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Investigating collaborative information behaviours in complex product development work

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Abstract

Modern engineering projects are increasingly collaborative, often developed over a network of organisations and involving multiple actors and stakeholders. Actors in such projects are dependent on multiple contextual factors which include technologies, processes and procedures. The outcomes of such projects are dependent on how actors interact with these contextual factors. However, this dependency remains poorly understood and, as a result, it is difficult to assess the impact of collaborative aspects of information behaviours on engineering projects. In this paper I outline an activity theory (Engestrom, 1987; Allen et al., 2011) approach to assess the tensions and disruptions affecting collaboration. I apply this approach to the cases of product development in two high value engineering organisations. Through this approach, I reveal that engineers consistently adapt their collaborative information behaviours in response to tensions caused by technologies originally introduced to support their work. As a result, I show that this introduces significant practical disruptions to complex projects. I propose that these disruptions can be generalised across a range of industries and should be considered as significant factors for professionals seeking to diagnose disruptions to information flows. Identifying these disruptions, through activity theory, provides a first step to more effective design and implementation of information systems, collaborative work processes and workflows.

Collaborative Information Behaviours in Engineering Product Development

Engineering product development is a complex and resource-intensive process in which products are increasingly developed in collaborative environments. Apart from involving multiple actors, these environments often span complex networks of teams and organisations (Vianello and Ahmed-Kristensen, 2012; McKay et al., 2016). As a result, there is increasing demand for new information systems to support interaction and decision making in high-value engineering projects, where challenges in making optimal decisions are considerable. Moreover, failing to overcome these challenges can have severe negative impacts on downstream processes, product quality, cost and delivery time (McKay et al., 2017; Van Oorschot, K.E. et al., 2013). This study sets out to diagnose factors that affect these negative impacts. Specifically, it seeks to directly determine the relation between collaborative information behaviours and the new technologies which are introduced to support engineering work.

Current research on information behaviours within engineering projects has largely focused only on information behaviours of individual engineers (Leckie et al., 1996; Freund, 2015). Indeed, much existing research into collaborative information behaviour explicitly defines it as an individual phenomenon (Reddy and Jansen, 2008; Karunakaran et al., 2013). While this approach is instructive, it cannot adequately engage with diagnosing problems to information flows in environments where work is inherently collaborative (Paul and Reddy, 2010; Hertzum, 2008). The introduction of information systems should, in-principle aid this collaboration. However, this presupposes that these systems intersect effectively with existing collaborative processes and practices. Furthermore, it remains an open question as to how collaborative aspects of information behaviour adapt to information systems in use (Hertzum and Reddy, 2015; Miettinen and Paavola, 2016).

Theoretical Lens of Activity Theory

This study proposes that the framework based on activity theory (Allen et al., 2011; Allen et al., 2013; Kaptelinin and Nardi, 2017) can be effectively applied to investigate collaborative information behaviours within engineering product development and help assess the impact of information systems on the collaborative practices of engineers.

Activity theory is based on the socio-cultural psychology of Lew Vygotsky (1978). Engestrom (1987; 2000; 2008) demonstrated its utility as a powerful framework capable of analysing and ultimately redesigning work practices within organizations. In this approach, an activity system consists of a subject, individual or collective, who acts on an 'object of activity' through the use of material-conceptual tools. An 'object of activity' is defined as the focus of a subject's attention, where the subject's motivation is to achieve a desired outcome (Kaptelinin, 2005; Nicolini et al., 2012). The tools can be defined as existing procedures and processes, and material and digital artifacts which mediate action (Nardi, 1996; Miettinen and Virkkunen, 2005). Activity takes place in the context of a community or communities with shared rules of interaction and division of labour (Engeström, 1987; Kaptelinin et al., 1995). Engestrom (Engeström, 2001a) further developed activity theory through the introduction of multiple or interlinked activity systems, where several activity systems partially share an 'object of activity' (Fig 1.). The concept of interlinked systems makes activity theory particularly well-suited to the analysis of complex collaborative work, for example when diverse teams work on the design of interfacing components of a shared system.

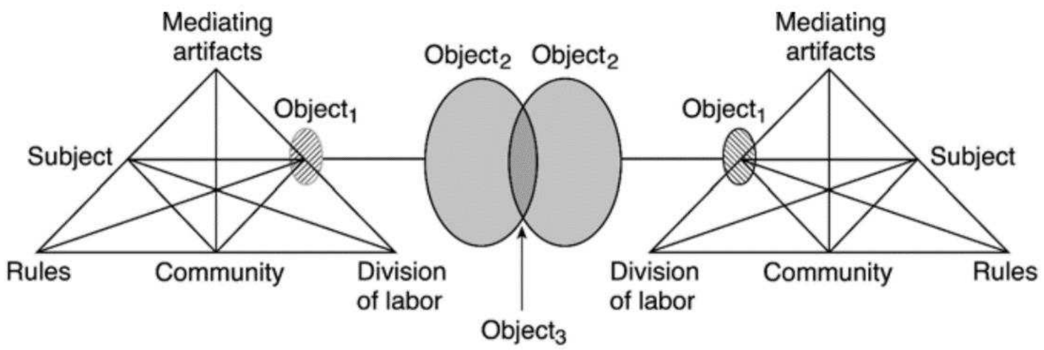

Figure 1. Third generation activity theory with a joint object of activity (Object 3) being partially shared between two interacting activity systems (Engestrom 2001, p. 136).

There are several reasons why activity theory is a potent tool for investigating collaborative work. Firstly, it is versatile and allows for multiple contextual factors to be included in the analysis of collaboration (Wilson, 2006). It also links information behaviour to the 'object of activity' which is the common motive for all of the collaborators. Motives arise from information needs, which are dependent on contextual factors (Allen et al., 2011). These factors include project and task characteristics, personal and professional backgrounds, as well as social, cultural and organizational settings. The resulting multi-layered context makes it possible to characterise collaborative aspects of information needs in detail.

Secondly, the concept of mediation in activity theory can account for the role of digital and material artifacts in shaping collaborative information behaviour (Allen et al., 2011; Karanasios, 2018).

Numerous material, digital and abstract tools mediate interactions between people and information. These tools and their associated work procedures shape information needs through prescribing what, how, when, where and who should be using the information. Employing this notion of mediation provides an insight into how specific procedures and collaborative artifacts shape the way actors interact with information.

Finally, activity systems are in a state of constant dynamic change and adaptation due to external and internal contradictions (Karanasios and Allen, 2014). Such contradictions are manifested as tensions, disruptions and dilemmas experienced by actors in the course of their work. Experiences of tensions and disruptions force actors to modify their behaviour to work around the contradictions or to resolve them. This, in turn, causes the transformation of activity systems. Activity theory can therefore be deployed to analyse change and adaptations in information behaviour over time (Allen et al., 2011).

The PhD research which informed this study applied activity theory to the study of collaborative information behaviours within product development in two high value engineering organisations. The present study focuses specifically on investigating contradictions related to the use of information systems and ICT technologies in two companies and links these contradictions to adaptations in collaborative information behaviours exhibited by engineers in the course of their work.

Study Design, Data Collection and Analysis

The empirical findings reported in this paper are based on data from two case studies conducted in two multinational engineering organisations. The organisational data is anonymised due to confidentiality and data protection. Company A designs and builds electrical and communication systems for private and public sector customers. Company B is a multinational automotive parts manufacturer. Both companies are business to business (B2B) oriented and work closely with their customers throughout the product development process.

The development of products and services in Company A and Company B involves a diverse range of experts representing multiple engineering disciplines and domains. On average, an engineer involved in product development in companies A and B communicates with between 2-5 people every day, and also interacts weekly with a further 10-20 people through a mix of face-to-face and ICT mediated communication. In both companies, product development projects last on average from 2 to 5 years. Both companies use structured processes to manage their product development work, such as the stage gate product development process model (Cooper, 2008).

The goal of the data collection was to build a rich and complete description of collaborative information behaviours and decision making practices within product development projects in the case study organisations. Data was collected through one to one interviews with professionals engaged in product development in both companies. The interviews followed a semi-structured approach and lasted between 45-90 minutes. Nine interviews were conducted in Company A, and seventeen in Company B. The interviewed engineers represented diverse roles and functions within product development, ranging from very senior strategic roles such as the Head of R&D to more technical roles such as product designer. Participants were experienced in their particular industries with work experience ranging from 5 to 30+ years.

The data was analysed using the framework of activity theory (Karanasios and Allen, 2014), with a two-phased data analysis. During the initial, ‘open’ coding phase a content analysis technique was used to make sense of the data (Ezzy, 2013), with the data systematically searched to identify main themes or patterns (Brown and Clarke, 2006; Strauss and Corbin 1998). Once the first coding phase was completed the data analysis process entered a second stage guided explicitly by the framework of activity theory and, specifically, the concept of contradictions (Groleau et al., 2012; Engeström, 2001b; Engeström, 1995; Allen et al., 2013). To identify contradictions, the researcher investigated the data for evidence of identifiable tensions expressed by interview participants, including expressions of conflicts and disruptions in work situations (Engeström, 2008). Specifically, the data was searched for evidence of forces presenting participants with a dilemma; pulling him or her in opposite directions in terms of their decision making strategies (Ezzy, 2013; Karanasios and Allen, 2014).

The Two Vignettes

The findings are presented through a discussion of two examples or vignettes from the case studies. These vignettes illustrate two different scenarios whereby digital artifacts mediate interactions between engineers and sources of information. In Vignette 1 the mediating digital artifact is the new communications technology (ICT) which is increasingly used to facilitate collaboration in place of a face to face, in-person interactions (as was the case before spatially distributed work became a popular strategy in companies A and B). In Vignette 2, the digital artifact is the document management system. Table 2 includes an overview of digital artifacts considered in this study, their role within product development activities in companies A and B, and the contradictions associated with their use.

Product development activities discussed in Vignettes	**The mediating technological artifact analysed in the Vignette**	The contradiction within product development activity system associated with the artifact	Adaptation in collaborative information behaviour of engineers
Vignette 1 Actors collaborating during design and development of a product	ICT communication technology - mediates communication between actors	ICT mediated communication makes it harder to build shard understanding and mutual trust, important components of engineering work	Engineers prefer face, in-person communication. They use other strategies (e.g. sending a thank you note) to build trust and relationship in absence of in-person contact
Vignette 2 Actors accessing information on previous designs and related project documentation	Digital document management and archiving system - mediates the access to design documentation	Document management system cumbersome to use, and knowledge management is not top priority for engineers when faced with time pressure	Reliance on informal communication channels - Engineers use colleagues as information sources, or to direct them to the right information.

Table 1. The two Vignettes, mediating artifacts analysed within product development activities in companies A and B, and the contradictions.

The first vignette focuses on the role of ICT as a tool mediating communication between engineers working on join product development project. Engineers across the two case study companies expressed strong preference for interacting with collaborators through in-person, face-to-face meetings. Existing research confirms a preference for face-to-face and unstructured interactions among engineers, which enables them to receive contextual information, discover so called ‘unknown unknowns’ and problem solve more effectively (Hertzum and Pejtersen, 2000; Aurisicchio et al., 2010). In both case study companies, face-to-face contact is preferred, as it seen as facilitating networking, building trust and forging relationships, as well as allowing engineers to efficiently and quickly exchange knowledge and align their understandings.

However, the companies A and B are increasingly engaged in product development projects which feature technology-mediated collaboration, such as networked product development spanning different locations and partner organisations where teams are not co-located. This creates tensions in product development work activity systems in these companies, evidenced in the interviews with engineers. The tensions related to how product development was conducted in the past, with the centrality of face-to-face contact, and the way the activity has since moved towards communicating through emails, phones and videoconferencing. In activity theory terms, this tension is an example of an underlying contradiction between the traditional activity and the new version of the activity.

Due to this contradiction, product development professionals are forced to come up with various strategies and workarounds to manage relationship building and alignment process without the everyday face-to-face contact. For example, one of the strategies used by an engineer in A was an emphasis on showing gratitude and appreciation for collaborators whom he doesn't see often by sending a special token of appreciation, such as a 'thank you' note. Thus, professionals are forced to use creative strategies to manage tensions between the preferred communication practices, which are based on short and frequent, in-person communication channels, and new ways of working which demand managing long distance working relationships, often with unfamiliar collaborators.

The second vignette illustrates an example where the information system failed to meet the needs of the activity. Here, the mediating tool analysed was a document management system. The document management systems used in companies A and B are based on technological solutions such as digital databases and designated folder catalogues. Engineers from both companies voiced complaints that their existing document management systems were not at all intuitive to use and very labour intensive.

Document management issues experienced by engineers related to problems with the location of information, problems with duplicate files and version confusion. Typically, there were several filing systems in use, and a lack of transparency over how they are used. The practices around existing document management systems were highly individualised, with particular designers and teams using the systems in a specific way. As a result, the engineers often relied on their personal networks to point them to the 'right' information and used informal means to override problems with the formal system. A common problem compounding such inefficiencies was de-prioritization of documentation in the course of daily product development work practices; "We are not very good at constant documentation" admitted one engineer from B.

From the point of view of activity theory there is evidence of a contradiction between, on one hand, the existing document management tools which seem to be cumbersome to use, the rules of the knowledge management which demand knowledge (design reports etc.) to be captured and kept accessible, and on the other hand the motives of product development professionals. For product development professionals archiving or efficient knowledge management is not a priority as they are faced with many more pressing demands on their time. In effect, the engineers rely on personal knowledge, and on the knowledge of their colleagues, to find the information their need in the document management systems. This contradiction creates a paradoxical situation in which an apparent trade-off exists between sound knowledge management and efficient and timely product development. Such trade-off has been observed in research into knowledge management in product development (Van Oorschot, K. et al., 2018; Müller-Stewens and Möller, 2017).

Conclusion

This research explored how the digital artifacts used to mediate information flows in complex product development influence the collaborative information behaviours of actors. Focussing on two multinational engineering organisations, two separate vignettes were examined: 1) the ICT communication technology which enables engineers to communicate remotely, and 2) document management systems used in companies A and B for archiving design and project documentation.

Using the theoretical lens of activity theory, the findings illustrated how the use of these tools within product development activity systems are subject to contradictions. Contradictions may stem from the fact that the technological tools are in conflict with the existing configurations of interests and preferences, in effect 'forcing' ways of working that are contrary to established or preferred practices. Or the use of such instruments, while mandated by the official rules, might be ill suited to everyday work practices. In response, actors adjust their collaborative information behaviours, working around existing procedures, and relying on informal communication to compensate for deficiencies in existing tools.

Activity theory has shown, in this context, that a considerable aspects of collaborative information behaviour in product development is shaped by technological artifacts. Activity theory also aids the diagnosis of underlying factors leading to disruptions in information flows and analyses how people adapt their collaborative information behaviours in response to disruptions. Thus, activity theory can facilitate impactful research interventions into the design of information systems and communication practices in information intensive, complex work environments. As such, it can inform both the theory and the practice of collaboration and information management. The resulting knowledge gained can be exploited in industry, and contribute to general theories of collaborative information behaviour in organizations.

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