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The dynamics of design: Exploring heterogeneity in meso-scale team processes

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Highlights

- > A work sampling study of meso-scale team processes in two engineering design cases.
- > Novel characterisation of goal/action and temporal heterogeneity in design work.
- > Identification of principals of proportional goal/action composition.
- > Proposed framework for understanding heterogeneous team processes in design.
- > Proposed 'archetypal process types' linking goal/action and process patterns.

The dynamics of design: Exploring heterogeneity in meso-scale team processes

Abstract

There is a critical gap in understanding how meso-scale team processes i.e. interactions between individuals in a team, develop in design teams and specifically how they dynamically balance design/managerial effort. We treat this deficit by contrasting two in-depth cases using work sampling data. We identify a number of contributions. First, we describe how design team processes display both goal/action and temporal heterogeneity. Second, we demonstrate how this heterogeneity is underpinned by common principles that consistently shape team processes in design. Specifically: proportional goal/action composition and recurring process patterns over time. Finally, we describe how these principles can be integrated via 'archetypal process types'. Together, these substantially extend prior theory and point to specific implications for future design research.

Keywords: case study, design activity, design practice, work sampling

Understanding teams' design processes is central to design research (Cross, 2018; Stompff, Smulders, & Henze, 2016). Here, the interaction between multiple individual's design activities produces an intertwined set of 'team processes' that give rise to states such as transactive memory and shared understanding (Dong, Kleinsmann, & Deken, 2013; Marks, Mathieu, & Zaccaro, 2001). Team processes are thus an essential theoretical lens for understanding design work (Bissola, Imperatori, & Colonel, 2014; Valkenburg & Dorst, 1998).

Team processes are defined as: *member's interdependent acts that convert inputs to outcomes through activities directed toward achieving collective goals* (Marks et al., 2001); and generally conceptualised in terms of taskwork i.e. *what* the team is doing, and teamwork i.e. *how* the team is interacting (Crawford & Lepine, 2013). Team processes thus form the interface between individual and organisational dynamics (Gorman, 2014; Kleinsmann & Valkenburg, 2008), as well as between design related taskwork and management related teamwork (Entin & Serfaty, 1999; Sim & Duffy, 2003). This makes team processes a subject of focus in both design and management.

The design literature has a general focus on micro-scale (i.e. individual level processes) description of design related action over the duration of a specific task (often measured in seconds or minutes). See, for example, representative works by Paletz et al. (2017) on micro-conflicts or Deken et al. (2012) on knowledge sharing.

In contrast, the management literature has a general focus on macro-scale (i.e. inter-team level processes) interactions between constructs, such as high level, static perceptions of knowledge sharing or shared understanding, across a whole project (often measured in months or years). See, for example, the examination of managerial knowledge sharing by Hult et al. (2004) or Pemartin et al.'s (2018) discussion of collaborative communication. Together, these literatures reveal a number of gaps in current research at the meso-scale (i.e. team level processes) critically relevant to design.

First, in terms of variation in interaction and team member characteristics, Hay et al.'s (2017; 2017) review of design research emphasises a focus on heterogeneity, while Leenders et al.'s (2016) review of management research highlights a general assumption of homogeneity. For example, Eris (2002) illustrates the heterogeneity of specific knowledge sharing interactions between specific team members, however, it is not clear how these impact larger scale team or organisational outcomes. Thus, we pose Research Question (RQ) 1: *To what degree do team processes display heterogeneity across team members at the meso-scale and how does this impact team processes' progression?* Second, central to understanding heterogeneity across team members is temporal heterogeneity (Leenders et al., 2016; Navarro, Roe, & Artiles, 2015). This is often neglected in macro-scale management research (Leenders et al., 2016), and is not fully explainable via the micro-scale research forming the typical focus in design (Cash, Hicks, & Culley, 2015; Grossman, Friedman, & Kalra, 2017). As such, meso-scale team process dynamics bridge micro- and macro-scales and offer a lens for understanding design work across scales taking into account insights from organizational psychology (Cash, Hicks, & Culley, 2015; Kozlowski, Chao, Grand, Braun, & Kuljanin, 2016). Thus, we pose RQ2: *To what degree do team processes display temporal heterogeneity at the meso-scale and how does this impact team processes' progression?* Together, these empirical and theoretical deficits lead to substantial questions surrounding the viability of current team process theory at the meso-scale (Leenders et al., 2016), particularly in the design domain (Cash, Hicks, & Culley, 2015). Specifically, while design research focuses on taskwork linked to the creation of a design artefact (Vermaas & Dorst, 2007), management research focuses on coordination related teamwork (Gorman, 2014). This is despite the fact that there are potentially critical interactions between these, as illustrated by Kleinsmann and Valkenburg's (2008) case-based description of how the design team/company interface can enable/block the creation of shared understanding during co-design. Thus, we pose RQ3: *To what degree do team processes mix taskwork and teamwork at the meso-scale and how does this relate to team member and temporal heterogeneity (RQ1, RQ2)?* Deeper insights in this area could significantly improve understanding of how designers work as part of a team in the longer term.

In order to answer these RQ's, the aim of this research is to examine meso-scale team processes in design. To do this we build on a conceptual framework grounded in the team processes model provided by Marks et al. (2001), elaborated with respect to design teamwork and taskwork. As this research is exploratory, we

build on insights from two cases in engineering design and manufacturing companies. Thus, we contribute to design research by refining understanding of the constructs involved in team processes as well as developing new descriptions of their relationships and underpinning mechanisms in design (Cash, 2018).

1 Theoretical Background

In this section we describe the theoretical context and dynamic character of team processes before outlining the conceptual framework used as the basis for the empirical work.

1.1 Team Processes in Context

Team process theory describes the interdependent activities of team members as a single interwoven process. Here a team is defined by Kozlowski and Ilgen (2006) as: “(a) two or more individuals who (b) socially interact; (c) possess one or more common goals; (d) are brought together to perform organizationally relevant tasks; (e) exhibit interdependencies with respect to workflow, goals, and outcomes; (f) have different roles and responsibilities; and (g) are together embedded in an encompassing organisational system, with boundaries and linkages to the broader system context, and task environment.” (Kozlowski & Ilgen, 2006, p. 79). Teams and team processes provide a meso-scale bridge between individual and organisation (Kleinsmann & Valkenburg, 2008). They link micro-scale cognitive processes (Cagan et al., 2013; Cross, Dorst, & Roozenburg, 1992), to macro-scale organisational processes (Hult et al., 2004) via meso-scale activity processes (Cash, Hicks, & Culley, 2015). For example, Zhang et al. (2014) use a series of team-based experimental studies to show how meso-scale information distribution within teams affected macro-scale relevant product development decisions, based on micro-scale principles drawn from social psychology. Of particular importance for design, team processes are critically impacted by the context specific micro-meso interface between individual and other team members (Kozlowski et al., 2016). Further, meso-scale insights from design research serve to explain overall macro scale phenomena, such as how shared understanding develops from knowledge sharing (Dong, 2005; Hult et al., 2004). As such, design work can be characterised as the synthesis of individual activities and team dynamics, bridging micro- and macro-scales, and couched within the wider context of the design team. Thus, it is important to distinguish processes at the micro-, meso-, and macro- scales.

The *micro-scale* deals with the individual and self (Kozlowski et al., 2016; Wiley, 1988), and their activity (linking behaviour and cognition) (Bedny & Harris, 2005). Processes at this scale are driven by cognitive and meta-cognitive mechanisms (Ball & Christensen, 2009). A key meta-cognitive driver at this scale is uncertainty perception, which has been found to be critical in both the design and management literatures as illustrated by the structured review and subsequent protocol study of Cash and Kreye (2017, 2018). This perception is

then translated into motivations and goals that are addressed via multi-layered activity (Bedny & Harris, 2005).

The *meso-scale* deals with interactions between individuals in a team (Kozlowski et al., 2016), and their interdependent activities, which connect individual micro-scale activity into an interwoven team process, with emergent properties (Kozlowski & Ilgen, 2006). Processes at this scale are driven by the joint understanding and interacting perceptions of the team members (Wiltschnig, Christensen, & Ball, 2013). For example, O'Connor and Rice (2013) used a longitudinal study of 12 radical innovation projects to demonstrate uncertainty perception as a key driver at this scale. Joint understanding and perception is then translated into shared goals that are addressed by team- and taskwork (Gorman, 2014; Marks et al., 2001).

Finally, the *macro-scale* deals with interactions between teams (Kozlowski et al., 2016; Wiley, 1988), as well as interaction with wider organisational and social structures (Gorman, 2014). These interactions shape the perceptions and behaviour of individuals via, for example, culture, organisational shared understanding and uncertainties (Daft & Lengel, 1986), and subsequently influence how meso-scale team processes are enacted (Donnellon, 1993).

At the meso-scale, team processes are typically described in terms of Marks et al.'s (2001) I-P-O (input-process-outcome) model. *Inputs* describe, for example, the team members' attributes, team context, and organisational setting; *processes* describe the intertwining behaviour and cognition enacted by the team members; and *outcomes* include obtained knowledge as well as team member effects such as satisfaction. The *process* part of this model describes what it is the team members do and how they interact in order to accomplish their goals i.e. their activity (Crawford & Lepine, 2013). This generally aligns with the conceptualisation of micro-scale activity operationalised in design literature by, for example, the models proposed by Cash and Kreye (2017) and Sim and Duffy (2003). An important distinction made by Marks et al. (2001) and others (Grossman et al., 2017; Mathieu, Heffner, Goodwin, Salas, & Cannon-Bowers, 2000) is the difference between the activity carried out by team members and "emergent states", which are properties of the team that dynamically vary as a function of team inputs, processes, and outcomes (Marks et al., 2001, p. 357). As such, emergent states form proximal outcomes driven by the interdependent activity of the team's members (Kozlowski & Ilgen, 2006). Thus, while emergent states are important mediators of outcomes (Dong, 2005; Sivasubramaniam, Liebowitz, & Lackman, 2012), analysis of the activity processes that drive them forms the foundation for understanding how teams work and requires specific research.

1.2 Team Process and Design Activity

The progression of team processes can be described in terms of the activities involved and how they vary with respect to: goal, underpinning action, and contextual system (Bedny & Karwowski, 2004; Leenders et

al., 2016). As such, design activity can be described by operationalising these elements with respect to design work, as illustrated by Cash et al.'s (2015) longitudinal protocol study of design practice.

Goal describes the purpose of an activity: directed towards teamwork or taskwork; which can be further decomposed with respect to sub-goals. For example, Marks et al. (2001) breakdown teamwork into ten specific subtypes related to various sub-goals, including: strategy formulation, systems monitoring, and conflict management. In design, Sim and Duffy's (2003) ontology describes management activities more related to teamwork, as well as definition and evaluation activities more related to taskwork.

Action describes how activities are connected to basic cognition and behaviour. In contrast to goal related descriptions, such as those provided by Sim and Duffy (2003) or Marks et al. (2001), this captures the cognition/behaviour interaction underpinning activity (Bedny & Harris, 2005). In design, Cash and Kreye (2017) identify three core actions: information action, knowledge sharing action, and representational action.

Finally, each specific action is enacted with respect to a *contextual system* of influencing factors. These include: subject i.e. the team member carrying out the action; object i.e. the thing transformed by the action; and tools, procedures and methods i.e. the things used in the action (Bedny & Karwowski, 2004). In addition, a contextual system can vary with respect to time and space, for example, across team members as illustrated by Maznevski and Chudoba's (2000) longitudinal study of global virtual teams.

Based on this conceptualisation, the activities underpinning team processes unfold in parallel and can be addressed by one or more team members who are collocated or distributed, and can act synchronously or asynchronously (Lahti, Seitamaa-Hakkarainen, & Hakkarainen, 2004; Marks et al., 2001). Further, they can be associated with one specific project as in a cross-functional project team, or with a specific design phase as in a functional team (Donnellon, 1993; Kozlowski & Ilgen, 2006). Thus, as team members move between team- and taskwork, and address various sub-goals, the individual threads of activity intertwine to form team processes.

While the design research literature is replete with micro-scale descriptions of heterogeneous, dynamic design processes (Kan & Gero, 2008; Wiltschnig et al., 2013), and the management literature with macro-scale models describing core variables (e.g. knowledge acquisition and information distribution activities) and overall relationships (Daft & Lengel, 1986; Hult et al., 2004), there are a number of key research gaps as outlined in the introduction. Specifically, the lack of theory adoption and development in design research means few studies address all the major dimensions needed to characterise meso-scale team processes, hampering synthesis of insights across fields (Cash, 2018). In contrast, the management literature suffers a lack of empirical studies that explicitly examine team process dynamics, and subsequently lack theory that is

sensitive to process heterogeneity and progression over time (Leenders et al., 2016). This theoretical and empirical deficit at the interface between design and management research is particularly critical because researchers such as Maznevski and Chudoba (2000) (via longitudinal cases) and Christensen and Ball (2015) (via protocol studies) have shown that team performance is often dependant on the dynamics of the team processes themselves. This brings into question major assumptions underpinning explanations drawn from theory insensitive to temporal effects (Navarro et al., 2015). As such, in this research, we address a significant gap in both literatures, as well as in basic team processes theory, with major implications for design research.

1.3 Conceptual Framework

The basic theoretical foundation for this work is drawn from Marks et al.'s (2001) model of team processes as an intertwined set of team- and taskwork activities, underpinned by numerous actions enacted by the team's members. This model is elaborated by the three main aspects needed to describe design activity (Section 1.2). First, the goals of activities are characterised based on the design specific ontology proposed by Sim and Duffy (2003) as: evaluation, definition, and management. Second, the core actions underpinning activities are characterised based on the Uncertainty Driven Action model of Cash and Kreye (2017) as: information action, knowledge sharing action, and representation action. Third, a contextual system was characterised, inspired by Robinson's (2010) multilevel approach to analysing design, including *subject* (who participated in certain activity), *object* (the topic of the activity), and *mode of action*.

2 Method

This research aims to develop theory by refining understanding of the variables involved in team processes as well as their relationships and underpinning mechanisms of interaction in design (Cash, 2018). We thus draw on two contrasting cases (Handfield & Melnyk, 1998). The presented cases provided unique data access offering detailed and in-depth insights on dynamic team processes at the meso-scale (Gibbert, Ruigrok, & Wicki, 2008; Yin, 2013).

2.1 Case Selection

Given our aim, a multi-case research approach was adopted (Handfield & Melnyk, 1998; Robson & McCartan, 2011, p. 154). Here, *analytical* and *theoretical generalisability* are the focus (Robson & McCartan, 2011, p. 154), which are supported by selecting cases that provide theoretical contrast i.e. cases with differences relevant to the theory of interest but otherwise similar (Yin, 2013). As such, the contrasting cases give insight into the mechanisms related to these differences (Eisenhardt & Graebner, 2007). Based on our conceptual framework, *design process phase* was selected as the contrast criteria, while other team process inputs were kept similar. Specifically, these inputs were: team members' attributes: number, background, level of experience and tenure (Kozlowski & Ilgen, 2006; Sivasubramaniam et al., 2012); and organisational setting

(Marks et al., 2001). Further, the cases were selected based on the extensive data access requirements essential to examining team processes. This procedure resulted in the selection of two cases dealing with different phases in the product development process.

Two functional teams were selected, each drawn from different engineering design and manufacturing companies. These teams were identified based on the organisational structure and overall project goals connecting the team members. Teams comprised 14 and 15 members (including team leader and team manager), worked in an established product development process, and shared overall goals associated with specific product development phases, thus dealing with numerous projects. Further, both teams were working with subsystems associated with larger complex systems, as specified in the case descriptions in Sections 2.1.1 and 2.1.2. The intent of this sampling was to give insight into team processes by contrasting the different goals and team contexts associated with different phases in the product development process. These cases were well suited to the research aim as their functional nature and positioning within their respective organisations meant that they were faced with substantial design and managerial challenges, making them ideal for exploring process interactions and dynamics.

2.1.1 Case 1: Control Embedded Systems for Energy and Transportation Sector Development

Case 1 comprised a SME i.e. a company with between 50 and 250 staff (Commission, 2003), whose development work was focused on control embedded systems used in solutions for generating, distributing, and transforming electrical energy. The selected team was primarily working on development of embedded systems for the railway transportation sector. The sampled work was related to the system-level design and detail design phases of product development (Ulrich & Eppinger, 2003).

2.1.2 Case 2: Automotive Development and Manufacturing

Case 2 comprised a large, first-tier organisation in the automotive industry i.e. more than 1000 staff providing components directly to the main goods manufacturers, whose work has a major role in product design and development. The selected team was primarily working on planning, refinement, and production ramp-up. Their work included development of production, logistics and procurement. The sampled work was related to the production ramp-up phase of product development (Ulrich & Eppinger, 2003).

This deliberate contrast formed the basis for elucidating fundamental insights into team processes' heterogeneity (Eisenhardt & Graebner, 2007). Here, robust results are derived by identifying critical similarities, differences and explanatory patterns drawn from the comparison between contrasting cases (Robson & McCartan, 2011). This follows comparative case logic with the aim of developing *analytical* and *theoretical generalisability* (**not** statistical generalisability) (Robson & McCartan, 2011, p. 154), which is particularly relevant for understanding the potential robustness of contributions when working in a theory

development mode, as in this research (Cash, 2018; Handfield & Melnyk, 1998, p. 332). Specifically, it would be expected that common features of team process heterogeneity are found across the contrasting cases based on the fundamentality of team process theory, the expected scale of heterogeneous features in team processes (Leenders et al., 2016; Navarro et al., 2015), and prior findings in design (Girard & Robin, 2006; Movahed-Khah, Ostrosi, & Garro, 2010). Thus, the selected contrasting cases provide a robust basis for developing team process theory, following methodological best practice and prior studies in this area.

2.2 Data Collection and Analysis

As the focus of this work is the examination of dynamic team processes during design (RQ1-3), traditional interview approaches offer only limited potential for describing processes in 'real-time'. Specifically, Navarro et al. (2015, p. 137) highlight the need for high-density repeated measurements, using temporally sensitive techniques. Thus, a custom work sampling mobile application was used to collect real-time data on team processes, based on sample data from the individual team members (Robinson, 2010b). Work sampling is a methodical approach for measuring how individuals spend their time performing certain activities. This is based on the collection of multi-faceted data about on-going activities sampled at specific time intervals. The most widely recognised examples of this approach in the design domain are the works of Robinson (2010b, 2010a), although work sampling has been widely used in other fields (Buchholz, Paquet, Punnett, Lee, & Moir, 1996). Work sampling provides high-density repeated measurements with a high degree of temporal sensitivity, making it ideal for this study.

Complementing the work sampling data, qualitative information was collected via pre- and post-sampling interviews and workshops carried out in the case companies. All interviews and workshops were carried out by the 2nd and 3rd authors, who have a technical background in the field of the case companies and are both experienced qualitative researchers. Detailed field notes were collected in all cases, and results and findings presented back to participants for validation at each stage of the research. This served to contextualise, triangulate, and validate the work sampling results, as well as provide additional depth (Yin, 2013).

Pre-sampling

Pre-sampling preparation dealt with three main elements, adapting and checking the work sampling application in each case team, training the case team in the application, and gathering qualitative information on the team itself. First, the work sampling application was presented to the whole team in both cases and each item discussed and operationalised for the specific case team. As such, the terminology in the work sampling application was tailored and validated for each case team in order to ensure construct and measurement validity (Gibbert et al., 2008), as well as ensuring common understanding amongst the team.

Such reflective implementation is essential to ensuring validity of the measurement approach (Seale & Silverman, 1997; Yin, 2013).

Second, training workshops were organised just prior to the start of the work sampling period, again with the whole team. The authors walked all participants through the operation of the work sampling application and provided them with a detailed instruction manual and guide. Prior to this workshop all participants had used the application for one day, followed by a data check in order to identify and discuss potential issues. This demonstrated that all participants were able to use the application, and had no problems with identifying items or reporting on their work, ensuring familiarity and acclimatisation (Cash, Hicks, Culley, & Adlam, 2015).

Third, qualitative data was collected in a number of ways. Open ended surveys were used to gather information on every participant's prior experiences in team work, information processing, and the extent to which they used knowledge from internal and external sources. Further, a structured 360-Degree evaluation was carried out for all participants to evaluate their prior performance and map their competencies, including problem-solving, decision-making, leadership and learning. Together these provided extensive insights on the participants and the general nature of their work. In addition, the researchers met with relevant management staff in each case company and familiarised themselves with pre-existing process documentation, as well as working practices in the organisation and its partners. This provided insights on the organisational structure, process architecture, time planning, and process stages.

Work sampling

Sampling lasted two weeks. A period of two weeks was selected as appropriate based on the characteristics of team process theory (where heterogeneity would be expected in a multi-week timeframe (Leenders et al., 2016; Navarro et al., 2015)), as well as prior studies in design and management (Cash, Hicks, & Culley, 2015, p. 9; Maznevski & Chudoba, 2000, p. 475).

During the sampling period, participants were prompted to complete multi-faceted self-reports using the work sampling application 6-10 times per person, per day. These prompts were distributed randomly over the working day with a minimum interval of 30 minutes and a maximum of 90 minutes. This enabled the detection of a tasks accounting for 5% of work time, with $\pm 20\%$ precision, and 90% confidence. For example, if an activity was calculated to account for 5% of the working day (i.e. 24 minutes in a standard 8-hour day), then it could be stated with 90% confidence that the actual time spent on that activity was between 4% and 6%. This provided a granularity suitable for describing heterogeneous meso-scale team processes and their development over time (Grossman et al., 2017; Marks et al., 2001).

To maximise robustness, we split each day into four quarters labelled Time 1-4 (T 1-4) each corresponding to a two-hour timeframe supported by multiple data points. When prompted, participants self-reported one option in each of the sampling facets described in Tables 1 and 2, for every data point. This provided detailed, real-time information on the goal of the activity (Table 1), the core actions underpinning the activity (Table 2), and the other influencing factors described in Section 1.3 (including: activity subject, object, and mode of action). Thus, for each data point all elements of the conceptual framework were self-identified and self-recorded by the participants via the work sampling application. The application and development of the sampling approach was based on the work of Robinson (2010b, 2010a) and the more recent developments by Skec et al. (2017) and Martinec et al. (2017). Throughout the sampling period the research team was available to clarify questions or other issues encountered by the participants.

Table 1: Overview of sampling options for goals based on Sim and Duffy (2003) and Marks et al. (2001)

Goal		Description
Teamwork	Management	Planning, resolving conflicts, resource assignment, negotiation, and coordination
Taskwork	Evaluation	Analysis, simulation, decision making regarding the design, measurement, testing, monitoring, and reviewing
	Definition	Conceptualisation, detailing, coding, ideation, improvement, documenting, and prototyping
	Other	Sales, procurement, user support, and miscellaneous

Table 2: Overview of sampling options for actions based on Cash and Kreye (2017)

Action	Description
Information action	Searching, requesting, interpretation/validation, and storage/archiving
Knowledge sharing action	Discussion, creation, development, and interpretation of information in a group
Representation action	Manipulation of external representations of information

In order to implement the options described in Tables 1 and 2 in the work sampling application the options were adapted into terminology that was able to be understood and consistently identified by the participants. This was achieved via the pre-sampling workshops and validated via the post-sampling interviews and workshops. Importantly, this meant that terminology in the application varied slightly from case to case. However, all adaptations started with the core options in Tables 1 and 2 and were only to do with the terminology used in the cases themselves. As such, a consistent link between the theoretical options and the operationalised terminology was maintained across the cases. All participants experienced the same sequence of questions and options outlined in Table 3.

Table 3: Sampling applications menu screens and their purpose

Screen	Title	Description
1	Work type	Working in a team or alone
2	Development activity	Working with respect to which goal (Table 1)
3	Work context	Working on the product, the process, or other administration
4	Parties involved	Working with who: from other team members, to suppliers or customers
5	Manner	Working using what tool or software
6	Action	Working via which type of behaviour (Table 2)

Post-sampling

Following the characterisation of individual team member's activity using the multi-faceted work sampling data, it was possible to explore the interactions among individuals and between individual and team. As with the pre-sampling, post-sampling secondary data were also collected to triangulate the understanding and representativeness of the schema and the subsequent findings (Yin, 2013). Workshops were carried out with all participants and responsible managers. Here, all major data and findings were presented, as well as contextual insights regarding overall organisational structure, process architecture, time planning, and process stages. This allowed for all work sampling data and assumptions to be validated with the participants themselves (Gibbert et al., 2008). In addition, unstructured interviews were conducted with team leaders and responsible managers in both cases, where data and assumptions were again validated, specifically with respect to work distribution, subgroup collaboration, and sequence of activities. Further, they were asked to reflect on the experience, competencies, and roles taken by each participating team member. Again, this served to triangulate, validate and contextualise the results derived from the work sampling (Yin, 2013).

2.3 Data Characterisation

Across the two cases there was a mix of participants. The team in Case 1 comprised participants with backgrounds in: electrical engineering (7), software engineering (4), and mechanical engineering (3), while Case 2 comprised: mechanical engineering (7), engineering sales (5), and logistics (3). In addition, Case 1 participants had a mean experience of 12 years (min. 0.5 years, max. 30 years), while Case 2 had a mean of 12 years (min. 5 years, max. 26 years). As such, while the teams comprised a mix of backgrounds, they both had a distinct engineering focus and similar levels of experience overall.

For the work sampling data, ~1360 alarms were emitted during the sampling period (~2 weeks) in each case, with each participant responding to ~75-85 alarms. This difference in number is the result of the random sampling of the alarms throughout the sampling period, following work sampling methodology (Robinson, 2010b). The response rate was 88% in Case 1 and 83% in Case 2, with respectively 79% and 69% being completed within 30 minutes of an alarm. As the response rate was very high, and the response time equivalent to the work sampling detection threshold it can be concluded that the data is representative and reliable, in line with best practice for work sampling research (Robinson, 2010b, 2012).

3 Results

The work sampling data analysis revealed two major findings related to team process heterogeneity in product development. These are associated with goal/action composition and temporal heterogeneity, which together illustrate heterogeneous taskwork/teamwork interaction. As a basis for understanding these findings it is important to note that both cases reflected high performance teams with consistent and high

levels of motivation, good understanding of established organisational structures and relationships, and overall success in delivery of outputs on time and on budget. Further, both cases were able to be effectively described using the sampling schema, with qualitative validation supporting the findings. Thus, the cases reflect teams of similar performance and overall characteristics, while still providing suitable contrast for theory development, as discussed in Section 2.

3.1 Goal/Action Heterogeneity and Proportional Composition

The first major finding, distilled from contrasting the work sampling data in the two cases, was the identification of distinct features of heterogeneous goal/action composition. An overall breakdown of the goal/action composition in the two cases is given in Table 4. The main action accounted for ~60% of work time in both teams: representation action in Case 1 and knowledge sharing action in Case 2. This was complemented by secondary goal related action accounting for ~25%: knowledge sharing action in Case 1 and information action in Case 2.

Table 4: Overview of action and goal composition for the whole team

		Teamwork	Taskwork			Total
		Management	Evaluation	Definition	Other	
Case 1	Information action	0%	5%	1%	5%	11%
	Knowledge sharing action	5%	10%	7%	5%	27%
	Representation action	3%	11%	49%	0%	62%
	Total	8%	25%	57%	10%	
Case 2	Information action	0%	1%	0%	24%	25%
	Knowledge sharing action	21%	10%	5%	23%	59%
	Representation action	3%	2%	8%	2%	15%
	Total	25%	13%	13%	50%	

The taskwork (i.e. *evaluation*, *definition* or *other* related action) in both cases was coordinated and directed by teamwork (i.e. *management* related action) focused knowledge sharing action in proportion to the extent of the team's network within the organisation. Here, the interaction between the team and the wider organisational and external network substantially influenced the intensity of certain aspects of the team process. Specifically, both cases allocate comparable proportions of their knowledge sharing action to team internal coordination, however, while Case 1 only draws on company external network to support their overall process progression, Case 2 dynamically interacts with a large number of other teams within the case organisation as well as numerous company external partners. While the absolute proportion of work time used on team internal knowledge sharing in the two cases is substantially different: Case 1 = 9%, Case 2 = 14%, proportional team coordination is comparable, as shown in Table 5. Thus, despite substantial goal/action heterogeneity both cases draw together distinct elements of teamwork and taskwork in proportionally comparable composition at the team level.

Table 5: Proportional distribution of knowledge sharing action

	Case 1: 14 members	Case 2: 15 members
Team internal only	35%	36%
Involving other teams	0%	51%
Involving company externals	65%	19%

Elaborating the work sampling findings at the individual team member level, both cases displayed similar characteristics in terms of proportional work composition. Specifically, team members displayed commonality in terms of the general distribution of their work. Each team member displayed an average ratio of ~70%/~20%/~5% in the composition of their goal/action. We term this primary/secondary/tertiary, denoting the ranked ordering of goals/actions for each participant. Thus, while individuals combine all types of action, they display a clear focus in their work processes as illustrated in Table 6. This distinction between primary/secondary/tertiary at the team member level is statistically supported by both t-tests and Mann-Whitney U tests, which confirm: primary > secondary for goal and action in both cases $p < 0.0000$ (for both tests); secondary > tertiary for goal and action in both cases t-test $p < 0.01$ and Mann-Whitney U test $p < 0.05$. Further, comparing the magnitude of primary etc. across the cases, again using t-test and Mann-Whitney U tests, revealed no significant differences.

Table 6: Proportional composition of action and goals at individual team member level

	Case 1: 14 members		Case 2: 15 members	
Action composition	Mean	SD	Mean	SD
Primary	74%	17%	68%	23%
Secondary	22%	14%	27%	11%
Tertiary	4%	6%	5%	5%
Goal composition				
Primary	67%	18%	63%	15%
Secondary	20%	9%	28%	10%
Tertiary	13%	11%	9%	10%

Following these results, it was possible to identify general goal/action compositions or ‘archetypal process types’ common across team members and cases. Here, work process characteristics were distilled in two complementary analyses: i) overall evaluation of each team member’s work flow using the work sampling data across the sampling period ii) K-Means clustering of team members using the actions and goals as defining variables (MacKay, 2003). By analysing prevailing combinations of actions and goals for team members from both cases, it was possible to inductively identify and distinguish between four main archetypal process types, which we term: ‘the design engine’ delivering design focused taskwork via representation action; ‘the cross-cutter’ balancing information and representational taskwork and knowledge sharing teamwork linking sub-teams and sub-tasks; ‘the information engine’ delivering information focused taskwork drawing information into the team and then pushing it to the relevant team members; and ‘the coordinator’ focused on knowledge sharing teamwork and balancing their time between ‘other’ administration duties and the active ‘management’ of the team itself.

These groupings were supported by a K-Means analysis. This was first used to check if the overall identification of four groupings in the results also corresponded to the best Calinski–Harabasz pseudo- F value, following best practice for K-Means analysis (Calinski & Harabasz, 1974). The Calinski–Harabasz pseudo- F value was best for four clusters (26.31), compared to three, five, and six possible clusters (33.57, 23.62, and 22.68 respectively), thus supporting the overall identification of four groupings. Second, K-Means analysis was used to describe the quantitative goal/action compositions of each of the four clusters. This resulted in percentage goal/action compositions (drawn from the K-Means analysis) that closely aligned with the descriptions for each cluster, consistent across cases, as illustrated in Table 7. For example, one K-Means cluster was associated with substantial definition and evaluation related (68% and 23% respectively) representation action (82%). This corresponds to the identified ‘design engine’.

In addition to this, further analysis of the subjects associated with each action revealed how these archetypal process types could be generally categorised with respect to their organisational facing and overall role within the team i.e. focused on team internal interaction or on team external interaction. Here the team leader formed a critical bridge between the work carried out by the ‘design engines’ and ‘cross-cutters’, which were almost exclusively team internal focused, and the external interfacing ‘information engines’, which had very few team internal connections. Overall, the K-means analysis was supported by triangulated qualitative data from the 360-Degree evaluation, the skills survey, and the follow up interviews/workshop. Notably, both team leaders were identified as ‘coordinators’ by the K-means analysis, while, the technical specialists in both cases were clustered as ‘design engine’/‘information engine’. Interestingly, long term follow-up with the case companies revealed that the main ‘cross-cutter’ from Case 1 had been promoted to team leader explicitly due to their central role in integrating work within the team.

Table 7: Mean distribution of action and goals for team member ‘archetypal process types’

	Design engine		Cross-cutter		Information engine		Coordinator	
	Mean	SD	Mean	SD	Mean	SD	Mean	SD
Action distribution								
Information action	2%	4%	14%	13%	61%	15%	16%	9%
Knowledge sharing action	16%	10%	37%	12%	37%	17%	72%	12%
Representation action	82%	12%	48%	5%	2%	3%	11%	14%
Goal distribution								
Definition	68%	21%	71%	8%	1%	2%	7%	9%
Evaluation	23%	16%	11%	6%	24%	40%	12%	13%
Management	4%	3%	13%	11%	62%	33%	43%	17%
Other	5%	5%	6%	4%	13%	10%	48%	20%
Case Distribution								
Case 1	8		3		1		2	
Case 2	1		1		3		10	

To conclude, it was found that team process goal/action composition displayed both substantial heterogeneity and common features in the proportional composition of work across team members.

3.2 Temporal Heterogeneity and Recurring Process Patterns

The second major finding is that the process in both teams displayed substantial heterogeneity, which was linked to an interplay between the taskwork – providing the impetus pushing the whole process forward – and the team internal focused teamwork – providing the direction and coordination.

In terms of taskwork, Case 1 spent 49% (Table 4) of its time on representation/definition work, which formed the impetus for the whole process, determining overall progression, content delivery, and much of the interaction with the team's wider network. This was then moderated by team internal knowledge sharing/management (5%, see Table 4), determining task coordination, team alignment, and handover between sub-projects and sub-tasks. Similarly, Case 2 spent 57% of its time on taskwork related team external information and knowledge sharing action directed towards drawing together information from different parts of the organisation and combining this into production plans. This again determined the progression of the whole process and the majority of interaction with the team's wider network. Further, while progression in Case 2 was also mediated by knowledge sharing/management (21%, see Table 4), determining task coordination and team alignment, the intensity of this coordination effort was increased due to the rapid and substantial influx of information drawn into the team via the core taskwork. Despite this, both cases displayed common temporal patterns as is illustrated in Figure 1. For example, in Case 1 formal team meetings followed a 14-day cycle (based on interviews with the team and observation data on Day 1), in parallel to a number of sub-projects with two-day cycles. Similarly, Day 2 and Day 12 represent formal team meetings in Case 2, while the other peaks reflect the multiple parallel sub-tasks being undertaken by sub-groupings within the team that were usually related content-wise (i.e. activity subject). In particular, this starts to explain the more intense and frequent peaks in Case 2, because in addition to within team sub-groupings there is a large number of additional sub-groupings created via organisational network interactions external to the team. Figure 1 shows how the 'within team' directed teamwork (mostly knowledge sharing based) and taskwork (mostly information and representation based, hence mixed colouring) fluctuate from day to day in both cases, with teamwork peaks corresponding to the cyclical team meetings describe above. Figure 1 serves to highlight the overall temporal heterogeneity and general team process structure across the two cases.

Figure 1: ‘Within team’ directed teamwork and taskwork distribution showing temporal structure

Elaborating the taskwork/teamwork interaction, Figure 2 highlights goal/action heterogeneity where proportional composition is again evident. Specifically, primary and secondary actions in both teams interact with managerial knowledge sharing to define the overall process structure. Both cases displayed a heterogeneous distribution of action and goal types over time and across team members, as well as a distinct interplay between specific goal/action combinations. This was evident in the overall interplay between goals/actions across the whole team as well as for individual team members. The complexity of this heterogeneous progression is illustrated in Figure 2. Here, even at its most intense, no single action accounts for more than ~70% of any given period, and substantially less when aggregated across any given day or team member. Further, there are fluctuations in the distribution of goal/action shaped by exchanges between periods of taskwork and teamwork, as well as exchanges between team members. Thus, while the focus is different between cases, they share characteristics in terms of heterogeneous goal/action dynamics substantially related to team process progression. Abbreviations are used in Figure 2 for brevity as follows: Knowledge Sharing action (KS), Information action (I), and Representation action (R).

More practically, the differences illustrated in Figure 2 reflect the different operating styles of the two teams. The team in Case 1 was typically working on multiple projects simultaneously, with an organisation-based structure, while the team in Case 2 was project-based, and more multi-disciplinary. As such, Case 1 had less knowledge sharing as the team was more mono-disciplinary and centrally coordinated. In contrast, Case 2 had substantially more knowledge sharing as the team was comprised of a number of multi-disciplinary sub-groups working and coordinating in parallel. Although Case 2 had more teamwork overall less team members were involved in each interaction. This reflected a more specialized knowledge sharing strategy where the team was focused on specific technical areas, where interaction with external actors was a priority. Further, the differences in information and representation action reflect the phases of product development. The team in Case 1 was more directly focused on specific aspects of product design while the team in Case 2

needed to gather and share information about the planning, refinement, and production ramp-up. Critically, Figure 2 illustrates the heterogeneous intersection between goal/actions.

Figure 2: Heterogeneous goal/action progression in team processes across the two cases

3.3 Illustrating Taskwork/Teamwork Interaction

Finally, in order to better understand the results outlined in this section, we detail two examples from Case 1. These exemplify the interplay between taskwork and teamwork when knowledge sharing is more or less intense (Figure 3). Each example shows all the periods of work associated with a specific project goal. As such, they reflect a directly linked series of actions addressing a common object. Participants are ordered by the degree of work on the example as well as the level of interaction with other example participants in order to aid clarity in presentation of the figure.

Example 1 (Figure 3a) shows distinct teamwork and taskwork. This is characterised by substantial representational taskwork by Participants (P): P3, P5, P12, and P14 ('design engines', see Section 3.1). This work is directed by periodic interactions with teamwork focused P2, complemented by P6 and P15 (respectively an information engine, design engine, and coordinator). The interaction between these two groups is then mediated by P9 who bridges teamwork and taskwork and is the primary means of linking the taskwork to external collaborators.

In contrast, Example 2 (Figure 3b) shows intense interaction between teamwork and taskwork. This is characterised by daily iterative external/internal teamwork interactions via knowledge sharing action by P4, P8, P10 (cross cutters). This shapes the representation taskwork via ~2-day periodic interactions with P11 (a design engine). P7 and P11 alternate between goal/action combinations mediated by their interaction with other team members. P8 draws in externals, and together with P4 and P10 alternate between knowledge sharing and representation in order to coordinate the teamwork and taskwork processes.

In both examples, team members distribute work and alternate between primary and secondary types of action. Thus, while overall process structure is complex and draws together different goal/actions, there are similarities in the basic compositional and temporal factors underpinning interplay between taskwork and teamwork.

Figure 3a: Example 1 (key below): Low degree of interaction between team members and low alternation of goal and action types

Figure 3b: Example 2 (key below): High degree of interaction between team members and high alternation of goal and action types

Figure 3: Examples showing distribution of work across team members, as well as changes in goal/action types, each action is associated with all goal types as illustrated by variations in shading

4 Team Process Dynamics in Design

This research delivers three key insights on team process heterogeneity and dynamics in the design context, by answering the RQs outlined in the introduction. First, team processes in design, linking taskwork and teamwork, show substantial compositional and temporal heterogeneity. This contrasts prior theory that has typically focused on modelling either taskwork or teamwork, with little consideration for heterogeneous interaction effects (Leenders et al., 2016). Second, despite this heterogeneity we identify a number of common principles that consistently shape team processes in design. Specifically: proportional goal/action composition and recurring process patterns over time. Third, we describe archetypal process types combined in the team. This substantially extends prior research surrounding the factors influencing team processes, and contrasts prior static assumptions (Navarro et al., 2015). We distil these insights into a number of propositions (P1-3) encapsulated in a conceptual model as in Figure 4.

Figure 4: Proposed conceptual model describing principles underpinning team process dynamics in design

First, our research explicitly refutes prior assumptions of team process homogeneity in terms of goal/action composition and work distribution across the team (Gorman, 2014; Leenders et al., 2016). Specifically, we show that design teams dynamically combine taskwork and teamwork elements and a wide range of goal/action combinations with substantial variation across team members. This calls into question the suitability of current theory in the design or management domain for modelling design work in an organisational context. In particular, models of design underplay the complexity of coordinating teamwork integrating and shaping design taskwork progression (Vermaas & Dorst, 2007). Further, models focused on teamwork do not effectively treat the significance of the taskwork impetus pushing the whole design process forward (Gorman, 2014). While this deficit has been hinted at by authors such as Kleinsmann and Valkenburg (2008) or Crawford and Lepine (2013), our research explicitly defines the interdependency between design related taskwork and management related teamwork and illustrates its heterogeneity across team members and over time. Further, the observed interdependence between all three action types highlights a second

area of theoretical contribution. Specifically, information processing and similar models (Hult et al., 2004) focusing only on information and knowledge related action do not effectively account for representation in design work (Robinson, 2010a; Wasiak, Hicks, Newnes, Dong, & Burrow, 2010), and similarly, models dealing with representation rarely cohesively integrate information and knowledge sharing elements (Cash & Kreye, 2017). Thus, our research takes a step towards providing new theory integrating taskwork and teamwork perspectives, sensitive to the interplay between the core actions characteristic of design. Further, we highlight possible deficiencies in information processing focused models of design or managerial work. We thus distil the following:

P1a: Goal/action heterogeneity mediates team process progression.

P1b: Proportional goal/action composition mediates team process progression.

Second, our research extends current theory by explicitly highlighting temporal heterogeneity in team processes, and – within this fluctuation – the presence of recurring process patterns over time. Specifically, while prior descriptions in the design domain have described micro-scale process patterns via models such as problem/solution (Maher, 2000), Function-Behaviour-Structure (Gero & Kannengiesser, 2004) or Uncertainty Driven Action (Cash & Kreye, 2017), our study shows substantial meso-scale patterns based on interdependency between taskwork and teamwork. While substantial insights have been generated at the micro-scale, their impact on meso- and macro-scale processes is difficult to assess due to the emergent properties of teams and organisations (Marks et al., 2001, p. 357; Sivasubramaniam et al., 2012). As such, this work significantly extends prior design theory by suggesting temporal heterogeneity and process patterns are critical at the meso-scale, refuting assumptions of temporal homogeneity (Leenders et al., 2016; Navarro et al., 2015). Further, this serves to elaborate discussions of the potential for process cycles or ‘temporal rhythms’ affecting design work (Maznevski & Chudoba, 2000, p. 486; Navarro et al., 2015). Specifically, we refute static models of team processes from the management domain, which treat information processing in isolation from taskwork considerations (Hult et al., 2004; Leenders et al., 2016). Further, our identification of interdependency between goal/action composition and multiple overlapping process patterns (associated with specific team members and their interactions with respect to the team, multiple sub-teams, and wider organisational network) explicitly refutes assumptions of homogeneity across team members and their interactions (Leenders et al., 2016). Thus, our research suggests an intersectional model combining aspects of design and management to account for process progression and temporal patterns, based on dynamic interaction between taskwork and teamwork. We thus distil the following:

P2a: Temporal heterogeneity linking taskwork and teamwork mediates team process progression.

P2b: Recurring temporal patterns mediate team process progression.

Linking these propositions, we identify a number of archetypal process types, which suggest possible directions for future theory development. Specifically, we identify characteristic distribution of primary/secondary/tertiary goal/actions common across cases and team members. This fundamentally extends prior descriptions that have focused on the distribution of specific actions or tasks carried out by designers (Austin, Steele, Macmillan, Kirby, & Spence, 2001; Robinson, 2012), by pointing to principles of composition and temporal process patterning. Building on this, we identified four archetypal process types distilling the essence of the work carried out by the 29 individuals in this study, as illustrated in Figure 5.

This finding nuances our results regarding interaction between teamwork or taskwork. Specifically, the taskwork focused 'design engine' can be described using frameworks such as the Design Ontology (Storga, Andreasen, & Marjanovic, 2010) or F-B-S (Gero & Kannengiesser, 2004). Similarly, the 'coordinator' is well served by teamwork focused models dealing with team information processing (De Dreu, 2007; Deeter-Schmelz & Ramsey, 2003; Kanawattanachai & Yoo, 2007). However, the intersectional nature of the 'information engine' and 'cross-cutter' are poorly described by current models despite aspects of their observed work processes being highlighted from a teamwork perspective by Cronin and Weingart (2007) and from a taskwork perspective by Kleinsmann and Valkenburg (2008). While teamwork/taskwork interaction has been hinted at by Crawford and Lepine's (2013) small-scale network models of team process emergence, the bifurcation of theoretical perspectives means that no current model is well suited to describing the overall interdependent progression of taskwork and teamwork. This study directly describes their real-time interaction and emergent properties and suggests common compositional principles. We thus distil the following:

P3: Archetypal process types combined in a team mediate team process progression

If the identified archetypes prove to be robust they would serve to extend the discussion on team creation and management beyond the traditional focus on characterising team members in terms of personality or skills (Barrick, Mount, & Li, 2013; Kleinsmann, Deken, Dong, & Lauche, 2012; Tracey & Hutchinson, 2016). By introducing a process perspective, the archetypes complement team roles and personality traits, when tailoring a design team to the task at hand. For example, an information processing focused task would point to the need for a detail-oriented team with information skills, but also with a mix of 'information engine', 'cross-cutter', and 'coordinator' archetypes (De Dreu, Nijstad, & Van Knippenberg, 2008). However, further research is needed to examine how these archetypes evolve longitudinally across different design phases, as well as how they align (or not) with personality trait and skills assessment models.

Figure 5: Archetypal process types based on Table 7

5 Limitations and Further Work

The first limitation of note is the extent of the sampling data and the inherent limitations of work sampling as a method. Although the sampling session lasted for only two weeks, comparison of the two cases revealed a number of dimensions of alignment in terms of individual activity and team dynamics. Further, these results were found to fall within the scope of prior findings in the design domain, despite differences in context (Robinson, 2010a; Wasiak et al., 2010). As such, the reported data can be considered as sufficient for the claims outlined in Section 4. However, there is substantial potential for further investigation of the interaction between individual activity and team dynamics in other stages of the design process. The

robustness of the findings is also supported by the triangulation of post sampling interviews, feedback to the teams and team managers, and alignment with secondary documentation e.g. participant time sheets.

Second, the conceptual framework is of limited scope (Section 1.3), and does not consider aspects such as motivation, uncertainty or other cognitive drivers highlighted in prior studies (Ball & Christensen, 2009). As such, although sufficient for describing manifest activity in the reported cases, the current theoretical model and reported data only hints at the designers' perception of the situation or their interpretation of activity consequences. Thus, further empirical and theoretical work is needed to better characterise the full cycle of activity from antecedent to perception of consequent outcome.

Third, the 'archetypal process types' point to the need for further development both theoretically and empirically. Specifically, future work could seek to further nuance the details of each archetype's contribution to the design team, and impact on the design process. More generally, there is a need to further develop the conceptualisation of process types in conjunction with role and team processes theory.

6 Conclusions

This work set out to examine the meso-scale team processes in design in order to address critical gaps in prior theory associated with assumed homogeneity in composition and progression over time, as well as bifurcation in discussion of taskwork and teamwork. Thus, the aim of this work was to develop theory by refining understanding of the variables and underpinning mechanisms shaping team process progression in design. We addressed this aim by contrasting two in-depth cases using work sampling data to describe multifaceted team processes over time. Based on this we identify three major contributions. First, we describe how heterogeneity is a fundamental characteristic of design team processes. This mixes taskwork and teamwork elements in a process that displays both goal/action and temporal heterogeneity. Second, we demonstrate how this heterogeneity is underpinned by common principles that consistently shape team processes in design. Specifically: proportional goal/action composition and recurring process patterns over time. Finally, we describe how these principles can be integrated via 'archetypal process types'. Together, these substantially extend prior theory and point to specific implications for future design research.

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