others. Flexibly supporting role adoption was essential, since we could not

		determine in advance who would display leadership.
Community	(what is the environment in what the activity is carried out?)	Hybrid sessions (n=2) and Co-located session (n=1)
Outcome	(what is the desired outcome from carrying out this activity?)	An idealised outcome would be based on teams that have asynchronous roles. Our student teams displayed limited division of labour in their team discussions but did report that the open nature of the activity design and exemplar artefact facilitated their workflow.

Table 5-31. Heuristic dc4 AODM summary.

AODM discussion of findings (heuristic dc4)

Heuristic dc4 is informed by Hutchin's (1965) view that cognitive processes within a team are delimited by the functional relationships among the team members and the corresponding **activity of interest** is to explore this through student's attitudes to roles in hybrid teamwork. This represented a challenge in our design as our cohort are not required to adopt specific team roles. In fact, CHARM-EU students typically swap or rotate administrative roles or display distributed leadership in their approach to their teamwork. The **objective** was to address this view with a design rule that could support maximum flexibility in team roles while working with the tool. The most sensible approach was to ensure that all members could access the same information so that teams could determine their own approach. Our exemplar artefact **tool** included live feedback on both a default set and user defined set of topics to support asynchronous roles. Since the feedback and ability to add topics were equally available to all team members, this gave teams the necessary degree of flexibility for any individuals in the team to manage the topics list and the activity instruction **rules** emphasised this approach. To investigate this, we asked our focus session participants if they had discussed the task together and probed deeper by inquiring if all team members interacted in the same way. In most cases (n=5), team members reported sharing the **division of labour** with at least two members adding topics. We observed from our topics data that for one team, only a single individual added the topics. It is unclear if these topics were discussed with the team or added independently by the individual. This could be explained by the student displaying leadership but may also indicate an informal administrative role where the student recorded their teammates suggestions, although we did not receive consent from this student to investigate their motivation. **Community** was not noted as a contributing factor in our data.

The **outcome** for this heuristic is mixed. Formal roles were not mentioned although a scribe was alluded to when referencing note taking and there is indication of distributed leadership from students. Some teams discussed their approach before beginning while others jumped straight into the activity. Students liked the live feedback and the fact that any team member could add topics. Several did use the tool in a different way by adopting a note taker role, although other teams shared the task equally and uniformly adopted this role. The tool was able to scaffold flexible roles, which in turn formatted the team's discussion and considered thusly the design rule implementation of heuristic dc4 was successful. However, the lack of formal roles in CHARM-EU teams makes further investigation of the cogitative operation and delineation of asynchronous team roles difficult, which imposes a limit on our analysis of heuristic dc4.

5.4.5 Distributed cognition of teams heuristics (DiCoT)

Blandford and Furniss's DiCoT theory is informed by Hutchins views, and we have presented our DiCoT heuristics using the same "dc" code to indicate this relationship. Webb's additions are treated similarly.

Blandford & Furniss, (2006) and later Webb, (2008) developed the Distributed Cognition of Teams theory which presents a set of principles for supporting distributed teams. The first ten of these are sourced from the original conceptualization of DiCoT by Blandford & Furniss, (ibid). Webb (ibid) extended the theory to highlight the need of considering the development of practice and development of practitioners when supporting distribute teams. We did not explicitly investigate the practice and practitioners' principles in focus session as our study did not include longitudinal data, however we informally covered these concepts in our general discussions with students. We therefore included ten of the DiCoT principles in our collection, which represent each of the three categories of Blandford and Furniss's principles of Physical layout, Information Flow and Artefact models, while noting any comments regarding students' attitudes to their professional and team development to address Webb's additions.

- Physical Layout: Space and Cognition
- Physical Layout: Subtle Bodily Supports
- Physical Layout: Situation Awareness
- Information flow: Buffering
- Artefacts: Representation – Goal Parity
- Artefacts: Coordination of Resources

The original full set and our rationale for selection are described in our literature review, (section 2.2.3, Distributed Cognition). The remainder of this section describes the subset of the DiCoT principles that were examined in our focus sessions.

5.4.5.1 Distributed cognition of teams, heuristic 1 (dc5)

Both DCog and DiCoT subsets of our heuristics represent our Distribute Team Cognition category. The first DiCoT principle to receive a detail analysis is covered by tables 5-44 to 5-46.

ID	**Heuristic**	**Design Rule Response(s)**	**Cross Reference(s)**	**Focus Session Question(s)**
dc5	Physical Layout: Space and Cognition	PLOs as the first items "above the fold"	None	How did working with the PLOs first contribute to being able to have your challenges discussion?

Table 5-32. Heuristic dc5 overview.

Case	**Related deductive codes**	**Related inductive codes**
Case 1 (Capstone Focus Session 1)	**Clarity of process, Ease of use, Naturalness principle**, Onboarding of a tool**, Suitability of tools to tasks**, Tool design issues, Developing shared mental models, Effort to change.	Project priorities, Team values.
Case 2 (Capstone Focus Session 2)	**Display of textual information**, Evolving requirements, Mental representations, Naturalness principle, **Situation awareness**, Suitability of tools to tasks, Usefulness of tools, Effort to keep changing, Timely feedback.	Project priorities.
Case 3 (Capstone Focus Session 3)	Appropriateness of abstractions, **Display of textual information**, **Evolving requirements**, **Threshold to usability**, Timely feedback, Tool design issues.	Project priorities.
Case 4 (Phase 1 Interview 1)	Clarity of intent, **Suitability of tools to tasks**, Timely feedback, Usefulness of tools, Situation awareness.	Hybrid teamwork challenge, Communication, Informal collaboration.
Case 5 (Phase 1 Interview 2)	Clarity of process, Instructions and guidance, **Naturalness principle**, Onboarding of a tool, **Space and cognition**.	Project priorities, Team process development, Teamwork scaffolds.
Case 6 (Phase 1 Focus session 1)	**Arrangement of equipment**, Clarity of process, Consequences of tool use,	Project priorities, Reflection, Teamwork scaffolds.

	Developing shared mental models, **External factor impact,** Mental representations, **Situation awareness**, **Suitability of tools to tasks**, Usefulness of tools, Giving and receiving feedback, Onboarding of a tool, Use of tool features.	

Table 5-33. Heuristic dc5 codes and themes.

AODM Analysis

Step	Definition	Details
Activity of Interest	(what sort of activity are we interested in?)	Scaffolding the main activity with example content.
Objective	(why is the activity taking place?)	Students were asked to review their programme learning outcomes as introductory content for using the tool prior to their own team challenge discussion.
Subjects	(who is involved in carrying out the activity?)	First semester students, Capstone students, CHARM-EU teaching staff, The researchers.
Tools	(by what means are the subjects carrying out this activity?)	Using the tool to share sentiment values for each of the known PLOs before working with their own challenge topics.
Rules and Regulations	(are there any cultural norms, rules or regulations governing the performance of this activity?)	Students were asked to work with the PLOs first before moving onto their own topics.
Division of Labour	(who is responsible for what, when carrying out this activity and how are the roles organised?)	Most teams adopted an informal round-robin approach to sharing with some reports of more vocal students encouraging others in some teams. No formal division of labour was required.
Community	(what is the environment in what the activity is carried out?)	Hybrid sessions (n=2) and Co-located session (n=1)
Outcome	(what is the desired outcome from carrying out this activity?)	All students reported having difficulty with the PLOs due to their Multi-dimensional nature, which made it difficult to assign a single value. Capstone students valued the PLO discussion less than semester 1 students. However, encountering and working with the PLOs first was seen as an effective scaffold for the bespoke discussions by most of the participants we asked.

Table 5-34. Heuristic dc5 AODM summary.

AODM discussion of findings (heuristic dc5)

Blandford and Furniss (2006) reason that the physical layout of a team's environment influences their work. They refer to this as the Space and Cognition principle. The authors earlier studies focus on the arrangement of physical equipment within multiuser environments. Since our heuristics aim to support hybrid teamwork, heuristic dc5's **activity of interest** focuses on arrangement of the information architecture and on-screen elements of the tool rather than physical equipment, although feedback relating to student's arrangement of equipment was also considered relevant. We received feedback relating to physical device usage when questioning students about other aspects of their experience and students mentioned leaning-in and getting a better view to improve their horizon of observation, and consequently their situational awareness, clarity of process and clarity of intent. The analysis **outcome** showed that different working modes and **divisions of labour** were employed. One team confirmed that they did every step together, while other worked individually before coming together as a group during the session. We received little feedback on this point in the context of our dc5 question responses, but related clarifying comments were offered at other points during the sessions.

"[a team member] looking at their screen and us going through the […] questions"

"everybody was looking at their own screen but sort of down and going [… name …] why did you put this? And then we'd all look up immediately."

"Two people from the same laptop"

This feedback shows that students needed to make subtle body support changes during the sessions by extending their horizon of observation to improve situational awareness. Our focus in heuristic dc5 however relates more to improved clarity of process arising from the arrangement of the programme learning outcomes "above the fold". Our **objective** was to scaffold the process of team topic discussions by introducing this material on the first page of the tool where students would not need to scroll to see the prescribed content. Our only guidance (**rule**) given to the teams was to work with the PLO items first before moving onto their own list of challenges.

First semester students, who were less well acquainted with the programme learning outcomes, valued seeing them at the top of the discussion topics list.

"good practice also for what was following"

"I think it was nice to have them at the beginning"

Our capstone students valued the PLO's less, since they felt that they already understood them well.

"a little bit sick of hearing it."

With our capstone students, the question of whether working with the PLOs in the tool acted to scaffold their discussion is less obvious. Some focus session participants became fixated on issues with the PLO's themselves rather than reflecting on how they scaffolded the activity process.

"the PLOS descriptions were kind of complicated"

"PLOS in general, I guess every time we have to use them, we face that clarity issue"

The feedback shows that our participants struggled with our implementation of this heuristic, giving the reasons that each of the CHARM-EU PLO's contains multiple concepts, which frustrated efforts to assign each an individual sentiment score. This represents a design challenge regarding the stability of the tool to the tasks, and in hindsight a more simplistic introductory topic may have been helpful. Regardless of struggles with the content, the process was well received and many students found beginning with recognised content to be a helpful scaffold. Our evaluation of the implementation of heuristic dc5 is that it stimulated good team discussions and likely supported students in being able to conduct their own topics discussions, which aligns with the goals of the heuristic, however the content itself was problematic. It is unclear from student's feedback whether the arrangement of the PLO's or merely the introduction of recognised content had more of an effect on the outcome. While either case could be interpreted through a space and cognition argument, further work is required for deeper insights.

5.4.5.2 Distributed cognition of teams, heuristic 2 (dc6)

ID	Heuristic	Design Rule Response(s)	Cross Reference(s)	Focus Session Question(s)
dc6	Physical Layout: Subtle Bodily Supports	Mobile first design	th5	th5

Table 5-35. Heuristic dc6 overview.

We did not ask participants specifically about heuristic dc6 (table 5-47) due to the conceptual overlap with heuristic th5 and relevance to the PLO positioning and screen information architecture in dc5. With no direct feedback to code, we do not include codes and themes here but offer an overview discussion below (table 5-48) that is based on general feedback from our focus session students relating to their subtle body supports.

AODM Analysis

Step	Definition	Details
Activity of Interest	(what sort of activity are we interested in?)	An investigation of how students used the tool, in terms of their physical interactions.
Objective	(why is the activity taking place?)	Subtle body supports are considered an indication of distributed cognition, for example, pointing at an item on list to keep track while discussing it.
Subjects	(who is involved in carrying out the activity?)	First semester students, Capstone students, CHARM-EU teaching staff, The researchers.
Tools	(by what means are the subjects carrying out this activity?)	Subtle body supports are individualistic and sometimes unique to each person. A mobile first design offered the most flexible interface for such unexpected usage patterns.
Rules and Regulations	(are there any cultural norms, rules or regulations governing the performance of this activity?)	We asked students to use their own devices.
Division of Labour	(who is responsible for what, when carrying out this activity and how are the roles organised?)	Some evidence of asynchronous usage was reported, but most students used the same approach to interact with the tool.
Community	(what is the environment in what the activity is carried out?)	Hybrid sessions (n=2) and Co-located session (n=1)
Outcome	(what is the desired outcome from carrying out this activity?)	There is evidence of individuals leaning into peers screens for a better view which suggests a subtle body support used to facilitate cognition.

Table 5-36. Heuristic dc6 AODM summary.

Overview discussion (heuristic dc6)

This heuristic addresses the tendency of people to use their body to help with thinking. Obvious examples of this include counting on one's fingers and pointing. Our aim in examining this heuristic was to investigate how our students used the tool in terms of their physical interactions with their devices and teammates during the activity. There is a thematic overlap with heuristic th5 from our teamwork set and since subtle body supports can be unique to an individual's behaviour, we felt it best to look for mentions of such behaviour in our focus session rather than attempt to include design rules and questions specifically for an unknown quantum. Our design response was therefore to aim for maximum flexibility in how and where students could use our tool. To this end, we chose to build the tool using a mobile first design for our interface.

Our focus sessions found limited extensive evidence of students adopting subtle body supports however a few instances are worth noting. During our first instance of the intervention, the database connection for the tool failed which meant that most students could not complete the activity. However, one focus session participant mentioned that some members of their team had already loaded the page before the failure occurred and that they were able to conduct a group discussion by sharing screens or showing their devices to their peers. This facilitated a group cognition during the discussion topics, but it is difficult to claim that this is an individual's subtle body support that contributed to their own cognition, since their actions were conducted for the benefit of teammates rather than themselves. The database issue was resolved for the subsequent sessions and our feedback on these sessions contains some clearer examples. The first of these relates to an indirect report of a team member who added their sentiments using a mobile phone before leaning into their peer's screen for the discussion part of the activity. This conscious action extended the horizon of observation of the student to improve their situation awareness. We also gathered several reports of students looking up from their devices towards their co-located teammates when uncertainties arose, which represents good evidence of a subtle body support aiding in social cognition and group clarity of process.

5.4.5.3 Distributed cognition of teams, heuristic 3 (dc7)

Our analysis of heuristic dc7 is detailed over tables 5-49 to 5-51.

ID	Heuristic	Design Rule Response(s)	Cross Reference(s)	Focus Session Question(s)
dc7	Physical Layout: Situation Awareness	Scaffolded discussion topics: PLOs and learner defined team topic discussions as part of the intervention design.	None	How did the activity and tool structure help you to understand the aims of the discussion (i.e. to recognise and begin to conceptualise your team challenges)

Table 5-37. Heuristic dc7 overview.

Case	Related deductive codes	Related inductive codes
Case 1 (Capstone Focus Session 1)	Evolving requirements, **Giving and receiving feedback, Naturalness principle**, **Timely feedback**.	Hybrid teamwork challenge, Team health, Suggested improvement.
Case 2 (Capstone Focus Session 2)	**Display of textual information**, Evolving requirements, Mental representations, **Naturalness principle, Situation awareness**, Suitability of tools to tasks, Usefulness of tools, Effort to keep changing, **Timely feedback**.	Project priorities.
Case 3 (Capstone Focus Session 3)	Instructions and guidance, **Timely feedback**.	Reflection, Suggested improvement.
Case 4 (Phase 1 Interview 1)	Suitability of tools to tasks, Usefulness of tools, Work practices.	Collaboration, Team process development, Teamwork scaffolds.
Case 5 (Phase 1 Interview 2)	**Clarity of process**, Developing shared mental models, **Giving and receiving feedback**, Mental representations, **Situation awareness**, Suitability of tools to tasks, **Timely feedback**, Usefulness of tools.	Communication, Hybrid teamwork challenge, Reflection, Team health, Teamwork scaffolds.
Case 6 (Phase 1 Focus session 1)	**Clarity of intent, Clarity of process**, Instructions and guidance, Suitability of tools to tasks.	Teamwork scaffolds.

Table 5-38. Heuristic dc7 codes and themes.

AODM Analysis

Step	Definition	Details
Activity of Interest	(what sort of activity are we interested in?)	PLO topics are presented at the top of the interface to scaffold teams in adding their own discussion topics in the later part of the activity. This introduces the interface mechanic via recognised content.
Objective	(why is the activity taking place?)	To support students understanding of the discussion aims (i.e. to recognise and begin to conceptualise their team challenges), they should add and discuss their own challenges.
Subjects	(who is involved in carrying out the activity?)	First semester students, Capstone students, CHARM-EU teaching staff, The researchers.

Tools	(by what means are the subjects carrying out this activity?)	Our exemplar tool included the CHARM-EU programme learning outcomes as the first set of topics to discuss, to introduce the usage to students through a familiar context.
Rules and Regulations	(are there any cultural norms, rules or regulations governing the performance of this activity?)	No additional rules were included for this heuristic.
Division of Labour	(who is responsible for what, when carrying out this activity and how are the roles organised?)	No formal division of labour required. Feedback indicates a mixture of informal and round robin style engagement during the discussion.
Community	(what is the environment in what the activity is carried out?)	Hybrid sessions (n=2) and Co-located session (n=1)
Outcome	(what is the desired outcome from carrying out this activity?)	Positioning the PLOs at the top of the screen was not seen as helpful for being able to add teams' own challenges although encountering these topics first helped to setup students to undertake the activity and they reported that their resulting discussions helped them to think about their project scope and aims.

Table 5-39. Heuristic dc7 AODM summary.

AODM discussion of findings (heuristic dc7)

Heuristic dc7's **activity of interest** aligns with the **objective** to support the building of situation awareness within a team by scaffolding their challenge discussions. The CHARM-EU PLOs are displayed first as recognizable discussion topics in the **tool** to introduce the interface mechanic to students (**subjects**) and this structure establishes how the discussion should proceed for the later bespoke team topics. Setting up a discussion format in advance of the team topics discussions provides a discussion template for the challenges topics and reduces uncertainty about the activity goals by establishing process **rules**. For an expansion of team learning to be possible, the team must reflect on these topics and try to find solutions, and an exploration of the perceived challenges can stimulate such an expansion.

Our design response implementation is to introduce the activity process through recognised content (i.e the CHARM-EU PLOs). This anchors the discussion and adds scaffolding structure to how the teams should work through their own challenge topics. We did not introduce any additional rules for this heuristic and teams reported an informal **division of labour** when conducting the activity. Our **outcomes** were mixed as most participants reported that encountering the PLOs first was helpful for understanding how to complete the activity and they agreed that it promoted reflection regarding competencies and opened up discussion topics that they had so far ignored, however as we have noted in our discussion of the space and cognition heuristic (dc 5), capstone students reported an over exposure to the PLOs. The following semester 1 student quotes illustrate positive outcomes.

"…helped us define our roles and what we're comfortable doing"

"We definitely had discussions that we'd never had before"

When we enquired whether students had considered how team resources would influence their projects, one focus participant told us that they did not expect a connection between the activity intervention and the issue of how the team should think about their work, and therefore did not ask themselves about how their skills would influence the project. This individual suggested that explicit instructions and additional time for this point would help to clarify the connection that they needed to make. We note that this was one of our capstone teams who had been working together from one month at the time of the activity and had already developed some of their own team processes, therefore a perceived effort to restart project work may have influenced their discussion in this regard. Capstone students indicated that they believed that the timing of the activity would be more useful at an earlier stage in their projects. The observed differences between cohorts are interesting and likely to be explained by the fact that the first semester students' teams were newer and therefore primed to think about how they should interact, whereas the capstone teams had already started their process development and were beginning to settle into working together. In summary, the feedback for this heuristic is that for most teams encountering the PLOs first, did contribute to team situation awareness by scaffolding the team challenge topic discussions. Students raised questions during their discussions concerning how their team skills might be used to address the PLOs and began to assess their team resources in this regard. However, this improved situation awareness did not contribute to process development insights for every team as noted by one team not continuing their discussion to cover this aspect of their teamwork.

5.4.5.4 Distributed cognition of teams, heuristic 4 (dc8)

Our analysis of heuristic dc8 is detailed in tables 5-52 to5-54.

ID	Heuristic	Design Rule Response(s)	Cross Reference(s)	Focus Session Question(s)
dc8	Information flow: Buffering	User added topics enable discussion topic queues.	None	Did topics get queued? How did you manage the queue?

Table 5-40. Heuristic dc8 overview.

Case	Related deductive codes	Related inductive codes
Case 1 (Capstone Focus Session 1)	Team did not add topics.	Team did not add topics.
Case 2 (Capstone Focus Session 2)	**Developing shared mental models, Giving and receiving feedback**, Naturalness principle, Social-protocols, Mental representations, **Situation awareness**.	Informal collaboration.
Case 3 (Capstone Focus Session 3)	**Suitability of tools to tasks**, Work practices.	Reflection.
Case 4 (Phase 1 Interview 1)	Fluency with a tool, Onboarding of a tool, Tool interactions.	Hybrid teamwork challenge, Suggested improvement.
Case 5 (Phase 1 Interview 2)	Fluency with tools, Naturalness principle, Social-protocols, Tool interaction, Tool usage patterns, Use of tool features, Work practices, **Developing shared mental models**, Display of textual information, **Space and cognition**, Threshold to usability.	Inclusion, Informal collaboration, Team health, Team roles, Team values.
Case 6 (Phase 1 Focus session 1)	Only one topic added.	Only one topic added.

Table 5-41. Heuristic dc8 codes and themes.

AODM Analysis

Step	Definition	Details
Activity of Interest	(what sort of activity are we interested in?)	Managing the discussion flow while including challenge suggestions from all team members.

Objective	(why is the activity taking place?)	Support team cognition and the challenge discussion flow while avoiding cognitive overload
Subjects	(who is involved in carrying out the activity?)	First semester students, Capstone students, CHARM-EU teaching staff, The researchers.
Tools	(by what means are the subjects carrying out this activity?)	The exemplar artefact, team topics list.
Rules and Regulations	(are there any cultural norms, rules or regulations governing the performance of this activity?)	Students were asked to add topics in the tool as needed.
Division of Labour	(who is responsible for what, when carrying out this activity and how are the roles organised?)	Feedback indicates a round robin approach to the discussion and adding of topics, although secondary data indicates only a small number of individuals actually added topics for their team.
Community	(what is the environment in what the activity is carried out?)	Hybrid sessions (n=2) and Co-located session (n=1)
Outcome	(what is the desired outcome from carrying out this activity?)	Evidence that the topics helped to scaffold the team in discussing their most critical challenges while also keeping track of less pressing items.

Table 5-42. Heuristic dc8 AODM summary.

AODM discussion of findings (heuristic dc8)

The **activity of interest** for heuristic dc8 (Information flow: Buffering) is to support the team discussion by allowing students to self-manage the flow of their topic discussions. Controlling this flow is essential to manage cognitive overload in an environment where every team member can submit an unlimited number of topics. The **object** therefore is for the team to address the issues that they feel are important, without losing track of less pressing items. Our design response for dc8 is the inclusion of a team topic list to which any team member may add items, so as to provide a transactive memory system for the teams' challenge topics. Our instruction **rules** for this heuristic were for participants to freely add challenge topics that they felt were important to their projects. Concerning **outcomes**, the feedback is limited for this heuristic since not all teams managed to work on their own discussion topics. Of our focus session sets, one team did not add topics at all and a second added only one topic. However, the feedback from the other four sessions is substantial and we can see that once again the teams mentioned a free flow approach to adding topics with an informal round robin **division of labour** regarding topic discussions. The focus session participants reported that they could add topics freely, however, of the teams that did add topics, quantitative data from the database shows that this was limited to one or two team members rather than the full team as our participants had indicated. All teams were able to manage their discussion flow smoothly. Our feedback from students regarding the custom topics is overwhelmingly positive and reasons given align well with our expectations from theory. However, our expectations were concerned with the improved team efficency that greater flow control would bring, so we were happy to receive some positive and unexpected feedback from one participant who described using the topics as an informal way of monitoring team health and improving inclusion by directly engaging every team member on topics that might not otherwise be raised. The participant recognized the benefit to team health by exploring team values in this way. The overall **outcome** for the heuristic is that the discussion flow control was supported by the intervention and valued by participants.

5.4.5.5 Distributed cognition of teams, heuristic 5 (dc9)

Table 5-55 details heuristic dc9 and our analysis is described in tables 5-56 and 5-57.

ID	Heuristic	Design Rule Response(s)	Cross Reference(s)	Focus Session Question(s)
dc9	Artefacts: Representation – Goal Parity	Custom topics are intended to address the project goals.	Some alignment with tmm1 but discussed independently here.	In what ways were your team clearer about your team project and teamwork goals following the activity?

Table 5-43. Heuristic dc9 overview.

Case	Related deductive codes	Related inductive codes
Case 1 (Capstone Focus Session 1)	**Timely feedback**, Threshold to usability.	Suggested improvement.
Case 2 (Capstone Focus Session 2)	**Evolving requirements, situation awareness**, Work practices.	Collaboration, Hybrid teamwork challenge, Project priorities, Team process development, Teamwork scaffolds.
Case 3 (Capstone Focus Session 3)	MISSED QUESTION*	MISSED QUESTION*
Case 4 (Phase 1 Interview 1)	**Clarity of process**, Social-protocols, Work practices.	Inclusion, Team health, Team process development, Teamwork scaffolds.
Case 5 (Phase 1 Interview 2)	**Developing shared mental models, Giving and receiving feedback**, Perceptual principle,	Team roles, Team process development, Team values, Teamwork scaffolds.

	Situation awareness, Social-protocols, **Timely feedback**, Work practices.	
Case 6 (Phase 1 Focus session 1)	**Situation awareness**.	Team health.

*Table 5-44. Heuristic dc9 codes and themes. *Note, this question was not asked of capstone group 3 due to a methodological oversight by the researcher.*

AODM Analysis

Step	Definition	Details
Activity of Interest	(what sort of activity are we interested in?)	Clarifying goal parity for team members
Objective	(why is the activity taking place?)	Recognising the team challenges and competencies will inform team members regarding their capacity to tackle specific issues. Establishing goal parity aligns the team's shared mental model.
Subjects	(who is involved in carrying out the activity?)	First semester students, Capstone students, CHARM-EU teaching staff, The researchers.
Tools	(by what means are the subjects carrying out this activity?)	User defined topics and the discussion process.
Rules and Regulations	(are there any cultural norms, rules or regulations governing the performance of this activity?)	All students were encouraged to add topics.
Division of Labour	(who is responsible for what, when carrying out this activity and how are the roles organised?)	Informal and round robin approaches were reported by students.
Community	(what is the environment in what the activity is carried out?)	Hybrid sessions (n=2) and Co-located session (n=1)
Outcome	(what is the desired outcome from carrying out this activity?)	Student reported having a better shared understanding of their project goals following the activity, which supports this heuristic.

Table 5-45. heuristic dc9 AODM summary.

AODM discussion of findings (heuristic dc9)

Heuristic dc9's **activity of interest** relates to clarifying goal parity for team members,. While the entire exemplar tool may be seen as a design response to this, we specifically expected the custom topics discussions to support this requirement by allowing students to raise items that they considered to be teamwork challenges in their own projects. The **objective** is therefore intended to help student recognise an "explicit representation of the relationship" (Blandford and Furniss, 2006) between the current state and a goal state of their transdisciplinary team project work. The optimal goal state is a successful transdisciplinary synthesis that makes full use of team competencies, and our design supports this with recognition of student voice and agency in defining the challenges needed to be overcome in achieving their specific, and perhaps unique goal state. Our feedback for this heuristic comes from five of the six sessions, as the question was not asked of the **subjects** in case three due to a methodological oversight. As no specific instruction was given for this item, there are no additional **rules**, and no obvious **division of labour** was reported. Concerning **outcomes**, the feedback was limited as most participants considered that they had already answered the question during responses to earlier heuristics. Our capstone students in case 1 reminded us that the timing of their intervention was somewhat late to help inform them about teamwork goals. Our first semester cases all reiterated that the activity had improved their situation awareness, helped them to establish team interaction social-protocols regarding how their skillsets might interact and to develop expectations about their project work. Students in case six felt that they had covered the topic well and had little extra to add for the question response, mentioning only that the activity alleviated potential conflict and that the team members had a clearer view of how their team could work together following the session.

5.4.5.6 Distributed cognition of teams, heuristic 6 (dc10)

Analysis of heuristic dc10 is covered in tables 5-58 to 5-60.

ID	Heuristic	Design Rule Response(s)	Cross Reference(s)	Focus Session Question(s)
dc10	Artefacts: Coordination of Resources	The structured discussion process informs the team regarding each members competencies and task interest.	None	What aspects of planning did you discuss? How did the activity and tool support that discussion?

Table 5-46. Heuristic dc10 overview.

Case	Related deductive codes	Related inductive codes
Case 1 (Capstone Focus Session 1)	Ease of use, **Effort to change**, **Methodologies**, **Suitability of tools to tasks**, **Threshold to usability**.	Collaboration.

Case 2 (Capstone Focus Session 2)	**Evolving requirements, Situation awareness**, Work practices.	Collaboration, Hybrid teamwork challenge, Project priorities, Teamwork scaffolds, Team roles.
Case 3 (Capstone Focus Session 3)	Planning was not discussed by the team.	Planning was not discussed by the team.
Case 4 (Phase 1 Interview 1)	**Clarity of process**, Social-protocols, Work practices.	Inclusion, Team health, Team process development, Teamwork scaffolds.
Case 5 (Phase 1 Interview 2)	**Clarity of intent, Developing shared mental models, Giving and receiving feedback.**	Communication, Team process development.
Case 6 (Phase 1 Focus session 1)	Planning was not discussed by the team.	Planning was not discussed by the team.

Table 5-47. Heuristic dc10 codes and themes.

AODM Analysis

Step	Definition	Details
Activity of Interest	(what sort of activity are we interested in?)	Supporting teams understanding of available resources.
Objective	(why is the activity taking place?)	Build a better understanding of the team capabilities to support project planning.
Subjects	(who is involved in carrying out the activity?)	First semester students, Capstone students, CHARM-EU teaching staff, The researchers.
Tools	(by what means are the subjects carrying out this activity?)	Team members are encouraged to discuss ways to overcome challenges that they see in the default topics and user added topics.
Rules and Regulations	(are there any cultural norms, rules or regulations governing the performance of this activity?)	No specific rules were mentioned to students for this heuristic.
Division of Labour	(who is responsible for what, when carrying out this activity and how are the roles organised?)	No specific division of labour was reported, except for in case 1 where a team member already had project management experience and lead the planning efforts by introducing a tool of their own.
Community	(what is the environment in what the activity is carried out?)	Hybrid sessions (n=2) and Co-located session (n=1)
Outcome	(what is the desired outcome from carrying out this activity?)	Mixed feedback as two teams in our sample did not discuss planning. Those teams that did develop their thoughts about team resources all mentioned benefiting from improved situation awareness.

Table 5-48. Heuristic dc10 AODM summary.

AODM discussion of findings (heuristic dc10)

The **activity of interest** regarding our final heuristic from Blandford and Furniss focuses on artefacts that support the coordination of resources within a team. These cover a wide range of solutions such as information hubs, lists, ledgers or any other record of resources available to a team. The challenge for our students was based on developing their transdisciplinary synthesis approach and as such, the set of resources here includes the skill mix within the team. Disclosing and considering these skills with peers is the first step to coordinating their application. As our intervention was not longitudinal, we were not able to work with our students to develop a full project plan however we reasoned that student's ability to plan their projects would benefit considerably from these insights. The **objective** of heuristic dc10 is therefore to raise the team awareness regarding their available resources (i.e. skills) and to introduce the idea of capacity planning based on these resources. No specific **rules** were introduced for this heuristic beyond the intervention instructions. Most teams did not report any specific **division of labour** regarding planning. A student in case 1 mentioned that they did not discuss planning at all, since their team had already spent some time working on planning thanks to a team member having some prior project management experience and a preference for a specific third-party planning tool. This individual displayed an example of distributed leadership by introducing the tool to their team. We may interpret this as a tertiary contradiction between an earlier activity system and our intervention. Although these systems do not share a goal, a tension is still apparent from the student's preference.

An example of an ideal **outcome** for heuristic dc10 is for a team to uncover tacit skills in their group and to consider ways to incorporate these into their projects. Since two of our six focus sessions reported no project planning aspect to their teams' discussions, and one had already adopted a planning tool, data for dc10 is limited. Students in the remaining three focus sessions did not specifically discuss their available resources planning during the team discussions but did discuss aspects of planning relating to clarity of process and clarity of intent, as well as the development of shared mental models and teamwork practices.

5.4.5.7 Distributed cognition of teams, heuristics 7 & 8 (dc11 & dc12)

Detail of our heuristics based on Webb (2008) are include in table 5-61 and an overview AODM analysis is presented in table 5-62.

ID	Heuristic
dc11	Development of practice
dc12	Development of practitioners

Table 5-49. Heuristics dc11 & dc12 overview.

AODM Analysis

Step	Definition	Details
Activity of Interest	(what sort of activity are we interested in?)	Students views regarding their development of team practice and personal development as transdisciplinary practitioners.
Objective	(why is the activity taking place?)	To consider the complete set of heuristics may support students over a longer program.
Subjects	(who is involved in carrying out the activity?)	First semester students, Capstone students, CHARM-EU teaching staff, The researchers.
Tools	(by what means are the subjects carrying out this activity?)	Transdisciplinary Teamwork Tool and discussion scaffolds.
Rules and Regulations	(are there any cultural norms, rules or regulations governing the performance of this activity?)	No additional rules given or noted.
Division of Labour	(who is responsible for what, when carrying out this activity and how are the roles organised?)	Topic was not part of the intervention design so no specific duties were required.
Community	(what is the environment in what the activity is carried out?)	Hybrid sessions (n=2) and Co-located session (n=1)
Outcome	(what is the desired outcome from carrying out this activity?)	Students were conscious of the need for their ongoing skill development and improving team practices.

Table 5-50. Heuristic dc11 &c12 AODM summary.

AODM discussion of related feedback (heuristic dc11 and dc12)

Our final two heuristics in the DCog set are taken from Phillip Webb's (2008) additions to the DiCoT principles. Webb extended the theory to consider both the development of practice within a distributed cognitive system and the development of the practitioners within the system. These considerations address the improvement and steering of a distributed team cognition system over time, both in terms of its process improvement and of the skill development of its members. Our study did not include longitudinal data which makes a detailed investigation of these principles difficult in the current research. We would argue however that the development of practice and of practitioners is a fundamental goal of education, and as such it would be remiss to entirely ignore Webb's principles in our heuristics. We did not directly ask students about repeat interventions or ongoing use of the tool and therefore have scant data on their options in this regard. However, we did receive comments relating to recurring activity sessions by the team as a method to self-correct any drift regarding the team alignment of an accurate mental model. The participant goes on to mention a strategy for finding such assistance, indicating that our students are conscious of the need for ongoing self and team development.

"to see if we've progressed at all and then we can see what areas people want to focus on. And like E suggested, see who we can reach out to for needing support in a specific area"

5.5 Cycle 1 heuristics.

As the three heuristics from cycle 1 are thematically linked, we consolidated them into c1a and one corresponding focus session question (table 5-2). Table 5-3 describes the codes encountered in analysing the transcripts for this heuristic and table 5-4 illustrates the AODM analysis broken down into the eight-steps. This format has been used throughout this chapter for each of our heuristic vignette analyses.

ID	Heuristic	Design Rule Response(s)	Cross Reference(s)	Focus Session Question
c1a	Don't assume users will recognise UI controls	Include information from the instructor and in-app help info windows	None	What were your impressions of the instructions for the activity/app?
c1b	Our tool should provide detailed instructions	Include information from the instructor and in-app help info windows	c1a	c1a

c1c	XR onboarding is difficult for new users	Include information from the instructor and in-app help info windows	c1a	c1a

Table 5-51. Overview of cycle 1 derived heuristics.

Case	Related deductive codes	Related inductive codes
Case 1 (Capstone Focus Session 1)	Arrangement of equipment, Controllers and interface, Display of textual information, Ease of use, Instructions and guidance, Onboarding of a tool, **Situation Awareness**, Tool design issues, Use of tool features, **Threshold to usability**, **Clarity of process**.	Hybrid teamwork challenge, Inclusion.
Case 2 (Capstone Focus Session 2)	**Clarity of process**, Ease of use, **Onboarding of a tool**, Timely feedback, Tool design issues, Use of tool features.	Teamwork scaffolds.
Case 3 (Capstone Focus Session 3)	Instructions and guidance, Tool design issues, **Clarity of process**, **Onboarding of a tool**, **Tool usage patterns**.	Suggested improvement.
Case 4 (Phase 1 Interview 1)	**Clarity of intent**, Instructions and guidance, **Onboarding of a tool**.	None
Case 5 (Phase 1 Interview 2)	**Clarity of intent, Clarity of process**, Instructions and guidance, **Naturalness principle**, **Onboarding of a tool**, Timely feedback, Tool interactions, Working in multiple contexts.	Communication, Hybrid teamwork challenge, Teamwork scaffolds.
Case 6 (Phase 1 Focus Session 1)	Ease of use, Instructions and guidance, **Onboarding of a tool**, Tool interactions.	None

Table 5-52. Cycle 1, codes and themes.

AODM Analysis

Step	Definition	Details
Activity of Interest	(what sort of activity are we interested in?)	Examination of student’s views relating to the activity instructions and in-app help.
Objective	(why is the activity taking place?)	Cycle 1 showed that students can struggle with user interface elements and need guidance to work with new software tools. The instructions are intended to help students understand how to work during the activity and

		use tools features. The objective is that students understand how to engage in the activity.
Subjects	(who is involved in carrying out the activity?)	First semester students, Capstone students, CHARM-EU teaching staff, The researchers.
Tools	(by what means are the subjects carrying out this activity?)	Students were primed with a brief lecture and then asked to join their teams to begin the activity. Further details could be found in the exemplar artefact with information grouped into two popup modal windows containing instructions and inspirations. The instructions (model/vision) explained how students should structure their discussions by offering conversation prompts based on the elements of activity theory. The second window offered inspiration (mirror-data) drawn from cycle 2 worksheets and feedback of students' transdisciplinary teamwork experiences.
Rules and Regulations	(are there any cultural norms, rules or regulations governing the performance of this activity?)	We asked teams to conduct a normal meeting, as they would for any typical team session. Teams were asked to add their sentiment on the CHARM-EU PLO and the top tensions, and to then add their own perceived team challenges. No additional rules were given.
Division of Labour	(who is responsible for what, when carrying out this activity and how are the roles organised?)	Students were encouraged to explore the app features and help windows individually, although some discussed with their peers for clarifications before beginning. At least one team chose to add inputs individually before beginning their group discussion, whereas the majority explored the app features together.
Community	(what is the environment in what the activity is carried out?)	Hybrid sessions (n=2) and Co-located session (n=1)
Outcome	(what is the desired outcome from carrying out this activity?)	The instructions were seen as being clear and useful however the in-app help was missed by some students. Positive feedback was received from those students who explored the help section more deeply.

Table 5-53. Cycle 1, AODM summary.

AODM discussion of findings (cycle 1)

The **activity of interest** relating to this heuristic aimed to inform students about how they should approach their team discussions during the intervention. We were specifically interested in supporting the clarity of process regarding how they should frame their discussions and the appropriate way to use the tool to achieve the learning outcome for the activity. Our **objective** with this heuristic was to onboard each team to use the tool properly by providing appropriate instructions and guidance and explore student feedback relating to the instructions. Our **subjects** included the full class for two CHARM-EU cohorts, and our focus session cohorts including a balance of students from hybrid and co-located groups. While this difference influenced the **tools** usage patterns in each cohort due to some instances of co-located students sharing devices and therefore not individually viewing the in-app help, the instructions provided during class were well received and only one co-located team needed to discuss them in detail before continuing with the activity, with a second team having a short exchange between themselves to clarify their approach. Both teams were co-located students who reported using their own devices around a table to discuss the instructions. This closeness and additional familiarity with students that had been working together for some time may have resulted in deeper affiliative associations and a willingness to raise issues with their peers. The uncertainty was due to an assumption by the researchers that the cohort were all of a similar age profile however these teams included a student with prior master's experience (case 1), and a mature student with considerable prior work experience (case 3). There is an apparent tension between the **rules and regulations** regarding the objective for the activity in this regard since two teams still had some initial uncertainty about the discussion focus after reading the instructions. In this instance, the instructions and guidance did not provide the intended clarity of process recommended by heuristic c1a.

A **division of labour** is not apparent for this heuristic in the other cases, aside from one mention of students briefly chatting about the process before kicking off with the activity. Our other focus participants reported understanding how to proceed and did not need to coordinate within their teams before starting the task. Our mature student in case 3 took a leadership role by raising the question regarding prior experience, and the team discussion in case 1 is indicative of a distributed leadership approach. The mature student's uncertainty may be interpreted as a tension stemming from a lack of clarity regarding the rules, or as an influence from their membership of other communities, i.e. professional versus academic experience coupled with uncertainty about the purpose of the intervention led them to question the relevance of their experience in light of the instructions. Both interpretations are illustrated in figure 5-1. The mature student later explained during a focus session that they were worried about their extra experience influencing the study and raised the point to highlight this. We would assume that such questions are less likely outside of an intervention setting with a thoughtful participant, however the issue identifies a gap in the activity instructions that may be improved in alternative implementations of our heuristics.

There was no apparent **community** involvement mentioned for other teams although it is a truism that prior community of interest and community of practice experience exists to degrees in all individuals. We concluded that the **outcome** was successfully achieved for the design rule relating to this consolidated set of heuristics thanks to a successful onboarding that allowed all teams to conduct the activity correctly. All of our participating students agreed that the in-class intervention instructions were informative and helpful and that they added to their understanding of the aims of the intervention. Four of the six cases mentioned themes relating to improved clarity of process regarding how they should conduct their sessions. In cases 1 and 3, the students noted that their team discussion of the instructions also helped to improve their situational awareness of team skills due to them negotiating some initial uncertainty relating to the types of prior experience that they should include in the discussion (i.e. academic versus professional). While this represents a positive outcome which helped the teams to identified skills in their group, it also speaks to implementation issue regarding a threshold to usability where the clarity of process can suffer without improved instructions and guidance.

A student in case 1 reported not noticing or using the modal windows to view the model-vision or mirror data prompts. Others also reported a degree of confusion regarding the purpose of the in-app help content as they had only focused on the PLO discussion and had not produced their own list of tensions. These supports were not strictly required to work through the activity however and all students eventually managed to proceed without further instruction.

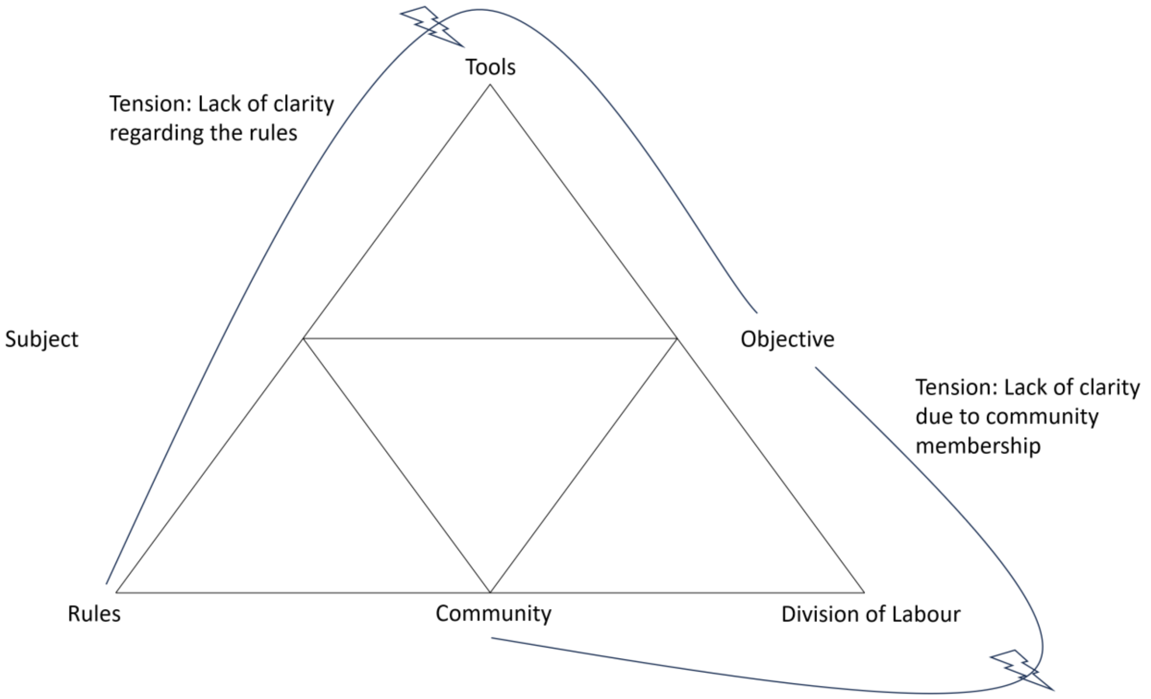


Figure 5-9. Tensions identified in our cycle 1 heuristics during the final analysis show how confusion with rules and uncertainty of which experiences to draw on, explain the initial confusion experienced in two teams.

Figure 5-1 (above) illustrates two interpretations of the same secondary tension associated with a lack of clarity regarding the lack of clarity regarding the activity purpose. The first of these is presented as tension between rules and objective, although an alternative explanation was proposed by our mature student who had considerable prior experience to draw upon (which we conceptualise as community membership), was responsible for them not know which prior experience to include.

In summary, this first analysis showed that our application of heuristic c1a supported students by clarifying the TTT usage and intervention instructions. A minor refinement to the instructions is recommended to further clarify the query relating to the relevance of prior experiences. This heuristic is an important first step since it sets the team members up to engage in the intervention. As such, this seemingly simplistic heuristic has an important place in our overall collection.

5.6 Cycle 2 heuristics

We developed three heuristics during cycle 2, each of which was implemented as a specific design rule. We tested each rule with a corresponding focus session question. These are discussed individually below. As with all heuristics in this chapter, three tables are given below to illustrate the heuristic details (table 5-5), codes encountered during analysis (5-6) and our AODM treatment (table 5-7).

5.6.1 Cycle 2, heuristic 1 (c2a)

ID	Heuristic	Design Rule Response(s)	Cross Reference	Focus Session Question
c2a	Remote teams experience reduced social presence and often miss social cues	Build in a clear, easy way to share cues. The TTT interface includes sliders that correspond to a range of emoticons states.	None	What did the emoticons make you feel about your team / teammates? What about the team average values?

Table 5-54. Heuristic c2a overview.

Case	Related deductive codes	Related inductive codes
Case 1 (Capstone Focus Session 1)	**Appropriate use of abstractions**, Expected behaviour of a tool, mental representations, **Naturalness principle**.	None
Case 2 (Capstone Focus Session 2)	Consequences of tool use, **Giving and receiving feedback**.	Team health, Team scaffolds.
Case 3 (Capstone Focus Session 3)	**Appropriate use of abstractions**, consequences of tool use, Controllers and interface, Effort to change, Interacting with IT, Mental representations, **Naturalness principle**, Comfort and accessibility, **Clarity of intent,** Ease of use.	Inclusion, Suggested improvement, Communication.
Case 4 (Phase 1 Interview 1)	Consequences of tool use, **Giving and receiving feedback**.	Communication
Case 5 (Phase 1 Interview 2)	Consequences of tool use, Developing shared mental models, **Situational awareness**, Space and cognition, Suitability of tools to tasks.	Inclusion, Team health, Team values, Hybrid teamwork challenge.
Case 6 (Phase 1 Focus Session 1)	**Clarity of expression, Clarity of process**, Developing shared mental models, **Giving and receiving feedback,** Mental representations, Perceptual principle, **Situational awareness**, Social-protocols, Space and cognition, **Timely feedback**.	Collaboration, communication, Mutual accommodation, Reflection, Teamwork scaffolds, Hybrid teamwork challenge, Team roles

Table 5-55. Heuristics c2a codes and themes.

AODM Analysis

Step	Definition	Details
Activity of Interest	(what sort of activity are we interested in?)	Remote teams experience reduced social presence and often miss social cues. Automatic sharing of the cue may be useful to such teams by establishing/improving affiliative associations, which is theorized to improve team health.
Objective	(why is the activity taking place?)	Scaffold the sharing of social cues.
Subjects	(who is involved in carrying out the activity?)	First semester students, Capstone students, CHARM-EU teaching staff, The researchers.
Tools	(by what means are the subjects carrying out this activity?)	Students shared their sentiments using the in-app sliders which presented an equivalent emoticon social cue to their peers.
Rules and Regulations	(are there any cultural norms, rules or regulations governing the performance of this activity?)	A cultural norm associated with age profile was mentioned by a mature student as potentially influencing their acceptance of using emoticons.
Division of Labour	(who is responsible for what, when carrying out this activity and how are the roles organised?)	Individual and self-paced, although students reported some confusion regarding the meaning of some emoticons and turned to their peers for explanation.
Community	(what is the environment in what the activity is carried out?)	Hybrid sessions (n=2) and Co-located session (n=1)
Outcome	(what is the desired outcome from carrying out this activity?)	Students reported positive sentiments and perceived an association between the emoticons and their teammates. Feedback indicates that the emoticons helped to transmit sentiment information, and that the team avatar average helped to establish a team identity by prompting team reflections regarding the disciplinary skillsets within the group.

Table 5-56. Heuristic c2a AODM summary.

AODM discussion of findings (heuristic c2a)

Our first cycle 2 heuristics holds that remote teams experience reduced social presence and often miss social cues. Our **activity of interest** with this heuristic focuses on the potential benefits of intentionally sharing such social cues via emoticons that act as abstracted mental representations of team member sentiment. We explored this in our focus session groups with a two-part question that asked students to reflect on how the individual and averaged emoticons made them feel about their teammates, i.e. "What did the emoticons make you feel about your team / teammates? What about the team average values?". Feedback to these questions supported theory by surfacing issues regarding the naturalness of the experience and how it was interpreted by participants. We received many positive comments relating to team health and team values, which we captured using inductive codes. Deductive coding also highlighted themes of improving clarity of expression and clarity of purpose that was scaffolded by the enriched communication, as well as positive tool usage comments relating to the appropriateness of the emoticon as an abstract representation of sentiment. Participants agreed that there were no surprises regarding expectations of how to use the tool.

The **objective** of this heuristic is to scaffold the sharing of social cues to promote a sense of connectedness amongst team peers that should begin to foster team affiliative associations and prompt team member insights regarding the extra disciplinary perspectives of their peers, since a successful outcome in this regard offers teams extended situational awareness of the skills, knowledge, and abilities present within their group. This sets the foundation for an expansion of team learning regarding how the team understand their collective capabilities, and in our transdisciplinary cohort how they should think about approaching their transdisciplinary synthesis. The emoticons and associated slider values were designed to act as mediating tools that directly conveyed the sentiment score of each team member to their peers, and a team average was included as a prompt for a team discussion on each topic. We did not expect the average value to be particularly meaningful and would obviously not claim that an average should be any kind of target for teams. However, the average would highlight differences in individual sentiment scores across the team and we encouraged students to explore any perceived differences during their topic discussions. As such, the average is simply a prompt to kick-start the discussion and not meant to be any kind of indication of the team goals or team capacity for a given topic. Our pre-activity instructions emphasised this point and we also note that our student **subjects** had begun to study transdisciplinary concepts in their coursework by the time the activity took place, so they already had some awareness of how disciplinary perspectives can differ on a topic-by-topic basis. Using a **tool** to mediate a discussion in this way establishes a social protocol for improved clarity of expression that can scaffold team interactions via the giving and receiving of feedback. This improves situational awareness within the team by exposing both explicit and tacit skills and team capabilities. Such facilitation is theorised to help students build mental representations or shared team mental models (Cannon-Bowers, Salas, & Converse, 1993; Mohammed, et al., 2010), which might be slower to evolve without such supports.

Students were asked to share sentiments using the tool, but no other specific **rules** were given and the individual nature of the task meant that the **division of labour** was evenly spread. **Community** associations were not mentioned in the responses.

In terms of **outcome**, both cohorts reported that the emoticon based intra-team feedback was helpful for reflecting on their team and their own personal development. They noted that it was helpful in pre-empting and defusing potential team tensions and in all but one instance, that reflecting on the emoticons felt natural. The first participant quotation below describes how this participant valued the TTT approach for revealing team tensions that their team had been ignoring thus far.

First semester cohort, session 2.

"the potential to possibly raise some tensions within the group, but I think that the tensions were probably needed once just because at the start in [] my group, you know, there was a, maybe a couple of clashing of personalities. So I feel like this was kind of a healthy way to maybe bring light to that and to kind of share our expectations of where we are and where we would prefer to be"

Sharing of feedback within the intervention activity was noted as being helpful in setting expectations for the teamwork and that this prompted moments of reflection regarding team competencies and possible skills gaps.

First semester cohort, session 3.

"I think I got more reassured that OK. I think we all have our weaknesses and strengths and it's going to be a mix".

"It was actually quite nice to be able to see where everybody's at with certain skills"

"if they need extra help, maybe because they've never done something like that, or if they [are] already, let's say experts in in that area"

The one individual that did not appreciate the emoticons was a mature student from the capstone cohort who qualified their response by suggesting that the age gap might have influenced their feelings regarding how suitable an emoticon was in a serious setting or as a response to an important question. They suggested that it undermined the credibility of the exercise for them, making interpretation of peers scores more difficult.

> *“undermined the credibility of the exercise with me slightly […] it's becoming vernacular among all generations, but it certainly would seem slightly more frivolous”*

This student had considered the issue previously and reported that they found it difficult to be sure how to both express themselves and to interpret edge cases while using emoticon type scales in other situations. The other student in this session offered a suggestion that such scales might benefit from a textual description next to each icon and our mature student agreed that that would be helpful for interpreting each step on the scale, and consequently their peers’ sentiments.

Our students in capstone case 2 reported that the high level of agreement on some topics made them feel confident in their ability to tackle related challenges.

> *“emotionally, it made us feel like kind of confident because they were [...] on the smiley side”*

Those in case 3 mentioned that the exemplar emoticons could have benefited from a longer scale and more expressive faces to aid interpretation of their peers’ sentiments. One may postulate endlessly to the benefits of perfect expressivity in any given type of interface but our aim for this heuristic is educational rather than that of improved UX. This is not to discount UX however. The UX aspects of a techno-social intervention alone could be researched and would fill a thesis, but the basic heuristic has been shown to be important and future iterations or alternative implementations should consider this. The resulting discussions that each team had when exploring these questions would appear to have been successful in raising team awareness as indicated by a wealth of positive participant feedback relating to improved situational awareness and clarity of purpose. We submit that despite the obvious limitations of the design implementation, the heuristic did achieve its objective of improving team awareness as the purposeful sharing of social cues prompted reflections and enquiry of their peers for the students during the activity.

5.6.2 Cycle 2, heuristic 2 (c2b)

Tables 5-8 to 5-10 detail and describe our analysis of heuristic c2b.

ID	Heuristic	Design Rule Response(s)	Cross Reference(s)	Focus Session Question
c2b	Interface controls that represent analogues of social cues should not feel unnatural to users.	Use sliders for a recognisable and low effort UI.	None	How well do you feel you could express your sentiment using the emoticon sliders?

Table 5-57. Heuristic c2b overview.

Case	Related deductive codes	Related inductive codes
Case 1 (Capstone Focus Session 1)	Expected behaviour of a tool, Mental representations, **Suitability of tools to tasks**.	Suggested improvement.
Case 2 (Capstone Focus Session 2)	**Clarity of intent, Clarity of process**, Ease of use, External factor impact, Mental representations, Methodologies, **Naturalness principle**, **Suitability of tools to tasks, Threshold to usability, Tool design issues**, Use of tool features.	Hybrid teamwork challenge.
Case 3 (Capstone Focus Session 3)	**Appropriate use of abstractions, Clarity of intent**, Mental representations, **Suitability of tools to tasks, Tool design issues.**	Communication, Inclusion.
Case 4 (Phase 1 Interview 1)	**Appropriate use of abstractions, Clarity of intent,** Giving and receiving feedback, Interpersonal clashes, Social-protocols, **Situational awareness, Suitability of tools to tasks, Working in multiple contexts, Usefulness of tools.**	Communication.
Case 5 (Phase 1 Interview 2)	Ease of use, Interacting with IT, **Threshold to usability**.	None.
Case 6 (Phase 1 Focus Session 1)	**Appropriate use of abstractions, Clarity of expression**, Expected behaviour of a tool, Giving and receiving feedback, Mental representations, **Naturalness principle**, Onboarding of a tool, **Social-protocols**, **Suitability of tools to tasks**.	Hybrid teamwork challenge, Inclusion, Suggested improvement, Teamwork scaffolds.

Table 5-58. Heuristic c2b codes and themes.

AODM Analysis

Step	Definition	Details
Activity of Interest	(what sort of activity are we interested in?)	Support the sharing of social cues in our interface with an appropriate interface.
Objective	(why is the activity taking place?)	To facilitate sentiment sharing via a natural experience, without increased cognitive load.
Subjects	(who is involved in carrying out the activity?)	First semester students, Capstone students, CHARM-EU teaching staff, The researchers.
Tools	(by what means are the subjects carrying out this activity?)	Each slider interface element in the TTT includes emoticons for every team member and a team average.
Rules and Regulations	(are there any cultural norms, rules or regulations governing the performance of this activity?)	Prior experiences of social sharing tools and expectations regarding how to behave in a hybrid class setting (netiquette). Activity instructions.
Division of Labour	(who is responsible for what, when carrying out this activity and how are the roles organised?)	Students adopted informal round robin turn taking
Community	(what is the environment in what the activity is carried out?)	Hybrid sessions (n=2) and Co-located session (n=1)
Outcome	(what is the desired outcome from carrying out this activity?)	Participants felt that they could express themselves well with the sliders, but two individuals suggested that a longer scale would feel more appropriate.

Table 5-59. Heuristic c2b AODM summary.

AODM discussion of findings (heuristic c2b)

The **activity of interest** for our second cycle 2 heuristic addresses our literature review finding that interface controls which feel unnatural to use can break immersion and increase cognitive load for a user of a system. Our **objective** when examining our students experience of this heuristic was to explore both their use of the slider and their attitudes towards the corresponding emoticon to see how closely, or how 'naturally', using the interface aligned with their actual sentiment regarding each topic The objective of this heuristic is therefore to present an interface that feels appropriate to the task without increasing cognitive load. All participants **subjects** reported a considerable degree of prior experience of computer use during our warmup questions for 21st century skills and we can claim with confidence that the full cohort of subjects were well acquainted with using sliders as interface controls. The mediating **tool** here is a combined interface of slider and emoticon which mediates the expression of sentiment from each subject to their teammates, and vice-versa. No specific **rules** or **division of labour** were noted however we did note possible **community** related tensions which we discuss below in the outcomes for this heuristic.

In terms of **outcomes**, we saw evidence of a tension relating to the step values of the sliders. When asked about how appropriate the step values were, all but two students reported that they found them to be suitable to the task and that they aligned with their expectations about how the tool should work. One participant suggested that a seven-point scale might be better aligned with a traditional Likert scale and might therefore be more useful for data analysis. A second student highlighted a design implementation concern relating to data that they had experience of regarding females' propensity to self-rate lower for certain competencies. This student suggested that a more granular scale would be useful to overcome this issue by reducing indecision when considering boundary values that might fall between steps.

> *"for women, for example, we tend to downplay a little bit our skills" ... "a system where there was a little bit more of options would have allowed for scoring just a little bit"*

This does not detract from our heuristic but does indicate a potential for improvement in the design rule implementation. While we did consider a more granulated range to support a traditional seven-point Likert scale, we opted for a simpler five-point scale in line with our earlier cycle 1 feedback that our interface should be as simple as possible. In the exemplar tool this facilitated an easier textual description for the steps and a less cluttered interface. The preference expressed by the student identifies a tension relating to the suitability of the range of the feedback scale to the task. This is an inclusivity issue that was missed in our initial design. More granulated steps may improve the implementation of this heuristic by making the user input feel more natural. The need for greater expressivity mentioned by our student begged the question of whether a linear scalar value might be more useful to cover the full range of possible sentiments rather and a stepped scale. When asked, our students did not feel that a this would be appropriate for the task and considered the stepped scale to be more useful for understanding and decision making. Figure 5-2 below, illustrates the desire for greater granularity in the length of the scale, framed as a tension between the subject and the tool.

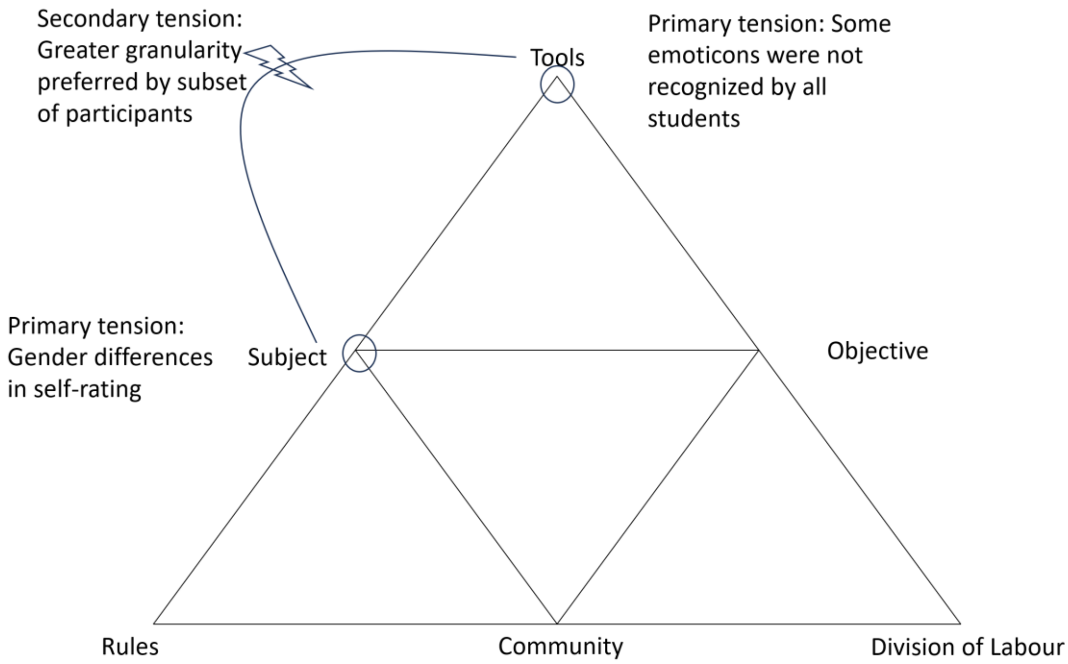


Figure 5-10. Two primary tensions and one secondary tension noted for heuristic c2b.

We identified an additional tension regarding the emoticon states which was reported in both the hybrid and co-located teams. In both cases a subset of the participants reported that they were initially confused as to the meaning of the emoticons. One student mentioned mistaking the least satisfied state with an angry emotion rather than dissatisfaction and took a moment to recognize the meaning. But overall, the students appreciated the visual social cues used in the app for helping them to engage with their teammates as well as prompting ideas and discussions. This suggests a degree of support for this heuristic of providing interfaces that do not feel unnatural, however the tensions identified in our exemplar tool implementation indicate that a more granular scale would have better addressed the goal of the heuristic.

Regarding the emoticons, we raise a point that was generated when discussing a later heuristic here as it relates to the naturalness of the interface. We will cover the point in detail when discussing students' opinions of emoticons under heuristic th7, "Be specific in communications", however the feedback is relevant to a general discussion of interface naturalness and should be mentioned before going further. A mature student in our capstone cohort gave us feedback that emoticons did not feel natural to them.

“I do want to flag that this could be a function of my age, but I think maybe it undermined the credibility of the exercise with me slightly”

The student qualified this as a possible function of their maturity, saying that they viewed emoticons as vernacular with younger persons. While an alternative interface style may have better suited the sensibilities of this student, and future research could explore this question, emoticon based interfaces are consistent with theory via DiCoT's Naturalness Principle which holds that the form of a representation should match the properties of what it represents, that is, it should be close to the form required for the task from the perspective of the user. For our mature student this closeness is not aligned fully, but it is sufficiently so. The aim is to stimulate discussion rather than dwell on the potential specificity of the interface and in this regard the interface achieved its intended purpose. We discuss our mature students feedback in terms of tensions in our analysis of heuristic th7, section 5.4.2.7, but it connects with this current heuristic regarding naturalness while reminding us to expect diverse views in transdisciplinary work and to be inclusive of all perspectives.

5.6.3 Cycle 2, heuristic 3 (c2c)

Tables 5-11 to 5-13 show the details, codes encountered during analysis and our AODM treatment of this heuristic.

ID	Heuristic	Design Rule Response(s)	Cross Reference(s)	Focus Session Question
c2c	Hybrid students want to get to know each other.	Include team member details (profile data) to support team relationship building and a team average avatar to promote team alignment sentiment.	None	Do you feel that you know your teammates better after the activity? How did the interface influence/contribute to that?

Table 5-60. Heuristic c2c overview.

Case	Related deductive codes	Related inductive codes
Case 1 (Capstone Focus Session 1)	**Evolving requirements, Timely feedback**.	Suggested improvement, Inclusion.

Case 2 (Capstone Focus Session 2)	**Situation awareness, Timely feedback**.	Communication, Reflection, Team health.
Case 3 (Capstone Focus Session 3)	**Suitability of tools to tasks, Timely feedback**, Tool design issues, **Usefulness of tools**, Arrangement of equipment, **Developing shared mental models**, Mental representations, Appropriate use of abstractions, **Clarity of expression**, **Giving and receiving feedback**, Naturalness principle, Perceptual principle, **Situation awareness**, Space and cognition.	Collaboration, Reflection, Team process development, Teamwork scaffolds, Informal collaboration.
Case 4 (Phase 1 Interview 1)	Consequences of tool use, Expected behaviour of a tool, Interacting with IT, Interpersonal clashes, Social-protocols, Suitability of tools to tasks, **Clarity of intent**, Clarity of process, **Developing shared mental models**, Mental representations.	Hybrid teamwork challenge, Informal collaboration, Team health, Teamwork scaffolds, Project priorities.
Case 5 (Phase 1 Interview 2)	**Giving and receiving feedback**, Mental representations, Situation awareness.	Communication, Inclusion, Team values, Teamwork scaffolds.
Case 6 (Phase 1 Focus Session 1)	Clarity of expression, Consequences of tool use, Mental representations, **Situation awareness**, Social-protocols, Usefulness of tools, Work practices, External factor impact, **Giving and receiving feedback**, Naturalness principle, Arrangement of equipment, Interacting with IT, Space and cognition, Tool interaction, Clarity of process, **Developing shared mental models,** Perceptual principle, Consequences of tool use, **Tool usage patterns**.	Hybrid teamwork challenge, Team roles, Inclusion, Informal collaboration, Teamwork scaffolds, Collaboration, communication, Team process development, Team values, Reflection, Team health.

Table 5-61. Heuristic c2c codes and themes.

AODM Analysis

Step	Definition	Details
Activity of Interest	(what sort of activity are we interested in?)	Structured and scaffolded team discussion that is designed to facilitate sharing of team members profile information to their teammates.
Objective	(why is the activity taking place?)	To foster intra team affiliative associations with the goal of

		raising team situation awareness and improving team communication.
Subjects	(who is involved in carrying out the activity?)	First semester students, Capstone students, CHARM-EU teaching staff, The researchers.
Tools	(by what means are the subjects carrying out this activity?)	Our artefact tool included an animated emoticon avatar for each student which displayed their name, academic background and their sentiment values per topic.
Rules and Regulations	(are there any cultural norms, rules or regulations governing the performance of this activity?)	Students were asked to consider their team members sentiment scores and engage in a discussion regarding how their disciplines influenced each person's sentiments per topic.
Division of Labour	(who is responsible for what, when carrying out this activity and how are the roles organised?)	Students reported conducting round-robin and less formal approaches to sharing their views. The tool design removes the need for individual administrative roles for this aspect of the activity.
Community	(what is the environment in what the activity is carried out?)	Hybrid sessions (n=2) and Co-located session (n=1)
Outcome	(what is the desired outcome from carrying out this activity?)	Improved situational awareness of team competencies. Improved intra-team relationship building. Participants reported knowing their peers better following the activity although profile info was not mentioned aside from positive comments regarding seeing the team together on screen. We attribute the successful

		outcome to the discussion rather than profiles.

Table 5-62. Heuristic c2c AODM summary.

AODM discussion of findings (heuristic c2c)

Our **activity of interest** with the final heuristic from cycle 2 stems from frustrations expressed by students regarding communication difficulties that they encountered while working within hybrid teams. Our cycle 2 students confirmed feeling the lack of connection that our literature review had indicated. The **objective** of this heuristic is to promote sentiments of affiliative association and a deeper sense of connection with team peers that should help to scaffold team discussions and peer awareness of the team's skills, knowledge and abilities. Building this level of understanding within a team is a necessary first step towards developing a coherent transdisciplinary team synthesis that can leverage the full capacity of the team, and our objective was to foster such connections. Our design rule response to the heuristic was to share team member profile data (i.e. names and academic discipline) to peers in support of team relationship building. Additionally, the **tool** included an animated team avatar that displayed the team average for each topic, with the goal of promoting a sense of team identity. Our intervention activity design rules asked students to collectively explore and elaborate on any differences that they perceived regarding the team discussion topics both between team members and compared to the team average avatar. Differences in responses across both cohorts are noteworthy. Our capstone students **subjects** claimed that although the activity helped them to form some minor insights into peers' backgrounds, they were already sufficiently acquainted and the activity did not add to this. These participants qualified their statements by suggesting that the timing of this kind of feedback is important and that they expected to find greater value in the activity at an earlier stage of their transdisciplinary team journey. It is interesting to note however that some of the capstone group reported developing a deeper understanding of how their peers viewed themselves with respect to their own confidence levels on the various topics and suggested that this was a valuable insight that would be helpful in navigating any future interpersonal clashes in their teams.

"sometimes in teamwork you're quite focused on how you view the other people. You don't often take time to really understand how they actually see themselves".

"for me, the real value is then actually seeing other the output of that introspection from every team member. And seeing how they see themselves. And that's interesting because you don't often get to, you know, crawl around inside somebody else's head".

Our first semester students had only worked together for two weeks prior to the intervention and their responses on this topic suggest that they found it to be considerably more useful thanks to the earlier timing. Overall, this group overwhelmingly responded that the activity was an invaluable and enjoyable experience. One student said they intended to run their own version of the activity in any future teamwork to gain insights into teammates before beginning any serious project work. Others mentioned that they had never considered this aspect of teamwork before, aside from cases where interpersonal problems had arisen within the team and needed to be addressed as triage for solving team dysfunction. We expected our mediating tool to help the students develop these insights through sharing of team member details and sentiments, however Activity Theory frames the prescribed format of the discussions as a rule that governs the use of the tool and viewed thusly, the combination of tool and rule contributed to the successful activity outcomes for the teams. In each case we can see that this combination of elements in the intervention was important in surfacing and transmitting richer information to the group about their teammates.

Cultural norms for sharing and openness are not universal **rules** and **community** membership can be a factor that influences the willingness of individuals to be forthcoming. Prior experience of leadership can affect an individual’s propensity to engage with others on this level, but this is often missing in novice teams. Our intervention design aimed to reduce the need for individual prompting of team members by making their sentiment explicit to their teammates before asking them to reflect individually and as a group, thereby sidestepping particular social protocols that might limit students’ ability to construct accurate mental representations of their teammates. This distributed techno-cognitive effect helps to build team awareness and team familiarity across the group while prescribing a **division of labour** to scaffold the discussion. Regarding **outcomes**, students appreciated the opportunity to learn about their peers. This indicates that our intervention design has addressed the heuristic successfully, even though our exemplar tool design implementation did not, since students did not offer feedback regarding the contribution of profile information to the outcome. We could not manage to contrast cohorts regarding the hybrid aspect of this heuristic due to the co-located capstone teams having already become well acquainted. This group did however indicate that they would have made useful connections and insights into their teammates specialties if the activity took place earlier in their programme.

5.7 Conclusion

Our purpose in reviewing of our collection of heuristics was to consider their potential to support distributed teams by identifying any challenges that students perceive as barriers to their success. But in conducting numerous AODM analyses of the problem space we have additionally gained valuable insights into our student's attitudes towards hybrid transdisciplinary teamwork. Overall, we are happy to assert that the intervention achieved its stated learning goal of helping students to reflect on their team capabilities and how best to integrate them in their projects, but at an individual heuristic level our findings are more nuanced. In some cases, student feedback exposed tensions that may have acted to limit students' ability to reach the learning goal. The identified tensions informed our final comments on our heuristics and addresses our first two research questions (RQ1 & RQ1a). An AODM analysis examined each heuristic to evaluate it (RQ1b) for inclusion in the final set, which is presented in the following summary on table 5-6.

Summary of heuristics analyses

The following table (5-63) presents our complete set of twenty-nine heuristics with highlighting to illustrate those thirteen that were consolidated, resulting in sixteen heuristics that were tested in the final design cycle intervention using the TTT exemplar artefact to answer RQ1b. The heuristics are presented in their final format, within the four category headings. Our category of user cantered considerations contains six heuristics that were produced during design cycles 1 and 2 and refined down to four themes during our analysis of cycle 2 and preparation for cycle 3. Our literature informed heuristics cover three categories, UX, Teamwork and Distributed Team Cognition. The UX category is included due to its importance for mediating technology experiences, and we clarified our rational for our limited treatment of this heuristic in our chapter 4, section 4.8.4, subsection 'Relevance of UX and DiCoT development heuristics'. Three heuristics from the teamwork set were not tested in cycle 3 due to their thematic overlap with heuristic c2b, which relates to expressivity of sentiment via interfaces. Although only indirectly tested in our study, they are well established landmark literature principles and are included on this basis. Our team mental models heuristic is grouped with our other teamwork set in this final presentation due to the strong thematic link with teamwork. The final literature informed category of Distributed Team Cognition covers Distributed Cognition and Distributed

Cognition of Teams principles. Three of these (dc1, dc3, dc6) were not directly tested for the same reason that they overlap thematically, although this time the overlap relates to heuristics in our teamwork set. As these also represent perspectives from landmark literature they are also included in the final set, although not directly tested in our study. Webb's (2008) extension to DiCoT emphasises the importance of developing practitioners and practice. These final two heuristics in our collection were not tested due to the limited scope of our study. They are included for their focus on supporting the development of team members, which strongly aligns first research question of supporting hybrid novice transdisciplinary teamwork. The heuristics we subsumed or otherwise excluded (see explanation above), have been shared in table 5-63 below.

ID	Heuristic	AODM Outcome
User centred considerations		
c1a	Don't assume users will recognise UI controls	The instructions were seen as being clear and useful however the in-app help was missed by some students and others were uncertain about how it should be used to inform the activity. Positive feedback was received from those students who explored the help section more deeply.
c1b	Our tool should provide detailed instructions	c1a
c1c	XR onboarding is difficult for new users	c1a
c2a	Remote teams experience reduced social presence and often miss social cues	Students reported positive sentiments and perceived an association between the emoticons and their teammates.
c2b	Interface controls that represent analogues of social cues should not feel unnatural to users.	Participants felt that they could express themselves well with the sliders but suggested that a longer scale would be helpful.
c2c	Hybrid students want to get to know each other.	Improved situational awareness of team competencies. Improved intra-team relationship building. Focus participants reported that they felt they did know their peers better following the activity although profile info was not mentioned aside from positive comments regarding seeing the team together on screen. We determine that the successful outcome is undoubtedly due to the discussion rather than any impact from profiles.
User Experience		
ux1	System Status, User Control and Freedom, Consistency and	Not specifically designed. Focus session warm up questions using Ravitz 21st century skills indicated that participants were confident using web interfaces and understood how to use

	Relevancy, Error Recognition and Recovery, and Task and Work Support	the tool. A failure of the database connection during the first cycle 3 intervention prompted students to support each other to extend their horizon of observation by sharing screens with peers.
Teamwork		
th1	Tool should adapt to the users' changing requirements.	Students added their own topics and reported finding this to be a useful feature that would benefit their teamwork.
th2	Support intra-team feedback.	Objective and outcomes align well, and students reported that they did feel that their communication improved as a result of using the tool during the activity.
th3	Support different roles and responsibilities	There is scant evidence that students adopted specific roles beyond prompting others for feedback and some general administrative suggestions. When asked about other potential role supports, the feedback focused on the user added topics potential for supporting project management related tasks.
th4	Support team mission objectives and norms.	tmm1
th5	Consider the environmental context	No mobile users took part in our focus sessions, so it is difficult to comment directly on the mobile first implementation. All teams both co-located and hybrid, were able to engage in the activity successfully, which supports this heuristic although as noted earlier, students spent some time finding a location to make their calls which delayed the start. The CHARM-EU hybrid classroom approach asked students to bring their own devices, so it is likely that most students were working in a familiar computing context.
th6	Foster team familiarity (to build affiliative associations)	One capstone group did not report any surprise insights regarding their peers' capabilities, but all felt that they were closer after the experience. First semester students reported very positive experiences and new knowledge about their peers thanks to their interactions during the activity.
th7	Be specific in communications	c2b
th8	Recognise and manage relative priorities	c2b
th9	Employ a clear working approach	c2b
tmm1	Support the building of mental representations of the key elements within a team's relevant	The limited features of our tool were not expected to be useful for planning, but we instead wanted to see evidence of questioning and sharing practice taking place and to see if students would recognise the value of this approach for their

	environment that are shared across team members	project planning needs. There was some limited support for this in student feedback.
Distributed Team Cognition		
dc1	Embodiment of information within the system	th2
dc2	Co-ordination between agents,	Evidence of mutual accommodation due to reflection during the discussion.
dc3	(Consider) The impact of set and setting (ecosystem) on the process taking place.	th5
dc4	Cognitive process is delimited by the functional relationships among the members	An idealised outcome would be based on teams that have asynchronous roles. Our student teams displayed limited division of labour in their team discussions but did report that the open nature of the activity design and TTT exemplar artefact facilitated their workflow. Examples of distributed leadership were noted in most teams.
dc5	Physical Layout: Space and Cognition	All students reported having difficulty with the PLOs due to their multifaceted nature, which made it difficult to assign a single value. However, encountering and working with the PLOs first was seen as an effective scaffold for the bespoke discussions.
dc6	Physical Layout: Subtle Bodily Supports	th5
dc7	Physical Layout: Situation Awareness	Positioning the PLOs at the top of the screen was not seen as being helpful when adding team's own challenges although encountering these topics first helped to setup students to undertake the activity and they reported that their resulting discussions helped them to think about their project scope and aims.
dc8	Information flow: Buffering	We saw evidence that the topics helped to scaffold the team in discussing their most critical challenges while also keeping track of less pressing items.
dc9	Artefacts: Representation – Goal Parity	Most participants reported having a better shared understanding of their project goals following the activity, which supports this heuristic.

dc10	Artefacts: Coordination of Resources	Mixed feedback as two teams in our sample did not discuss planning. Those teams that did develop their thoughts about team resources all made positive comments relating to improved situation awareness regarding their team capabilities.
dc11	Development of practice	These heuristics did not have design responses due to the short duration of our interventions and we instead looked for mentions of such development in participant responses. Overall, our participants recognised the need for continuing development of team practice to help with team health. They were conscious of the need to develop new skills as part of their project work.
dc12	Development of practitioners	

Table 5-63. Summary of all heuristic analyses.

6 Chapter 6. Discussion and Conclusion

6.1 Introduction

The work presented in this thesis explores the problem space of supporting novice transdisciplinary team synthesis in hybrid and distributed learning contexts. We propose and test a set of heuristics design recommendations as a solution space to support students engaging in such technology-mediated teamwork. Contemporary approaches to supporting distributed teamwork focus on establishing clear structures, keeping open communication and building trust, and these aspects are strongly represented in our teamwork category of heuristics. We extend these supports with heuristics that leverage distributed cognition to frame team process building. We began our study with the question of how we might design a system that includes such supports, and a literature review of the problem space identified a set of recommendations that should be useful for distributed novice transdisciplinary teams. Design based research that leverages design cycles was selected as suitable methodology to explore this newly emerging field and focusing our outputs on heuristics offered us a flexible decision-making framework in terms of the resulting design response to the problem. Following this approach, we used outputs from design cycles to help clarify our design response and implemented these in an exemplar artefact that was used in our final cycle intervention. The theme of each heuristic stems from our literature review and first two design cycles, however the design response to implement each heuristic was not possible to envision until we were well into our second cycle analysis and had begun to understand the unique needs of novice hybrid transdisciplinary teams. As our proposed solution, i.e., the full set of our heuristics, spans a range of supports, we conducted AODM based analyses of each individual heuristic to evaluate its inclusion in the final heuristic collection.

This study focused on a narrow slice of the types of hybrid teamwork that we anticipate becoming increasingly commonplace in knowledge work. The students in our study were transdisciplinary scholars who dedicate a considerable part of the first months of their term and capstone projects figuring out how to coalesce into a functioning team. This is due to the need in transdisciplinarity to understand the team's approach to the project in a way that is consistent with their own disciplinary perspectives while also being complementary to the disciplinary perspectives of their teammates. We would not expect such a synthesis to take place in the scope of a brief intervention. The synthesis is a necessary step on the transdisciplinary journey and to achieve such an alignment requires considerable team reflection and self-questioning to confirm one's own perspectives and understand how they relate to those of teammates. Our interventions took place at the start of this journey because our heuristics are selected to scaffold the initiation of synthesis and perspective taking, rather than detailed discussions of ontological alignment required in transdisciplinarity. Recent work from Ozkaramanli et al. (2022) reminds us that transdisciplinary teamwork implies "the need for new terms, vocabularies, and shared values", which emerge as an output of the teams' efforts to synthesize their world views. Our collection of heuristics addresses this need by scaffolding the initial groundwork to set the team up for success. Hybrid work is necessarily mediated by technology, and this introduces an additional set of challenges regarding the difficulties faced by new teams. Our heuristics in this regard focus on the distributed nature of the team's cognition to look at how the mediation of their communication can impact their project outcomes. Hutchins (1965) DCog theory and Blandford and Furniss' (2006) and Webb's (2010) DiCoT have informed the subset of our heuristics that are intended to act as scaffolds to support distributed team cognition. Mediation can be both positive and negative depending on how it occurs. For example, a conversation mediated by low bandwidth audio will be a difficult experience and is likely to introduce miscommunication. Conversations that can take advantage of the mediation have a greater chance at transmitting a clear and intelligible message due to the increased semantic richness that it affords (McLuhan, 1964; Daft & Lengel, 1986). Purposeful mediation, such as that employed in our exemplar TTT, leverages the additional bandwidth to introduce new modes of socially constructed, shared communication. Our cycle 3 data show support for this view of socially co-developed meaning-making in participant feedback that describes mutual accommodation of sentiment scores triggered by reciprocal sharing of sentiments within the team. Our quantitative findings support the qualitative feedback and examples of time-series sentiment data were offered. Leontiev's development of Activity Theory has been helpful in imposing structured rigour to our DBR study and is a useful lens to think about mediation within distributed team cognition, and Engeström's third generation of the theory has been helpful in uncovering culturally historical tensions that are relevant to our design. Additional notation from Bligh and Flood has complimented our analysis to help illustrate systemic contradictions. Our analysis of the complete set has identified stronger and weaker heuristics that offer varying supports for distributed teams, and we collate and summarise these in the current chapter.

6.2 Discussion

6.2.1 Revisiting research questions

We began this thesis by asking how we might design mixed reality systems that can support novice, hybrid transdisciplinary teamwork and how this could be translated into a set of relevant design heuristics. To explore the potential of our set we added a third research question to examine how well the heuristics would stand up to a test using an exemplar implementation artefact in a teamwork-based intervention activity. Our literature review was informed by a distributed social-cognitive perspective that good team cognition requires support for healthy teams, and targeted support for the cognitive operations that those teams work on. Distributed teams must learn to manage technology-mediated miscommunications by developing new types of competencies and literacies that mitigate the negative effects of mediation and leverage the positives. Our literature review identified a set of complementary teamwork theories that are consistent with the needs of hybrid teams, and a set of supporting principles derived from DCog and DiCoT researchers to scaffold distributed team cognition. Our first two design cycles resulted in six additional heuristics that are informed by student feedback of hybrid teamwork. Of the twenty-nine heuristics produced via literature review and design cycles, sixteen were directly tested in our final design cycle by discussing the TTT implementation of each with focus session participants. Feedback showed positive support for our landmark literature informed teamwork heuristics, distributed team cognition heuristics, and similar positive views regarding our user centred heuristics. This gave us confidence in our contribution of sixteen heuristics, that can be applied to XR supports for novice hybrid transdisciplinary teamwork. The TTT implementation of the heuristics is presented as the basis of a successful learning intervention and represents an additional contribution from our study as a novel data generation method and an effective team learning intervention tool.

Working in a novel problem space has its challenges and especially so when little exists in the way of accepted standards or established norms. We conducted three DBR cycles to address RQ1 and argue that DBR is the most appropriate methodology to explore such dynamic themes thanks to its flexibility. Our design cycles highlighted students' concerns regarding hybrid transdisciplinary teamwork and team synthesis, which has been useful feedback to drive the study forward with each successive cycle. We drew on our literature review and first two design cycles to produce this set of promising design heuristics that can support distributed transdisciplinary team synthesis. Applying Mwanza's Activity Oriented Design Method has been helpful in answering RQ1b by analysing the heuristics to identify student perceived hybrid teamwork tensions following a technology-mediated hybrid teamwork intervention activity. Our use of AODM to analyse hybrid teamwork tensions contributes new findings to the growing body of AODM research and our application of iconography from Bligh and Flood's Change Laboratory toolkit within our analysis represents a further, methodological contribution within the realm of third generation Activity Theory. Our AODM analysis of participant feedback helped us refine our heuristics between cycle 2 and cycle 3. To support AODM in analysing tensions that stem from culturally historical context, we discussed the additional aspects of Engeström's third generation activity theory that were beyond the context of Mwanza's study and illustrated instances of these in our data with figures based on Bligh and Flood's Change Laboratory toolkit. This stack of methods informed our evaluations of heuristics when answering RQ1b. We turn now to a consider the outcomes of our cycle 3 analyses and discuss how each speaks to our research questions.

- **RQ1.** How might we design XR systems that support novice hybrid transdisciplinary teamwork?
- **RQ1a.** What design heuristics can be used for such applications?
- **RQ1b.** How can the design heuristics be evaluated when implemented in a test artefact?

6.2.2 Transdisciplinary learning and team/group/project-based learning in higher education

When situated within the educational framing outlined in Chapter 2, the findings demonstrate how the heuristic set supports the learning processes underpinning hybrid, transdisciplinary teamwork. These processes are especially relevant in higher-education contexts, where novice student teams engage in group and project-based learning that requires shared regulation, coordinated action, and the co-construction of disciplinary and transdisciplinary understanding. Student groups must jointly regulate their activity, develop shared interpretations, and distribute cognitive work across tools and peers. The heuristics derived from the literature were intended to facilitate these processes, and the findings indicate that their implementation in our intervention activity supported collaborative learning by structuring interaction and externalising shared understanding.

The usability/UX heuristics (Muller, et al., 1998) emphasise clarity, scaffolding and error recovery—features that align with the needs of student teams who must quickly adopt new tools while coordinating academic tasks. Standardised interface features helped reduce cognitive overhead, enabling students to devote more effort to the substantive learning activity.

Teamwork-theory heuristics (Tuckman, 1965; Inverardi & Tivoli, 2009; LaFasto & Larson, 1989; Salas, et al., 2013; Katzenbach & Smith, 1993) aligned closely with how student groups naturally regulate collaborative learning. The findings demonstrate that students benefited when the system supported intra-team feedback, that the feedback was easily interpreted, and that the design made the learning objectives explicit. This echoes the established models of group development and cooperative learning drawn from our teamwork theory-based heuristics, altough we also noted various approaches to team norms and roles being adopted by different teams and we discuss the benefits of distributed leadership approaches to transdisciplinary teamwork in our Cycle 3 analysis (See section 5.4.4.4).

The team mental model heuristic (Mohammed, et al., 2010) was especially relevant in student contexts, where shared understanding is not a given, as this heuristic serves to scaffold the shared interpretation of activities. Student feedback showed that this was successful in our design, with team alignment and clarity of purpose emerging as strong themes.

Our DCog (Hutchins, 1995) and DiCoT perspectives (Blandford & Furniss, 2006; Webb, 2008) allowed the design to address learning as a distributed process. Findings show that intervention method assisted students in distributing cognitive effort across artefacts, peers, and settings.

6.2.3 Technology-mediated teamwork

Our goal in this research is to design XR supports for novice hybrid transdisciplinary teamwork, and our literature review identified a body of research that speaks to such supports. This corpus directly informed the development of our teamwork category of heuristics which cover the themes of, adapting to change, supporting the giving and receiving of feedback, supporting team roles, missions and norms, establishing and maintaining clarity in communications and planning, clarity of operational process and clarity of project goals.

Tuckman's work on teams is perhaps the highest profile and generally well-known research on the topic and this informs our first teamwork-based heuristic. Tuckman recognises that team's needs change as the team develops. This implied that our design response needed to be sufficiently flexible to adapt to such changes. Our response was to include user added topics in our exemplar artefact to offer a tool that could be used for any type of discussion that the team required. This approach supports student agency regarding the direction of their work, but a single intervention cannot do justice to Tuckman's insights as teams will not change very much during an hour-long class. However, our participants did report that they found the custom topics feature to be useful and recognised that they could use it for numerous different tasks. This aligns with the aims of the heuristic to support them as they grow. To generate student feedback in this regard, we wanted to know what our participants thought about the longer-term usage of the custom topics. We asked participants how useful they found the user defined topics and how they might continue to use the feature, or change using it over time. Our rational here was to enquire about how our tool mediated the teamwork, both during the intervention and potentially over the course of a longer period where usage patterns might evolve. Students commented that they envisaged using the tool as a check-in to clarify intent and process by confirming that they were still aligned towards their project goals. Prior activity systems of teamwork (that are mediated by other tools, processes, etc.) prepared our students to recognise that they would need to course-correct during their team projects. This is not encapsulated in a single activity in traditional teamwork (consider the breath of approaches in use today, including everything from Agile retrospectives and project planning applications to water-cooler moments). As such, the student's previous activities of team cohesion are mediated by many tools and consist of many discrete actions that on aggregate serve to mediate the activities of team integration and/or synthesis. Traditional approaches are therefore saturated in a multitude of culturally historical operations, actions and sub-activities, and any one of these may produce unexpected tensions. Surfacing the need to address team cohesion in our intervention consolidates these various discrete and occasionally informal actions into one cohesively and purposefully mediated activity.

Feedback is essential for team effectiveness since without it, we are likely to repeat earlier mistakes. It is also a fundamental practice for team health. LaFasto and Larson (1989) inform heuristic th2's aims to support intra-team feedback. Our work with the CHARM-EU cohorts gives us confidence that they are open to peer feedback and want more of it. In our analysis of cycle 2, students reported using feedback to identify and overcome team and inter-personal issues. This was reflected in cycle 3 feedback relating to current and previous team projects where our participants told us that in their previous experience, such team insights were more likely to occur after a problem had already negatively impacted the team. Mechanisms for feedback either did not exist in their earlier teams, or feedback was not part of the cultural norms expected by the team. Team dysfunction may be described as tensions between parallel activity systems that share a common objective, i.e. where each team member acts as their own system directed towards the project goal. Viewed thusly, we can see the importance of feedback to realign and regulate teamwork. By deliberately emphasising the mediation of feedback, teams can focus on the meaning and impact of any shared information. This facilitates the cognition of both team members and of the team overall by improving the bandwidth of their conversations. Our cycle 3 participants offered particularly encouraging comments about the type of feedback they received during the intervention, with one student telling us that they planned to use our approach in all of their future teams. The importance of reflecting on team integration feedback is under addressed in contemporary third level curricula despite being an essential skill for new graduates entering an increasingly hybrid workforce. It is our hope that structured feedback delivered in activities like the TTT can help to prepare graduates for real-world professional demands.

Salas et al. inform our next four heuristics. They emphasise the importance of leadership, mutual performance monitoring, anticipating the needs of other team members, being adaptable to changing requirements and holding a team orientation so that team goals are emphasised. By emphasizing these aspects, we can see that Salas et al. are interested in team members understanding of the structure and operations of the team's work. Roles create operational templates for how we should think about interacting to reach a goal and this contextual information about the team influences members in understanding what it means to be part of that team. Supporting different roles and responsibilities means that members can think about team interactions in a structured manner, which equates to less surprises and frustrations overall between members. Functional roles within teams align with Activity Theory's Division of Labour concept by defining the relationship between team members and how they should interact within the scope of an activity. In this regard, roles can help to establish team mission objectives and norms although they are not essential to this, as we observed with our CHARM-EU cohorts. Our full set of AODM descriptive analyses of participant feedback showed surprisingly few formal roles being adopted by our student teams, and numerous instances of shared responsibility that is indicative of distributed leadership practices. Distributed leadership (DL) is an approach to teamwork that is gaining popularity (Curtis, 2024). DL does not imply teams without leaders, but rather the ongoing development and exercise of leadership skills by each team member. In terms of how activities get conducted, DL is less structured than traditional leadership models that help to scaffold team interactions, and this might appear to be a potential frustration to transdisciplinary synthesis where team members work hard to understand one another in the early stages of their work. But DL can complement transdisciplinarity well since it encourages proactive behaviour and volunteering of ideas or effort, and we see evidence of this in our cohorts.

Salas et al. next tell us to consider the environmental context and this informs our next teamwork-based heuristic. This is something that we prepared for with a mobile-first design in the cycle 3 intervention. The final advice from Salas et al. in our collection relates to building team familiarity and affiliative associations within the team. Sharing of sentiments and profile information did kick-start the team relationships according to our cycle 3 participants, who reported enjoying the experience and mentioned feeling closer to their peers following the session. While it may never be possible to "be friends with everyone", promoting sharing and developing empathy are highly valued competencies that will be essential in future workplaces, and our approach scaffolds the development of this important 21st century transversal skill.

Katzenbach and Smith (1993) inform our three final teamwork heuristics, and they focus on clarity of communication to aid with interpretation and comprehension within groups. This involves being specific in communications, recognising and managing relative priorities and employing a clear working approach. We mapped this heuristic to a related theme during our cycle 2 analysis (c2b, transmission of social cues should not feel unnatural), and covered both by asking participants how well they could express themselves and their sentiments using emoticon sliders. From this we generated feedback on how well our students could express themselves using the tool to interpret the feedback of others. We received positive comments that most students did not encounter any challenges using the TTT communication channel to share their sentiment, although feedback from a mature student highlighted that sharing of emoticons may not be compatible with discussions of serious topics. In this example we can see that clarity in mediated communication is difficult due to the subjectivity that stems from the mediation. Our mature student has a valid culturally historical perspective that shapes their opinions of the communication and introduced the tension that they mention regarding the gravitas of the discussion topics. Our AODM analysis identified this as a tertiary contradiction between the mature student's earlier version of the activity system (i.e. their experience of cultural norms), versus the approach used during our intervention. Our first semester students' experiences involved more normalised usage of emoticons and their prior activity systems of emoticon interactions do not produce tensions from their perspective. In our study we focused on scaffolding team topic discussions to create moments of expansive learning, and this de-emphasises the need to strictly implement a universally clear communication channel as our design calls for clarity to emerge as an output of the team discussions. Feedback in this regard was overwhelmingly positive and our students clearly found our intervention to be an enjoyable and rewarding experience. Each of the participants in cycle 3 reported that their team discussions helped them to work with their peers and to develop insights about themselves and their teams. Mediating the discussion via the tool allowed students to raise topics that they had avoided, and which they felt needed to be addressed.

Our final heuristic in the teamwork category relates to the development of team mental models, a concept that aligns with our conceptualization of team synthesis. The type of team mental model that we target in our research relates to the collection of issues that teams need to discuss, reflect on and then agree to align with before addressing their project work. Our literature review included Cannon-Bowers, Salas, & Converse (1993) for their foundational work on mental models, and our conceptual framework focused on Mohammed (2010) whose views interpret the earlier theories of team mental models through the lens of teamwork. Their work resonates with our own in their claim that for team mental models to exist, teams must develop mental representations of the key elements within the team working environment that are shared across team members. Such a framing of team mental models aligns with Blandford and Furniss's concept of goal parity in team members, and our analysis noted the overlaps. To achieve an accurate and aligned mental model, teams need to understand their goals. Parity of goals implies that transdisciplinary team synthesis is close, since alignment is the basis of the synthesis step of problem framing and understanding how to go about the business of integrating. Our emphasis here is not to worry about the minutia of managing projects or designing work plans, but to see if students understood that a discussion of their team skills and resources could prime them to think about organising the work by reflecting on their team capabilities. The limited features of our exemplar tool were not expected to be useful for planning, but we saw evidence of questioning and sharing practice taking place, and of some students recognising the value of this approach for their project planning needs. To explore student sentiments in this regard, we asked participants how the activity might help them to track the key elements of their work. Clarity of process and clarity of intent were both noted as strong themes in the feedback and the timing of the activity was mentioned as being a factor that would determine the usage and benefits. This point shows an awareness of the development of the team's needs by this participant and resonates with Tuckman's view of team growth. Follow-up probing questions indicated that many students did not perceive a connection between key work elements and team skills however, and that many teams did not discuss planning or role related tasks during the intervention. Nevertheless, our impression is that an implicit expansion of learning took place which helped to prime students towards their discussions of team competencies addressing project goals, since we received several reports that they felt more confident about their upcoming projects after completing the intervention activity.

6.2.4 DCog and DiCoT framing

Our next category of heuristics relates to Hutchins (1965) DCog and Blandford & Furniss (2006), and Webb's (2008) work on DiCoT. Hutchins holds that cognition involves a mixture of humans and external artifacts that work together in a goal-directed group activity cognitive system (Perry, 2003). DCog is an approach to distributed cognition that views the act of cognition as a system of interacting actors and objects which influence each other to process information. It therefore frames cognition as a computational and transactional operation. Information is embodied within the system by being spread over the component elements (people and artefacts). Processing implies co-ordination between agents to achieve the cognition by transforming the information within the system. To explain this process of cognition across groups, Hutchins highlights that the functional relationships among team members define the modes of interaction, and member roles therefore delimit and add structure to the cognitive process. This has both positive and negative impacts. We have discussed team roles in the current text and comment on their potential to add structural clarity to teamwork.

When roles are less rigid, they do not give structure and instead can act to convolute team processes. Distributed Leadership is noted as a response to looser team roles that is gaining in popularity (Curtis, 2024). We observed many instances of students displaying distributed leadership and are impressed by the improved agency and confidence that it can foster. As a response to the lack of role clarity within transdisciplinary teamwork, DL offers novice learners a way of approaching their work that may help to overcome prior expectations about how the team should operate, while also building their transversal skills. Hutchins also tells us to consider the impact of set and setting (i.e. ecosystem) on the cognitive process taking place. We addressed this topic from a teamwork perspective when discussing Salas' (2013) advice to "consider the environmental context", and as noted in our cycle 3 analysis, the context is more complex than the use of our artefact and includes logistical challenges such as finding a private space to begin a hybrid.

Heuristics dc2 ("co-ordination between agents") should be of particular interest to transdisciplinary researchers. Co-ordination in such contexts implies a negotiation to adequately explore issues of ontological integration before developing team processes. Our AODM analysis of this heuristic found evidence of mutual accommodation of student sentiment scores resulting from students reflecting during the discussion. This was reported by students and triangulated using time series sentiment data for each team member. Direct comparison of all qualitative feedback to quantitative time series data was not possible due to incomplete consent in our cycle 3 cohort, but we were able to identify several examples showing clusters of mutual accommodation during the sessions. Or analysis did not extend to investigate the specific comments that prompted students to adjust their values, but we did ask for feedback on this from our focus session participants. Most students mentioned reflecting on their interpretation of their peers' values and said that they used this to scaffold the decision to change. However, two students reported aligning with their teams average score to either not appear too different or too confident in front of their new peers. This is a less positive outcome, and our we discussed the negative consequences that can result from this behaviour. Without guidance, this may develop into groupthink or a situation with one strong voice overpowering others. Groupthink results from a desire for consensus without conflict. It prompts decision making without critical consideration and is therefore damaging to transdisciplinary synthesis, which depends on reasoned argument and discussion. Groupthink presents a problem for Salas et al.'s perspective that affiliative associations benefit teams since as Janis (1971) cautions in his analysis of 1950's corporate management, the "more amiability and *esprit de corps* there is among the members of a policy-making ingroup, the greater the danger that independent critical thinking will be replaced by groupthink". How can we balance the need for closer relationships with heterogenous thought in teams? It is essential to answer this question in transdisciplinarity, where diverse views are so important, and a critical perspective is essential. On the one hand, closer bonds should create a sense of team emotional security (also known as psychological safety) where members should feel safe in raising non-conformist views. On the other hand, we see that bonds may reduce criticality and encourage groupthink. The views are incompatible, and the only answer must be to find a balance between strong relationships and critical engagement. Thankfully, transdisciplinarity includes practices that can mitigate groupthink. Firstly, by its very nature, it involves a diversity of disciplinary perspectives. Secondly through a process that does not need to be limited to transdisciplinary teams, stakeholder views are encouraged to deliberately broaden the set of perspectives in play during decision making. Distributed leadership offers a route to address the issue, and many successful examples can be cited in the work of multidisciplinary health research teams, with the COVID19 response being the highest profile in recent years. Our own students informally employed DL to organise their work although our study did not have scope to examine motivations behind team decision making. CHARM-EU's focus on inclusivity can also help to produce teams with a good balance of perspectives and promoting intellectual diversity is an important goal if we are ever to escape the transitional views that can frustrate our ability to address wicked problems. The use of a round-robin meeting format is an example of such inclusive practices in our cohorts. Distributed teams can benefit from inclusive practices and taking time to consider alternative perspectives may mitigate the negative effects of technology-mediated communication by giving space to reflect. Our cycle 2 and 3 interventions emphasised the need of developing reflective practices by asking students to consider their teamwork challenges in terms of third generation activity theory concepts, i.e. to frame team tensions to better understand their causes and impact. Both interventions *should* reduce groupthink as the design askes students to honestly explore and openly discuss their sentiments, however we did not specifically address groupthink in our study and our finding from the cycle 3 data highlights this as a real risk which alternative implementation of our heuristics would need to consider. Established strategies exist and can be leveraged to avoid groupthink. The most obvious of these is to ask members to prepare in advance and then offer each member a chance to present their prepared thoughts, although such an approach would need to be part of a larger team development process than was possible in the scope of our intervention.

Moving from DCog to DiCoT we now turn to distributed cognition within distributed teams. Both Blandford and Furniss, and Webb's conceptualization of DiCoT looked at teams that were distributed due to functional roles, e.g. ambulance control desk versus drivers. Our study focuses on novice teams beginning work where they either do not adopt formally defined asynchronous roles or do so on a rotational basis. As such we focus less on the need to support diverse roles, although we recognise the importance of this in other contexts. Our heuristics speak to strategies for overcoming the hurdles faced by novice distributed teams rather than the functional processes that team engage in, and the cognition that we wish to scaffold is a team mental model of transdisciplinary team synthesis, rather than daily project work. DiCoT views distributed team cognition being influenced by three themes, i.e. the physical layout of the work environment, the flow of information between members and the mediating artefacts used to communicate and conceptualize work concepts. Our heuristics address each of these themes and focus on those DiCoT principles most relevant to novice transdisciplinary team synthesis. Those principles that were beyond the design scope of our study have not been ignored however and the complete set of DiCoT principles has informed our analysis of the distributed team cognitions conducted by students in cycle 2 and cycle 3 of our study.

Representing the physical layout theme, we examined the Space and Cognition, Subtle Bodily Supports and Situation Awareness DiCoT principles as part of our heuristics. Subtle bodily supports were addressed with a mobile-first design. All focus session participants had a laptop or large tablet experience themselves but described mobile phone users choosing to avail of their peer's larger device screens during the activity to better view their peers avatars on screen. They reported that this subtitle bodily support acted to extend the horizon of observation of the individuals involved and thereby improved their situational awareness. Our investigation of the space and cognition and situational awareness heuristics both generated feedback that familiar topics were a welcome introduction to the tasks, but that the tool usage was not deemed to be problematic and therefore using the CHARM-EU programme learning outcomes to introduce a discussion format for team topics was unnecessary. Familiarity with web interfaces and the simplicity of our implementation explains why this scaffolding was not considered to be helpful, and we cannot say that the TTT layout or design implementation supported the aims of the space and cognition heuristic. Although the layout seems to have done little to scaffold the usage, we received contradictory feedback that the resulting discussions were considered extremely helpful by students for understanding their team dynamics as well as project aims and scope. This suggests that while the interface design did little to scaffold the discussions, the visible and familiar content did prepare students for their own team topic discussions. Both layout and content act as mediating artefacts in activity system of engaging in the team discussions. We anticipated that positioning familiar content 'above the fold' would make the mediation explicit such that students could understand the intervention aims and process. With feedback suggesting that the layout both did and didn't support the activity, we need to consider our participants responses more carefully and distinguish between Leontiev's concepts of action and activity to decompose this dilemma. For Leontiev, activities are composed of actions, and these in turn are composed of operations. Operations are defined as minor tasks that do not add considerable cognitive load.

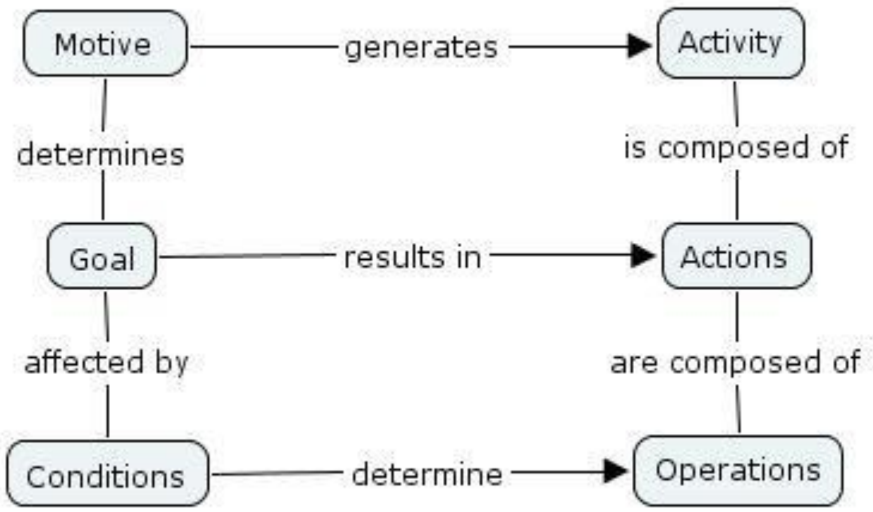


Figure 6-1. Leontiev's conceptualization of Activity, Actions and Operations, (Wilson, 2007)

In our examination of the themes relating to this heuristic, we find that usage of the tool cannot be mapped directly to the goal of team topic discussions but should be more correctly be categorised as an operation directed towards that goal. Experience of prior activity systems allowed the students to treat the tool usage as an operation, which reduces its importance from their perspective. Reflecting on the default programme learning outcome topics required a deeper cognition which we classify as an action directed towards the activity of conducting team discussions. By decomposing the activity for these heuristics, we can reconcile the incompatibilities in our participants responses. The implementation did act to prime students to work with their own topics, which implies a successful implementation of the space and cognition and situational awareness heuristics that produced an expansion in team learning.

Our next heuristic is based on DiCoT's Buffering Principle and addresses the information flow challenge of managing many new ideas at once, which is a fundamental hurdle for the cohorts described by our first research question. There is a danger that useful ideas may not have a chance to surface by being lost in the sea of ideas that occurs in co-creative efforts and our design for the cycle 3 intervention was conscious of this. User created team discussion topics offered a useful and practical design response to include information flow buffering in our intervention design and these were well received by our participants for the sense of agency and control they provided to students concerning their discussions. Cycle 3 participants reported that the custom topics helped when discussing their most critical challenges while also keeping track of less pressing items. Many note taking solutions exist, and teams should rely on the tools most suited to their needs, however the concept of a managed topic list represents the type of features needed to support information buffering. During our cycle 3 intervention we noted differences in the approach to note taking across teams between all members freely adding topics, or one individual adopting a notetaker role to record topic suggestions as they came up during the discussion. In established or more longer running teams this role may be formalised, although technology based artificial intelligence tools are quickly developing to offer a wide range of agentic services and distributed teamwork is sure to include the use of these supports in future. Whether the notetaker is human or otherwise is an exciting idea to entertain but beyond the scope of the present research. In either case, the notetaker functional role acts to mediate information flow, reduce cognitive load, and support the team's distributed cognition. Information flow is regulated with the aid of this intermediate storage that can be thought of by the team as a transactive memory system that reduces cognitive load by externalising the information, and can then be queried as needed. When every team member can access the topics list, shared understanding is facilitated and decision-making can improve.

DiCoT's Artefact model is represented in our study by our final two heuristics from Blandford and Furniss which relate to Goal Parity and the Coordination of Resources. Planning and reflection are essential to transdisciplinary team synthesis (Pohl, 2005) and important footsteps for our students on the path to conceptualizing their challenge-based project work. In challenge-based learning, project goals are often determined as part of the early project work, and this is the case in our CHARM-EU cohorts where students dedicate the first few weeks to discussing their project synthesis. The project goals, work practices and team commitments that are documented during these first weeks are indicative of the type of team working environment that members will experience. We can apply DiCoT's view of cognitive artifacts to think about this collection of resources as a template for the team operations and a basis for a team mental model, or conceptualization, of how the work should proceed. Understanding goals is therefore essential to reach a consistently aligned and accurate team mental model for each team member. We emphasised in our instructions to students that they should discuss how their collective skillset could address their project problem space by adding their own team challenges topics as an introduction to discussing project planning. A consideration of team resources and project goals allows teams members to develop a holistic overview of their team competencies and identify possible skills gaps relevant to their project scoping and planning. Use of the TTT exemplar artefact scaffolds this discussion by eliciting team member sentiment for each of their discussion topics. We did not expect detailed discussion in this regard but hoped to see some indication of students reflecting on how their unique team make-up might be best able to tackle their project goals. Unsurprisingly, our capstone participants reported that they had already spent time considering goals and did not dedicate much of their discussions to this topic. Our first semester students, who had only been in teams for one week, offer an opposing view that the timing of goal planning was helpful to their conceptualization of the project scope. The message is that these early supports are important, and timing is critical to align with the team's development.

Before we leave DiCoT we must address Webb's additions relating to the development of practice and practitioners. As noted, we did not design specifically for these two heuristics since they related to longitudinal team development issues. However, they are essential aspects of team health that should not be ignored. We harvested comments relating to these principles as they arose in other focus session discussions topics and our students clearly recognise their importance regarding academic success. Professional development is a learning outcome of the CHARM-EU M.Sc. and therefore our students were primed to recognise this, however professional development is an established and well addressed need in corporate teamwork too and we would expect most graduates to be conscious of this fact. We received scant comments relating to the development of practitioners specifically, aside from comments relating to skills gaps that the team had identified. We received more comments on the development of practice where students considered that repeat sessions using the TTT would be helpful for ensuring work would not drift from the project goals. This type of reflective course correction approach is commonly used in Agile cycles, and it is encouraging to note that students were able to foresee the need to reflect and understand how practice affects team performance.

To round out our section on Distributed Cognition, we wondered if our students had any other undisclosed thoughts about their activity experience. To enquire, we asked a general follow-up question at this point to see if students held any additional views about what other ways the experience supported (or hindered) their team interactions. A selection of positive responses echoing earlier comments was given which relate to raising difficult topics.

> *"it opened doors for us to discuss things that maybe had been avoided up until that point"*

This is an example of a situation where naturalness is unwanted, since the natural approach by the admission of the participant is to ignore some difficult topics. As such the tool mediates and enables a distributed cognition that might not otherwise occur. We can frame this as a tertiary tension between the team's typical approach and the newer techno-social approach used during our intervention. Using an artefact to mediate the discussion helped to surface difficult topics in a non-confrontational way that did not risk the emotional security of the group.

6.2.5 Social presence commentary

Our study employed sharing of social cues to scaffold hybrid team discussions and we examined interpretation challenges experienced by some students with additional comments from a mature student that question the appropriateness of using such cues in serious contexts. However, we were less interested in attitudes relating to our design or even students' accuracy of interpretating cues. Instead, our study focused on the resulting conversations that the sharing acted to scaffold and the negotiation of ideas that would lead students to reflect on their own sentiments, and we note positive outcomes and encouraging student comments regarding our heuristics relating to this learning goal.

As noted in our literature review (section 2.4.4) there are a plurality of definitions of social presence. The concept has evolved from Short et al.'s interpretation of social presence as a property of a medium. Biocca, Harms, & Burgoon (2003) framed it as a variable value that changes from moment to moment, based on the influence of numerous factors. Their definition moved from a one-sided interpretation to one that included the feelings that are perceived about others. This switches to a definition based on reciprocal behaviour (I perceive you, you perceive me), which frames social presence as an active process rather than a static value like a mediums capacity to transmit a signal. In this revision of social presence, individuals may experience it to varying degrees during an interaction due to a variety of influencing factors, chief of which is the subjective nature of individual human experience. Our study avoids the need to measure social presence by focusing on the outcomes of the experience. The current research is educational rather than psychological and it is sufficient to say that the sharing of social cues should have 'some impact' that induces the perceiver to reflect on its meaning.

6.3 Study Contributions

The current work represents an empirical contribution to the study of student team learning that is both theoretical and practical. Our study provides tools, methods and insights that may be applied in real-world educational settings.

- Sixteen tested and refined Design Heuristics across four categories to design XR novice transdisciplinary teamwork supports.

- Design and implementation of a Transdisciplinary Teamwork Tool exemplar implementation of design heuristics, and validation in a hybrid classroom-based team activity intervention.
- A methodological contribution expanding the use of Activity Theory and AODM to explore tensions in hybrid transdisciplinary team collaboration, expanded by Bligh and Flood’s Change Laboratory Toolkit.

6.4 Limitations of the study

Bias and subjectivity are inherent in all research, and it is important not just to recognise this but to respond to it. Our study relied on feedback from students, programme staff and our peers but despite numerous perspectives, the research is still situated in a particular context and informed by a limited set of views generated by individuals from a limited range of socioeconomic demographics.

During our analysis, we noted factors beyond the scope of our design that could influence participant perspectives. Personality and disposition may act to modify student response and a consideration of psychometric profiling such as Big 5 might help to inform the work. Additionally, internal team factors can influence feedback, such as a lack of emotional security within a team. This limit could be addressed by measuring emotional security within the target cohort and a longitudinal study would suit such an approach to allow for iterative measurements. A longer study would also allow for a more considered treatment of Webb’s additional DiCoT principles relating to development of practice and practitioners which we were unable to explore with a single intervention per cohort.

Our focus sessions uncovered inclusion issues relating to age and gender, i.e. preferences regarding emoticons and preferences for a longer scale length. These shortcomings related to our design implementation rather than the heuristics however they represent important considerations for improving the TTT intervention.

Mwanza’s AODM technique is an uncommon approach, albeit one that is gaining traction. Although the process is well scaffold with its own toolkit for guiding its application in research context, it is still a relatively unknown method, meaning that our own application of AODM has been informed by few studies (Mwanza, Greenhow & Belbas, and Dolonen), and as Greenhow & Belbas note, AODM must be interpreted for use in a particular context.

Our study relies heavily on student feedback, and one may question whether this can be viewed as a stable form of knowledge. The field of XR is moving quickly and impressions of the technology that persist today may become irrelevant in the near future. Use of heuristics helps to mitigate this as heuristics may be implemented in different modalities and future contexts, however there is still an inherent risk in this approach.

Two of our participants mentioned motivations for mutual accommodation that suggested a degree of groupthink could be at play in their teams. We discussed the negative impact of groupthink on team health, and we proposed improvements to our pre-instruction to students to reduce this. While better instructions to students can be helpful, groupthink is a limiting factor that conflates participant feedback by homogenising it to the team norm, and we are wary of the impartiality of feedback in cases where groupthink is evident.

The cycle 3 artefact implementation was only one interpretation of the heuristics and ended up being a more simplified traditional application augmented by the Teams collaborative tools. This approach did not push the full potentialities of XR.

6.5 Future Research Directions

Our cycle 3 intervention operationalises the transmission of social cues to stimulate reflection within team members. We have argued that the measurement of social presence is beyond the scope of our study, since we focus on the resulting discussions that arise due to these reflections. However, a measurement of the experience of social presence may inform alternative design implementations of our heuristics, such as more immersive XR environments. An example from our data showed that a mature student did not appreciate the use of emoticons for serious discussion topics, and this may have reduced their experience of social presence. A future study could consider this using a validated approach such as the Social Presence Coding Scheme (Rourke, Anderson, Garrison and Archer, 1999; Polhemus, Shih & Swan, 2001; Swan, 2002, cited in Whiteside, 2015), or newer activity informed approaches such as the Social Presence Behavioural Coding Scheme (Hayes, Hughes and Bailenson, 2022), or indeed Community of Inquiry informed approaches such as Guo et al. (2021) have proposed.

Each of our interventions were limited to a single session (or two in the case of our cycle 3 database error). As such we were not able to explore Webb’s additions to DiCoT fully from our cohorts’ perspectives. Ongoing training and development are core activities in most human resource departments, and clearly at the heart of any educational programme, so the requirement for development is well understood. A study designed to investigate these themes would need to be longitudinal if measurement of development is desirable, or clarity on the cause of hidden tensions is needed. In terms of educational value, a longer study offers potential to scaffold double stimulation tasks to support expansive learning activities. Engeström's work with the Change Laboratory design highlights this need to give time for students to overcome hurdles and develop insights. Although our cycle 3 intervention took place over a single session, the TTT artefact was designed to support a longer Change Laboratory format. Inspirational mirror data, a model-vision reference section and a note taking tool (team discussion topics) were included as part of our design such that the TTT could be deployed in a Change Laboratory study. We consider this a logical next step for our work, which would generate longitudinal data relating to ongoing development of practice and of practitioners.

We noted in our limits section that conflating factors such as the degree of emotional security or psychometric differences could influence participant response. A sensible improvement to our approach would be to include psychometrics such as Big 5 to help understand individual members motivations, and an evaluation of the degree of psychological safety in the team (Edmondson, et al., 2024).

While we went to lengths to discuss our approach with our peers and members of the CHARM-EU community, AODM has limited uptake, and we are not aware of any peers using Mwanza's techniques. Our study would therefore benefit from an interrater evaluation of our AODM analysis to offer a further perspective on our conclusions.

In our study we illustrated tensions experienced by team members using AODM to conceptualise the source of the tension. Our study highlighted tensions resulting from the interplay of AT factors, however we did not go into depth to uncover tensions that result from the interplay of the disciplinary perspectives. Transdisciplinary projects involve a unique blend of disciplines, and each team must negotiate their own unique integration steps. An analysis to contrast incompatible ontological perspectives was beyond the scope of this research but may benefit teams. A future study could incorporate design heuristics that scaffold transdisciplinary alignment on a case-by-case basis to offer more targeted support.

Recent advances in algometric and deep learning approaches to team composition (Georgara, et al., 2025) highlight the benefits of composing teams that are fit for a specified purpose. This aligns with established views of team coaching (Whitmore, 2002) that seek to compose teams based on the skills needed to address specific projects. While this approach offers good outcomes it is at odds with our aspiration to develop teamworking competencies in team members. Predesigned teams may offer better teamworking experiences, but they consequently reduce the learning potential for members to negotiate and overcome challenges. Artificial intelligence may yet offer an additional research focus for our project by detailing extra team health metrics that could help to scaffold team mental models.

6.6 Implications for practice/praxis

Those responsible for forming teams should consider the many factors that influence interpersonal relations within teams, but especially educators forming novice student teams. An AODM informed exploration of student tensions has been helpful in our research, and we recommend its potential for investigating dynamic team learning contexts. Third generation activity theory offers a lens to consider the culturally historical causes of tensions, which may be helpful for defusing them. Participant feedback indicated that reflecting on the elements of AODM was helpful when thinking about team project scope and transdisciplinary integration issues, and we would recommend approaches like our cycle 2 worksheet and cycle 3 TTT exemplar artefact to empower students in identifying and addressing such issues in their teamwork.

Whilst discussing our heuristics in the cycle 3 focus sessions, we noted feedback on an unrelated hybrid teamwork challenge concerning situations where multiple hybrid teams need to work independently within the same set of physical spaces (i.e. multiple classrooms with team members spread across each location). This tension relates to noise levels and setup time when beginning the exercise, since numerous teams were trying to start their hybrid team calls at the same time. Engeström would characterize this as a quaternary tension that arises due to the existence of a shared objective across neighbouring activity systems (figure 6-2).

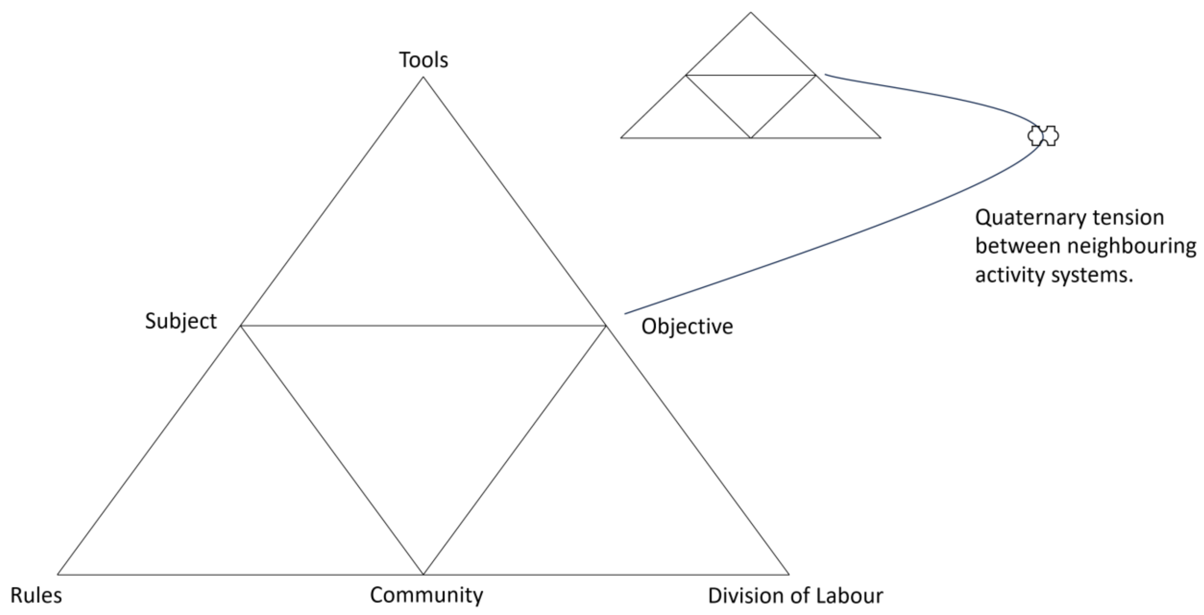


Figure 6-2. Logistical tension for multiple co-located hybrid teams, observed in the CHARM-EU hybrid classroom context.

While this would not be a concern for any one individual hybrid team, it does represent a considerable inclusivity challenge for settings such as CHARM-EU with multiple co-located teams working in parallel.

6.7 Closing comments

Education is a fundamental aim of the United Nations' sustainable development 2030 agenda and technology assisted learning offers the possibility to scale educational programmes to meet such an ambitious goal. We live in a time when the world faces challenges and wicked problems unlike anything we have encountered thus far. Curricula can be a transformational force to address these challenges, and transdisciplinary teamwork offers the adaptability and breath of skills required to engage with such complex issues. Increasing hybrid work and distributed project teams means that technology mediation will be a factor in the success of these efforts. Mixed reality can contribute enormously here for its capacity to foster empathy and perspective taking by creating emotional connections, which is essential in an era of increasingly distributed and hybrid teamwork, and a skill that is growing in demand from employers. Rapid technology adoption that jumps a computing generational paradigm is not unprecedented, such as has happened in Africa with mobile phones giving much of the population their first exposure to the Internet rather than desktop or laptop devices. But regardless of when mass XR adoption occurs, it has begun, and adoption is unlikely to slow down as fidelity and user experience continue to advance. Our Transdisciplinary Teamwork Tool is a minimal implementation of the types of emotional connections that future technologies will mediate. The heuristics on which the TTT is based aim to support hybrid transdisciplinary novice teams in many technology contexts. Mixed reality experiences such as the live collaborative social feedback features used in the TTT are already becoming embedded into everyday life via the devices we carry, and increasingly immersive paradigms seem likely to be developed. It behoves us to understand the ramifications of adopting any new tool but especially one that will shape human cognition so persuasively. We are entering a new era of human societal development where knowledge-based occupations will be increasingly outsourced to artificial agents, and where transversal skills become the only advantage that we humans have over AI. We deliberately avoid the maxim 'mere human' in making this statement to emphasise the importance of human centric technology solutions. Human connections are increasingly being mediated by technology platforms that view their users as a form of exploitable capital, and socio-technical researchers have a duty to decry the corrosive influence of user engagement strategies that hijack human emotions. For sincere, meaningful and open conversations to be possible, it is necessary to become conscious of the influences of technology-mediated communication on our minds and on our future societies. The relevant literacies for hybrid and distributed teams depend on continuous development of interpersonal skills and the capacity to reflect critically on the messages that we interpret via the medium.

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8 Appendices

8.1 Appendix 1. TTT Database Schema

```
CREATE TABLE `ratings` (
  `id` int NOT NULL AUTO_INCREMENT,
  `user_id` int NOT NULL,
  `topic_id` int NOT NULL,
  `score` int NOT NULL,
  `created_at` datetime NOT NULL,
  `updated_at` datetime NOT NULL,
  PRIMARY KEY (`id`),
  KEY `FK1_rating_user` (`user_id`),
  KEY `FK2_rating_topic` (`topic_id`),
  CONSTRAINT `FK1_rating_user` FOREIGN KEY (`user_id`) REFERENCES `users` (`id`) ON DELETE CASCADE ON UPDATE CASCADE,
  CONSTRAINT `FK2_rating_topic` FOREIGN KEY (`topic_id`) REFERENCES `topics` (`id`) ON DELETE CASCADE ON UPDATE CASCADE
)

CREATE TABLE `users` (
  `id` int NOT NULL AUTO_INCREMENT,
  `name` varchar(255) CHARACTER SET utf8mb4 COLLATE utf8mb4_unicode_ci DEFAULT NULL,
  `email` varchar(255) CHARACTER SET utf8mb4 COLLATE utf8mb4_unicode_ci NOT NULL,
  `first_name` varchar(50) CHARACTER SET utf8mb4 COLLATE utf8mb4_unicode_ci NOT NULL,
  `discipline` varchar(50) CHARACTER SET utf8mb4 COLLATE utf8mb4_unicode_ci NOT NULL,
```

```
  `email_verified_at` timestamp NULL DEFAULT NULL,
  `password` varchar(255) CHARACTER SET utf8mb4 COLLATE utf8mb4_unicode_ci DEFAULT NULL,
  `remember_token` varchar(100) CHARACTER SET utf8mb4 COLLATE utf8mb4_unicode_ci DEFAULT NULL,
  `created_at` timestamp NULL DEFAULT NULL,
  `updated_at` timestamp NULL DEFAULT NULL,
  PRIMARY KEY (`id`),
  UNIQUE KEY `users_email_unique` (`email`)
)

CREATE TABLE `topics` (
  `id` int NOT NULL AUTO_INCREMENT,
  `creator_id` int NOT NULL,
  `team_id` int DEFAULT NULL,
  `created` timestamp NOT NULL DEFAULT CURRENT_TIMESTAMP ON UPDATE CURRENT_TIMESTAMP,
  `status` int DEFAULT NULL,
  `topic_text` text CHARACTER SET utf8mb4 COLLATE utf8mb4_general_ci NOT NULL,
  `is_system` tinyint(1) DEFAULT '1',
  `created_at` datetime DEFAULT NULL,
  `updated_at` datetime DEFAULT NULL,
  `is_previous_year` tinyint(1) NOT NULL DEFAULT '0',
  PRIMARY KEY (`id`),
  KEY `FK1_topic_user` (`creator_id`),
  KEY `FK2_topic_team` (`team_id`),
```

```
  CONSTRAINT `FK1_topic_user` FOREIGN KEY (`creator_id`) REFERENCES `users` (`id`) ON DELETE RESTRICT ON UPDATE RESTRICT,
  CONSTRAINT `FK2_topic_team` FOREIGN KEY (`team_id`) REFERENCES `teams` (`id`) ON DELETE CASCADE ON UPDATE CASCADE
)

CREATE TABLE `teams` (
  `id` int NOT NULL AUTO_INCREMENT,
  `name` varchar(50) NOT NULL DEFAULT '',
  PRIMARY KEY (`id`)
)
```

8.2 Appendix 2. Instruments and Interview Protocols.

8.2.1 Cycle 1 Participant Survey Instrument

This instrument was adapted to focus on student attitudes to transversal skills and XR rather than frequency of activities. While this does undermine the validity of the instrument, the purpose was exploratory and aimed to sensitise the researcher to the problem space rather than make claims of statistical relevance regarding the cohort.

The original instrument asked:

How do you do the following? ('Almost never'; 'A few times a semester'; '1--3 times per month'; '1--3 times per week'; 'Almost daily')

The modified instrument asked:

I am confident that Mixed Reality would be helpful for me to... ('Strongly Agree', 'Agree', 'Don't know / Neutral', 'Disagree', 'Strongly disagree')

Author	Year
Ravitz et al.	2012

Compare information from different sources before completing a task or assignment?

Draw your own conclusions based on analysis of numbers, facts, or relevant information?

Summarize or create your own interpretation of what they have read or been taught?

Analyze competing arguments, perspectives or solutions to a problem?

Develop a persuasive argument based on supporting evidence or reasoning?

Try to solve complex problems or answer questions that have no single correct solution or answer?

Work in pairs or small groups to complete a task together?

Work with other students to set goals and create a plan for their team?

Create joint products using contributions from each student?

Present their group work to the class, teacher or others?

Work as a team to incorporate feedback on group tasks or products?

Give feedback to peers or assess other students' work?

Structure data for use in written products or oral presentations (e.g., creating charts, tables or graphs)?

Convey their ideas using media other than a written papers, posters, video, blogs, etc.)

Prepare and deliver an oral presentation to the teacher or others?

Answer questions in front of an audience?

Decide how they will present their work or demonstrate their learning?

Use idea creation techniques such as brainstorming or concept mapping?

Generate their own ideas about how to confront a problem or

question? Test out different ideas and work to improve them?

Invent a solution to a complex, open--ended question or problem?

Create an original product or performance to express their ideas?

Take initiative when confronted with a difficult problem or question?

Choose their own topics of learning or questions to pursue?

Plan the steps they will take to accomplish a complex task?

Choose for themselves what examples to study or resources to use?

Monitor their own progress towards completion of a complex task and modify their work accordingly?

Use specific criteria to assess the quality of their work before it is completed?

Use peer, teacher or expert feedback to revise their work?

Study information about other countries or cultures?

Use information or ideas that come from people in other countries or cultures?

Discuss issues related to global interdependency (for example, global environment trends, global market economy)?

Understand the life experiences of people in cultures besides their own?

Study the geography of distant countries?

Reflect on how their own experiences and local issues are connected to global issues?

Investigate topics or issues that are relevant to their family or community?

Apply what they are learning to local situations, issues or problems?

Talk to one or more members of the community about a class project or activity?

Analyse how different stakeholder groups or community members view an issue?

Respond to a question or task in a way that weighs the concerns of different community members or groups?

Use technology or the Internet for self--instruction (e.g., Kahn Academy or other videos, tutorials, self--instructional websites, etc.)?

Select appropriate technology tools or resources for completing a task?

Evaluate the credibility and relevance of online resources?

Use technology to analyse information (e.g., databases, spreadsheets, graphic programs, etc.)?

Use technology to help them share information (e.g., multi--media presentations using sound or video, presentation software, blogs, podcasts, etc.)?

Use technology to support teamwork or collaboration (e.g., shared workspaces, email exchanges, giving and receiving feedback, etc.)?

Use technology to interact directly with experts or members of local/global communities?

Use technology to keep track of their work on extended tasks or assignments?

8.2.2 Cycle 2 Interview Protocol

PART 1 (WARMUP).

See Ravitz, (2010) instrument used in cycle 1.

PART 2.

Category	Source	Question	Additional indicators	Priority
Social Presence Indicators	(Short, Williams and Christie, 1976)	How likely are you to experience the following during online work (vs offline)	**Did they experience?**	
	Argyle and Dean (1965)	Intimacy	physical distance, eye contact, smiling, and personal topics of conversation	High
	Wiener and Mehrabian (1968)	Immediacy	a measure of psychological distance	Low
Three categories of social expressions	(Rourke, Anderson,	**Categories**	**Indicators**	High

	Archer, and Garrison, 1999)			
		Affective	Expression of emotions	High
			Humour	High
			Self-disclosure	High
		Interactive	Continuing a thread	High
			Quoting from other messages / threads	High
			Referring directly to other messages	High
			Asking questions	High
			Complementing, expressing appreciation or agreement	High
		Cohesive	Vocalizations / Vocatives	High
			Inclusive pronouns	High
Social Presence Scale	(Gunawardena & Zittle, 1997)	When I have real-time conversations in this CSCL environment, I have my communication partner in my mind‟s eye		

		When I have asynchronous conversations in this CSCL environment, I also have my communication partner in my minds eye		
		When I have real-time conversations in this CSCL environment, I feel that I deal with very real persons and not with abstract anonymous persons		
		When I have asynchronous conversations in this CSCL environment, I also feel that I deal with very real persons and not with abstract anonymous persons		
		Real-time conversations in		

		this CSCL environment can hardly be distinguished from face-to-face conversations		
AT Intervention	Lenotiev	How did it contribute to your team dynamics		High

PART 3.

Review worksheet details with each team if time permits. As about the details they provided.

8.2.3 Cycle 3 Interview Protocol

PART 1 (WARMUP). Transversal skills / profile equivalence. 21st Century Skills Questions, (Ravitz, et al., 2012).

See Ravitz, (2012) instrument used in cycle 1.

PART 2. Focus session questions

Heuristic Code	Cycle 1 Heuristics	Related design feature	initial question	Post AODM rework of the question
Cycle 1 Heuristics				
c1a	Don't assume users will recognise UI controls	Information from the instructor. In app help = Modal info windows	How clear was the UI Did the instructions help you understand how to use the tool?	What were your impressions of the instructions for the activity/app?

c1b	Our tool should provide detailed instructions	Information from the instructor. In app help = Modal info windows	What did you think about the info provided?	What were your impressions of the instructions for the activity/app?
c1c	XR onboarding is difficult for new users	Information from the instructor. In app help = Modal info windows	What did you think about the info provided?	What were your impressions of the instructions for the activity/app?
Cycle 2 Heuristics				
c2a	Remote teams experience reduced social presence and often miss social cues.	Build in a clear, easy way to share cues	Seek feedback on seeing others sentiments and the idea of a team average?	What did the emoticons make you feel about your team / teammates? What about the team average values?
c2b	Interface controls that represent analogues of social cues should not feel unnatural to users.	Use sliders for a recognisable and low effort UI	Thoughts on use of sliders to share sentiment - how accurate do you think it can be for sentiment expression?	How well do you feel you could express your sentiment using the emoticon sliders?
c2c	Hybrid students want to get to know each other (not part of earlier set - later analysis)	Include team member details (profile data) to support team relationship	How did the team avatars and team average avatar make you feel?	Do you feel that you know your teammates better after the activity? How did the interface influence that?

		building and a team average avatar to promote team alignment sentiment.		
Teamwork heuristics				
th1	Tool should adapt to the users changing requirements	User defined topics	How useful do you think the user defined topic list was? might be over time?	Question: th1a: How useful do you think the user defined topic list was, and might be over time? Question: th1b: How might you use it? Change using it, over time?
th2	Support intra-team feedback	User defined topics and live team members feedback	How, did the tool contribute to giving and receiving feedback? (and to what extent)	th2a: How useful was the feedback? th2b: How might the topics be useful for feedback?
th3	Support different roles and responsibilities	All live feedback will be visible to every team member so that any (or every) member can lead the discussion.	If you discussed the team suggested challenges, how did you organise the discussion? How could a session like this (this type of tool and activity) support you in different team roles?	If you discussed the team suggested challenges, how did you organise the discussion? How could a session like this (this type of tool and activity) support you in different team roles?
th4	team mission objectives and norms	Design Rule th4: Promote Shared Mental	In what ways did the activity help to clarify aspects of your	tmm1

		Model building through scaffolded team interactions	teamwork and approach to your team project?	
th5	(consider) the environmental context	Mobile first design	How well do you think it worked as a hybrid classroom-based activity? How might this be useful outside of the classroom?	How well do you think it worked as a hybrid classroom-based activity? How might this be useful outside of the classroom? (MOBILE USAGE)
th6	Foster team familiarity (to build affiliative associations)	Intervention design (explain your sentiment to your peers)	Did you discover any (interesting/unexpected) KSA's within your team? (that might contribute to your work together? Was that helpful?	Did you discover any (interesting/unexpected) KSA's within your team? (that might contribute to your work together? Was that helpful?
th7	Be specific in communications	Use multistep sliders to simplify the sharing of data	how expressive do you think emoticons are in general? When paired with slides like in the tool? What about contrasted?	c2b
th8	Recognise and manage relative priorities	An aggregated smiley feature can highlight issues to help the team to recognise relative priorities	What did you think about the team average emoticon?	c2c

th9	Employ a clear working approach	1. Multistep slider 2. User defined topics	How might the sliders for your own team topics help you to expressive yourself more clearly?	c2b
Team mental model heuristic				
tmm1	Mental representations of the key elements within a team's relevant environment that are shared across team members	Intervention design rules (share and explain your sentiments) and sychronous feedback to all team members	How might this activity help you to track the key elements of your work?	How might this activity help you to track the key elements of your work?
DCog heuristics				
dc1	Embodiment of information within the system	Live Feedback	How useful / informative, was the feedback?	th2
dc2	Co-ordination between agents,	Live Feedback & user defined topics	Did you update any values when you saw the other team members / team average?	Did you update any values when you saw the other team members / team average?
dc3	The impact of set and setting (ecosystem) on the process taking place.	Responsive Design	Responsive Design?	th5
dc4	Cognitive process is delimited by the functional	Include live feedback user defined topics to support	Did you discuss the task together? How did you interact when using it?	Did you discuss the task together? How did you interact when using it?

	relationships among the members	asynchronous roles	Did you all use it the same way at the same time?	Did you all use it the same way at the same time?
			In what other ways did the tool support (or hinder) your interactions	In what other ways did the tool support (or hinder) your interactions?
DiCoT heuristics				
dc5	Physical Layout: Space and Cognition	PLOs as the first items above the fold	Seeing the PLOs as the first items, any thoughts? How did it contribute to being able to have your challenges discussion?	How did working with the PLOs first contribute to being able to have your challenges discussion?
dc6	Physical Layout: Subtle Bodily Supports	Mobile first design	Any mobile users?	th5
dc7	Physical Layout: Situation Awareness	Scaffolded discussion topics: PLOs and learner defined team topic discussions are part of the intervention	How well do you think using this activity helped you to conceptualize how you're going to work on your project?	How did the activity and tool structure help you to understand the aims of the discussion (i.e. to recognise and begin to conceptualise your team challenges)
dc8	Information flow: Buffering		Did topics get queued? How did you manage the queue?	Did topics get queued? How did you manage the queue?
dc9	Artefacts: Representation – Goal Parity	Their goal is learning how they can reach an accurate	In what ways are you clearer about your team project and teamwork	In what ways were your team clearer about your team project and

		and aligned shared mental model of the team project... help students recognise an "explicit representation of the relationship" between the current state and a goal state"(B&F, 2005)	goals following the activity?	teamwork goals following the activity?
dc10	Artefacts: Coordination of Resources	Team members are encouraged to discuss ways to overcome challenges that they see in the default topics and user added topics, in support of the Coordination of Resources principle.	What aspects of planning did you discuss?	Question: dc11a: What aspects of planning did you discuss? Question: dc11b: How did the activity and tool support that discussion?
dc11	Development of practice	Create opportunities for team	Question dc12: How useful do you feel the overall experience was	Potential Team charter connection?

		member reflection through team feedback.	to your skill development?	
dc12	Development of practitioners	Create opportunities for team member reflection through team feedback.	Question dc13: How might it help you to develop new team processes over time?	Potential Team charter connection?

8.3 Appendix 3. Cycle 1 survey data

Cycle 1, pre-test survey.

Compare information from different sources before completing a task or assignment	**Draw my own conclusions based on analysis of numbers, facts, or relevant information**	**Summarize or create my own interpretation of what I have read or been taught**	**Analyze competing arguments, perspectives or solutions to a problem**	**Develop a persuasive argument based on supporting evidence or reasoning**	**Try to solve complex problems or answer questions that have no single correct solution or answer**	**Work in pairs or small groups to complete a task together**	**Work with other students to set goals and create a plan for my team**
4	4	4	4	3	3	4	5

4	5	5	4	4	4	4	4
5	4	5	5	4	4	5	5
4	4	3	4	4	4	4	4
4	4	4	4	3	4	4	4
5	5	4	4	4	4	5	5
4	4	4	4	4	4	5	5
4.29	**4.29**	**4.14**	**4.14**	**3.71**	**3.86**	**4.43**	**4.57**
Create joint products using contributions from each student	**Present my group work to the class, teacher or others**	**Work as a team to incorporate feedback on group tasks or products**	**Give feedback to peers or assess other students' work**	**Structure data for use in written products or oral presentations (e.g., creating charts, tables or graphs)**	**Convey my ideas using media other than a written papers, posters, video, blogs, etc.)**	**Prepare and deliver an oral presentation to the teacher or others**	**Answer questions in front of an audience**
4	4	4	4	4	3	4	4
4	3	3	3	4	2	3	4
5	4	4	5	4	4	5	4
3	3	3	4	4	4	4	4
4	4	4	4	4	4	4	4
4	4	4	4	5	5	4	4
5	4	4	4	4	4	4	4
4.14	**3.71**	**3.71**	**4.00**	**4.14**	**3.71**	**4.00**	**4.00**
Decide how they	**Use idea creation**	**Generate my own**	**Test out different**	**Invent a solution**	**Create an**	**Take initiative**	**Choose my own topics**

will present my work or demonstrate my learning	**techniques such as brainstorming or concept mapping**	**ideas about how to confront a problem or question**	**ideas and work to improve them**	**to a complex, open-¬-ended question or problem**	**original product or performance to express my ideas**	**when confronted with a difficult problem or question**	**of learning or questions to pursue**
4	4	4	4	4	4	4	4
4	4	4	3	4	3	2	3
5	4	4	5	5	4	4	5
4	4	4	4	4	4	4	3
4	4	4	4	4	4	4	4
4	4	4	4	4	4	5	4
4	4	4	4	4	4	4	4
4.14	**4.00**	**4.00**	**4.00**	**4.14**	**3.86**	**3.86**	**3.86**
Plan the steps I will take to accomplish a complex task	**Choose for myself what examples to study or resources to use**	**Monitor my own progress towards completion of a complex task and modify my work accordingly**	**Use specific criteria to assess the quality of my work before it is completed**	**Use peer, teacher or expert feedback to revise my work**	**Study information about other countries or cultures**	**Use information or ideas that come from people in other countries or cultures**	**Discuss issues related to global interdependency (for example, global environment trends, global market economy)**
4	4	4	2	4	5	4	5
4	3	4	4	4	4	4	4

5	3	3	3	5	5	5	5
4	4	3	4	3	4	4	4
4	4	4	4	4	4	4	4
5	4	4	4	5	5	4	5
4	4	4	4	4	4	5	4
4.29	**3.71**	**3.71**	**3.57**	**4.14**	**4.43**	**4.29**	**4.43**
Understand the life experiences of people in cultures besides my own	**Study the geography of distant countries**	**Reflect on how my own experiences and local issues are connected to global issues**	**Investigate topics or issues that are relevant to my family or community**	**Apply what I am learning to local situations, issues or problems**	**Talk to one or more members of the community about a class project or activity**	**Analyze how different stakeholder groups or community members view an issue**	**Respond to a question or task in a way that weighs the concerns of different community members or groups**
5	5	4	5	4	5	5	4
4	4	4	4	4	3	4	4
4	4	5	5	5	4	5	4
4	4	4	4	4	4	4	4
4	4	4	4	4	4	4	4
5	4	4	5	5	5	5	5
3	4	4	4	4	4	4	4
4.14	**4.14**	**4.14**	**4.43**	**4.29**	**4.14**	**4.43**	**4.14**
Use technology or the	**Select appropriate**	**Evaluate the credibility**	**Use technology to**	**Use technology to**	**Use technology to**	**Use technology to**	**Use technology to keep**

Internet for self-instruction (e.g., Kahn Academy or other videos, tutorials, self-instructional websites, etc.)	technology tools or resources for completing a task	and relevance of online resources	analyze information (e.g., databases, spreadsheets, graphic programs, etc.)	share information (e.g., multimedia presentations using sound or video, presentation software, blogs, podcasts, etc.)	support teamwork or collaboration (e.g., shared work spaces, email exchanges, giving and receiving feedback, etc.)?	interact directly with experts or members of local/global communities	track of my work on extended tasks or assignments
5	5	5	5	4	5	2	5
3	2	3	2	2	2	3	3
3	2	4	5	4	5	3	2
4	4	4	4	4	4	4	4
4	4	4	4	4	4	4	4
4	4	5	5	4	4	4	4
4	4	4	3	4	4	4	5
3.86	**3.57**	**4.14**	**4.00**	**3.71**	**4.00**	**3.43**	**3.86**

Cycle 1, post-test survey scores and averages.

Compare information from different sources before completing a task or assignment	Analyse competing arguments, perspectives or solutions to a problem	Try to solve complex problems or answer questions that have no single correct solution or answer	Work in pairs or small groups to complete a task together	Work with other students to set goals and create a plan for their team	Create joint products using contributions from each student	Present their group work to the class, facilitators or others	Work as a team to incorporate feedback on group tasks or products
3	3	3	4	4	4	4	4
3	2	2	4	3	3	4	3
3	4	1	1	1	1	3	4
3	3	3	4	3	3	4	3
4	4	3	4	3	4	2	3
3.2	**3.2**	**2.4**	**3.4**	**2.8**	**3**	**3.4**	**3.4**
Give feedback to peers or assess other students' work	**Structure data for use in written products or oral presentations (e.g., creating charts, tables or graphs)**	**Convey their ideas using media other than a written papers, posters, video, blogs, etc.)**	**Prepare and deliver an oral presentation to the teacher or others**	**Answer questions in front of an audience**	**Use idea creation techniques such as brainstorming or concept mapping**	**Generate my own ideas about how to confront a problem or question**	**Test out different ideas and work to improve them**
4	4	4	4	4	4	3	4
3	2	4	4	2	3	2	4

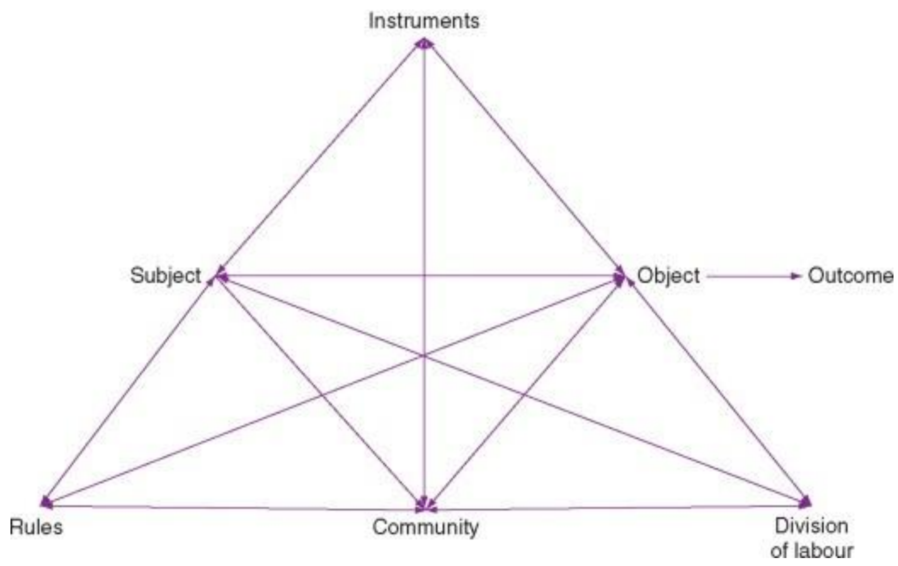
1	3	4	4	4	4	3	4
3	2	3	4	4	3	3	3
3	2	3	2	3	3	3	3
2.8	**2.6**	**3.6**	**3.6**	**3.4**	**3.4**	**2.8**	**3.6**
Invent a solution to a complex, open--ended question or problem	**Create an original product or performance to express my ideas**	**Take initiative when confronted with a difficult problem or question**	**Plan the steps I will take to accomplish a complex task**	**Monitor my own progress towards completion of a complex task and modify their work accordingly**	**Analyse how different stakeholder groups or community members view an issue**	**Respond to a question or task in a way that weighs the concerns of different community members or groups**	**Use as an tool for my own self--instruction (e.g., watching Kahn Academy or other videos, tutorials, self--instructional websites, etc.)**
3	4	4	3	4	4	4	2
3	3	3	3	4	4	4	4
4	4	3	4	2	3	4	2
3	4	3	3	3	3	3	4
2	3	2	3	3	3	3	4
3	**3.6**	**3**	**3.2**	**3.2**	**3.4**	**3.6**	**3.2**
Select appropriate technology tools or	**Evaluate the credibility and relevance**	**Analyse information (e.g., databases, spreadshe**	**Share information (e.g., multi--media presentati**	**Support team work or collaboration (e.g., shared**	**Interact directly with experts or members of**	**Keep track of my work on extended tasks or assignments**	

resource s for completi ng a task	of online resources	ets, graphic programs, etc.)	ons using sound or video, presentati on software, blogs, podcasts, etc.)	work spaces, email exchange s, giving and receiving feedback, etc.)	local/glob al communit ies	
4	2	4	4	4	4	2
4	4	4	4	4	4	4
4	2	2	1	4	4	2
3	2	4	4	4	3	3
3	3	3	4	4	4	4
3.6	**2.6**	**3.4**	**3.4**	**4**	**3.8**	**3**

8.4 Appendix 4. Cycle 2 student worksheet example.

An activity model to support the cohesiveness and effectiveness of remote teams.

In this exercise you are asked to consider your teamwork through the lens of Cultural Historical Activity Theory, to recognise the variety of socio-cultural factors that will influence your project.



A socially distributed Activity System, (Engeström, 1987)

Steps

1. **[SECTION 1]** Team should conduct a discussion to produce a list of factors for each of the CHAT attributes. Some topic suggestions are provided in the boxes below to help you begin, but you should add other factors that are specific to your own team and project. Try to be as specific as possible. **(4x5 minutes = 20 minutes)**
2. Team conduct a discussion to explore how the different factors might influence each other. (10 minutes)
3. Team tries to identify and list any tensions that may arise due to conflicting requirements or other constraints in the system, i.e. from the list of factors. Suggestions:

4. Tensions between element of an activity, e.g. usability,
5. Tensions between your current activity and some future iteration of the same activity
6. Tensions relating to division of labour
7. Etc.
8. (10 minutes)
9. Do not linger on unanswered questions but do make a note of these for later.
10. **[SECTION 2]** Team briefly discuss how to respond to the identified tensions. **(15 minutes)**

Section 1

Subject: **[REDACTED]** Environmental monitoring

Object(ive): Project completion / handover / academic submission

Rules

Societal norms, academic standards, quality, legal, etc.

-South African laws: visa requirements etc.

-French laws

-Academic: UM and UP ethical considerations

-Societal norms within South African society and the Indigenous Mnisi community

Division of Labour

List of team roles, third party services or suppliers, Any other external actors? How do they influence each other?

-Project manager

-External stakeholder manager

-Visual communications officer

-Research coordinator

-Logistics coordinator (for field work)

-Ethics officer

External actors:

-UP coordinators: **[REDACTED]**

-Academic supervisor: **[REDACTED]**

-UM teaching assistant: **[REDACTED]**

Tools

Examples, MS Teams, Office, Flexible Apps, Computer hardware…. ask yourself, what tools influence our workflows (positive and negative)

-MS teams

-Office

-Adobe suite for visuals (Premiere, Photoshop, Indesign) or Canva

-Whatsapp for instant communications

-Outlook for email

-Trello or Slack?

Tensions

List any tensions that you see between the identified factors

-Communication and cultural tensions between South African, Indigenous and French stakeholders

-Inequal division of labor between teammates

Community

Project Stakeholders, Family, Academic Community, Special Interest Groups, etc.

-CHARM-EU teachers

-CHARM-EU peers

-Student's families

-Indigenous advocacy groups: Association Jiboiana

-Environmental conservation groups: Greenpeace etc

-University of Montpellier staff

-University of Pretoria staff

-Mnisi authority

Section 2

How might we respond to or otherwise mitigate the tensions?

-Regular meetings and communication (via emails and WhatsApp for example)

-Take time to listen to everyone's understanding and expectations of the project

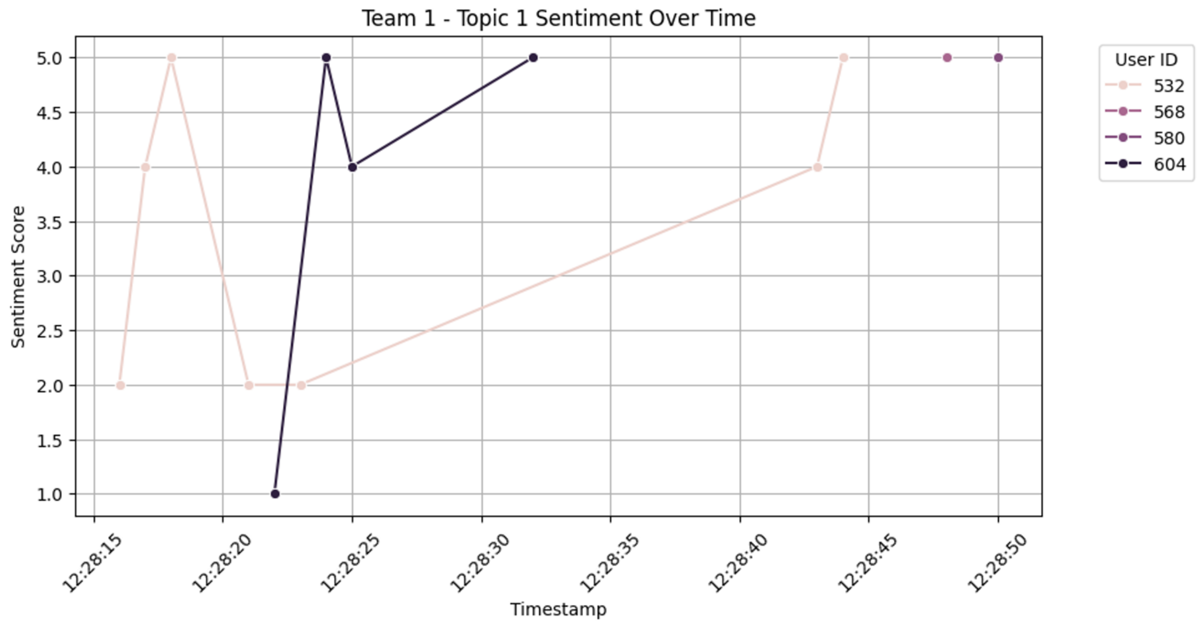
-Establish shared timeline and task list

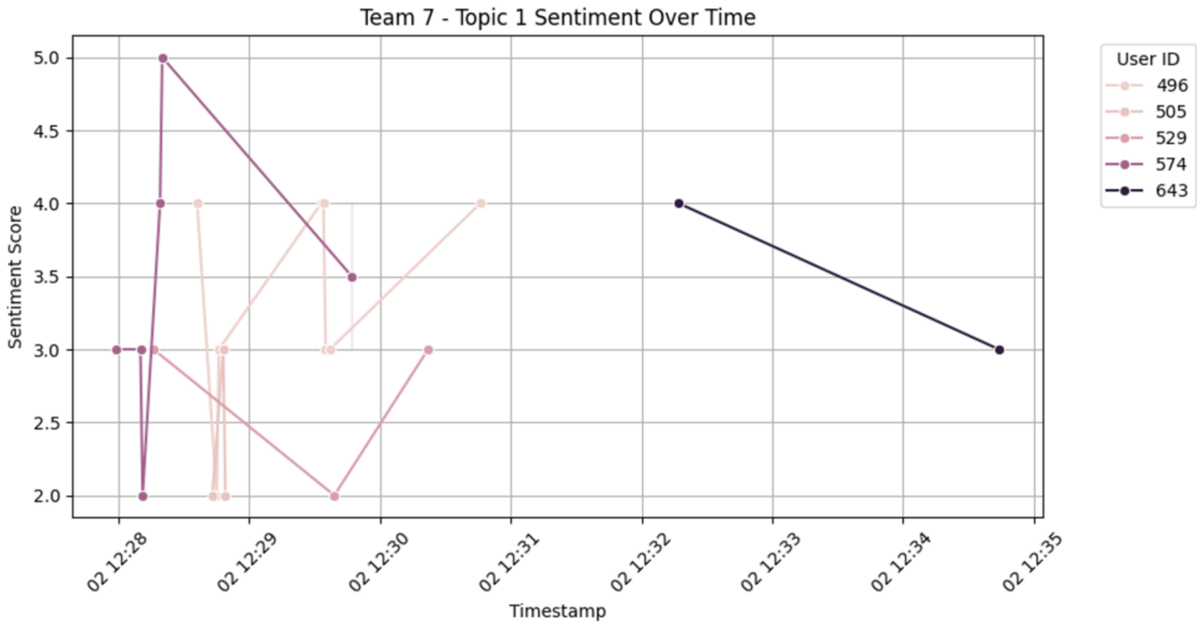
-Express shared values (empathy, respect...), talk about finding common ground

-Learn more about South African and Indigenous cultures

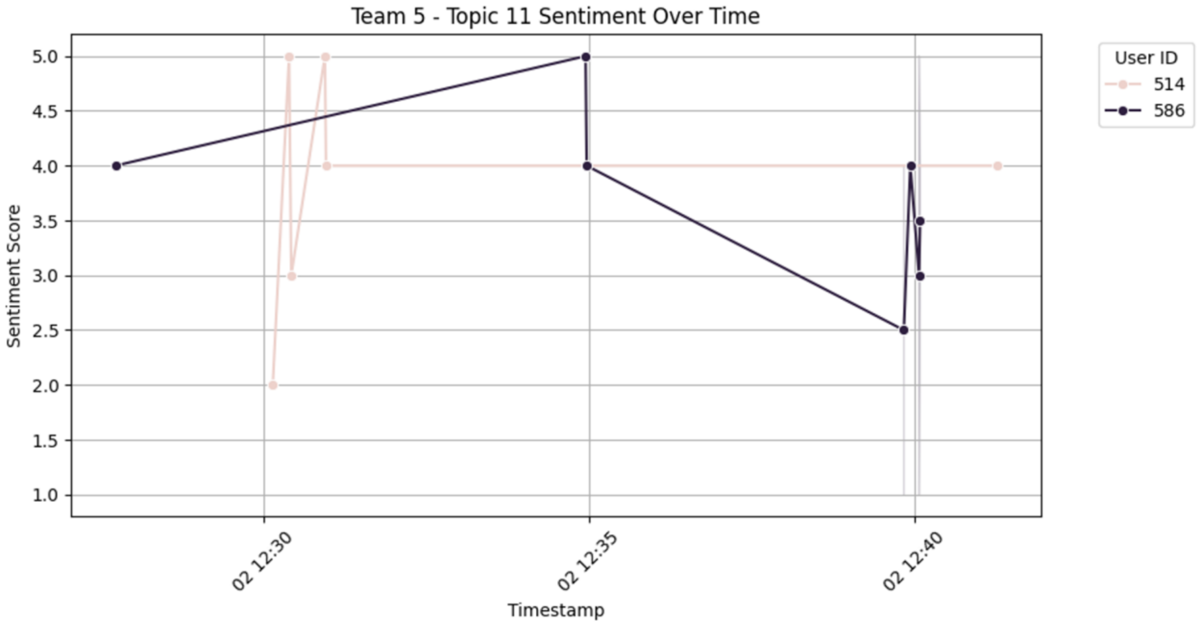
8.5 Appendix 5. Cycle 3 time series sentiment data, examples.

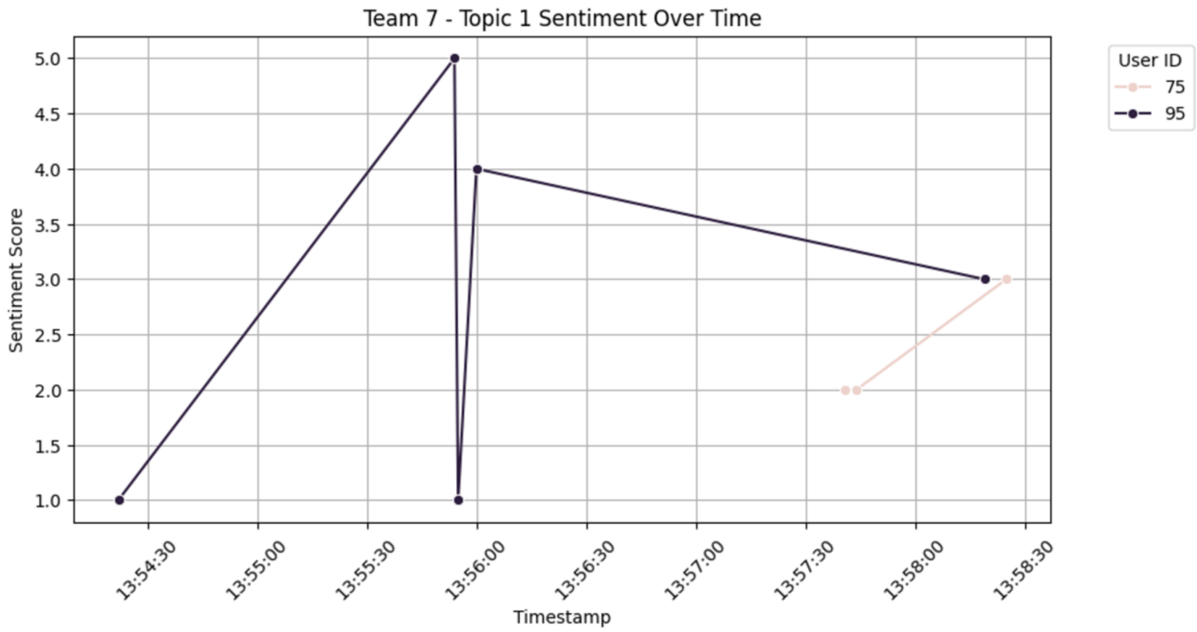
8.5.1 Sample from topic 1, evidence of students exploring the interface to view emoticons.



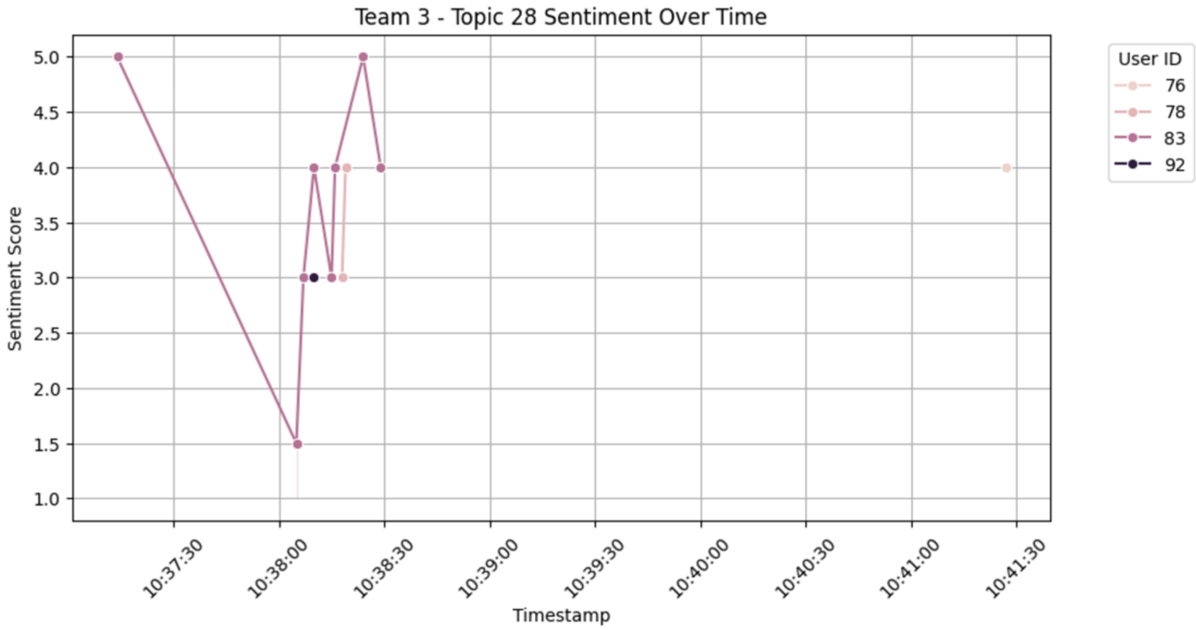


8.5.2 Later questions, with evidence of mutual accommodation.





8.5.3 Example of a student added topic, with convergence around the median.



8.6 Appendix 6. MySQL data handling and Python analysis scripts (Cycle 3).

8.6.1 Data cleaning

Data cleaning approach for MySQL data.

```
CREATE TABLE user_scores_team_pivot LIKE ratings_cleaned;

INSERT INTO user_scores_team_pivot SELECT * FROM ratings_cleaned;

ALTER TABLE user_scores_team_pivot ADD team_id int;


UPDATE user_scores_team_pivot

JOIN user_teams ON user_scores_team_pivot.user_id = user_teams.user_id

SET user_scores_team_pivot.team_id = user_teams.team_id;
```

8.6.2 chartTeamTopicSentiment.py

```python
import pandas as pd
import matplotlib.pyplot as plt
import seaborn as sns
import os

# Set the file path for Excel file
file_path = "cleaned_sentimentsscores_per_team.xlsx"

# Load the Excel file
xls = pd.ExcelFile(file_path)

# Choose the sheet to process
sheet_name = "phase1-2"  # Capstone, phase1-1, phase1-2
df = pd.read_excel(xls, sheet_name=sheet_name)

# Convert created_at to datetime format
```

```
df["created_at"] = pd.to_datetime(df["created_at"])

# Create output directory
output_dir = "team_topic_charts"
os.makedirs(output_dir, exist_ok=True)

# Group by team and topic
team_topic_combinations = df.groupby(["team_id", "topic_id"])

# Generate and save charts
for (team, topic), group in team_topic_combinations:
    plt.figure(figsize=(10, 5))
    sns.lineplot(data=group,  x="created_at",  y="score",  hue="user_id",
marker="o")

    plt.title(f"Team {team} - Topic {topic} Sentiment Over Time")
    plt.xlabel("Timestamp")
    plt.ylabel("Sentiment Score")
    plt.legend(title="User ID", bbox_to_anchor=(1.05, 1), loc="upper left")
    plt.xticks(rotation=45)
    plt.grid(True)

    # Save the figure
    filename = f"team_{team}_topic_{topic}.png"
    filepath = os.path.join(output_dir, filename)
    plt.savefig(filepath, bbox_inches="tight")
    plt.close()

print(f"Charts saved in {output_dir} folder.")


_topics))
```