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Factors of collaborative working: A framework for a collaboration model

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ABSTRACT

The ability of organisations to support collaborative working environments is of increasing importance as they move towards more distributed ways of working. Despite the attention collaboration has received from a number of disparate fields, there is a lack of a unified understanding of the component factors of collaboration. As part of our work on a European Integrated Project, CoSpaces, collaboration and collaborative working and the factors which define it were examined through the literature and new empirical work with a number of partner user companies in the aerospace, automotive and construction sectors. This was to support development of a descriptive human factors model of collaboration – the CoSpaces Collaborative Working Model (CCWM). We identified seven main categories of factors involved in collaboration: Context, Support, Tasks, Interaction Processes, Teams, Individuals, and Overarching Factors, and summarised these in a framework which forms a basis for the model. We discuss supporting evidence for the factors which emerged from our fieldwork with user partners, and use of the model in activities such as collaboration readiness profiling.

1. Introduction

A critical success factor for any community – at work and outside work – is the extent to which it can coordinate itself to communicate and achieve common goals: in other words, to collaborate. A study by Frost & Sullivan (2006) sponsored by Verizon Business and Microsoft Corp. found that collaboration, an organisation's strategic orientation and market turbulence were the three main business performance drivers, and that of these collaboration had the most impact. It is becoming increasingly difficult for multinational corporations to maintain a competitive edge over global competitors; companies which can create and support collaboration between departments or with supply chain partner companies can best harness their distributed resources and expertise (Hansen and Nohria, 2004). Collaboration is a ubiquitous presence in our lives and is a constant feature of modern society; 'work is always immediately social in that the object and the subject, the end and the means, the motives and the needs, the implements and the competencies, are socially mediated' (Schmidt, 1991, p. 2).

The advantages to be gained from good collaboration will vary according to the type of business or company, but the benefits can include: increased profit through sharing expertise across business units or companies; reduction in costs through sharing best practices; improved decision making through sharing insights and knowledge; innovation through sharing ideas; and an improved ability to pursue goals that involve distributed units or companies (Hansen and Nohria, 2004). To achieve these advantages, however, an organisation should also be fully aware that there are potential disadvantages and barriers to collaboration, in order to manage them. These potential barriers are discussed later in the paper in the discussion section.

For a concept so widely used in everyday language there is a surprising lack of a clear understanding of what it is to collaborate, and of how best to support and improve collaborative working. Definitions are often tailored to a particular environment. However, common themes do emerge from the multitude of definitions and integrating some of these (e.g. Henneman et al., 1995; Mattessich and Monsey, 1992; Meads et al., 2005; Montiel-Overall, 2005; Schrage, 1990; Wilson, 2006) gives us a simple first working definition: Collaboration involves two or more people engaged in interaction with each other, within a single episode or series of episodes, working towards common goals.

This paper presents a first framework for a model of collaborative working. The context was a major European research project

Abbreviations: CAVE, Cave Automatic Virtual Environment; CWE, Collaborative Working Environments; CSCW, Computer Supported Cooperative Work; FAL, Final Assembly Line; DMU, Digital Mock-Up; OEM, Original Equipment Manufacturer.

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concerned with tools, systems and organisational structures for co-located, mobile and distributed collaborative engineering and design (see next section). Therefore the framework applies more to IT, engineering/design and collaborative work systems design, with less emphasis on (although not to the exclusion of) work on collaboration within military and aerospace settings, or local and political communities.

In the next section we summarise the project CoSpaces, and consequently the rationale behind the framework and model. After this we identify the main factors and sub-factors which structure the model, summarising the literature in terms of evidence for each factor. In order to reduce what was an enormous quantity of documentation to a form that can be summarised in a single paper, we do this within a structured tabular format. Whilst it is clearly beyond the scope of the original research work never mind this paper to explore all the factors empirically, in the section afterwards we provide some evidence from our own fieldwork with industrial user partners and systems developers. Finally the paper contains a discussion of the framework and model development and how they have been used in a variety of ways to date; we identify potential barriers to collaboration, discuss the limitations in our work and summarise work to date on verification.

2. CoSpaces Integrated Project

CoSpaces was a large European Commission funded Integrated Project developing innovative collaborative working solutions that are responsive to industrial needs. The project had many industrial, research and business partners from 12 European countries (see http://www.cospaces.org/downloads.htm). The focus was how advanced technologies (virtual, augmented, tele-immersive, mobile, and context aware) can be deployed to create collaborative engineering workspaces for planning, design, assembly, architecture, construction and maintenance activities in the aerospace, automotive and construction sectors. European companies are increasingly required to reduce lead-times for new products, improve their quality, and their customer and market responsiveness. To achieve these goals, the design and manufacture of products, buildings and systems are reliant upon dynamic, multidisciplinary teams, increasingly involving multiple organisations on a trans-national basis. The CoSpaces technical development was a re-configurable and dynamic software framework to support creation of Collaborative Working Environments (CWE) for teams involved in design and engineering tasks. Team members participate in decision making, view drawings, models and designs, propose or carry out modifications, and draw on reference materials, with systems and data access being adapted to collaborating partners' function, professional background, resource availability and current location. The collaborative working is thus across professional and organisational boundaries, in distributed, co-located and mobile workspaces. The CoSpaces technology should be adaptable to suit end users and their context, empowering engineers and designers as individuals and in their respective teams.

CoSpaces included a substantial, central and real human factors contribution, not always the case on large or small European ICT projects. The authors of this paper were the main human factors team on CoSpaces, with roles to act as intermediaries between potential end users and the developers, thus ensuring that the wider human and organisational issues associated with collaborative work were considered, and feasible user requirements and related evaluation protocols were provided. In fact, many of our user partners were well aware from their own experience that a lack of consideration of human factors was a barrier to collaboration and to the use of collaborative technologies. Early on we structured the involvement of the human factors specialists into the overall project in such a way as to be as supportive as possible of the technical development teams, acting as the representatives of the users and translators of their requirements so that the resultant systems could be implemented to benefit engineering and business performance. This was whilst ensuring that the needs for collaboration performance and systems usability were not swamped in the rush to produce advanced architectures and exciting tools (Wilson et al., 2009a).

In order that development of such complex systems could be carried out in time for deployment within the user companies well within the project's 42 month time frame, the project technical manager produced some very early visionary scenarios on digital video. These illustrated the designer, engineer or architect of the future, collaborating on tasks with colleagues around the world from wherever they were, including on the move, and sharing and working on digital design models and related logistic and development information. The visionary scenarios were used by the developers to help potential users to skip a technology generation in their imaginations, and to project a very different future of engineering and design modelling, simulation, planning, construction, production and communications. In parallel the human factors team wanted to ground the requirements for the CoSpaces systems in the end users' opinions and knowledge of collaboration today and likely needs for tomorrow, irrespective of the type of technology; or indeed even if no technical system was used – which led to interesting discussions with developers! To do this we used an iterative process of developing stories, scenarios, top level requirements, detailed requirements, evaluation protocols and measures (see Fig. 1).

To provide a foundation for this process the project required a model of collaborative working, the CoSpaces Collaborative Working Model (CCWM). The CCWM was not to be a formal computational model but was to be descriptive in that it identified and distinguished the various factors which make up or influence collaboration at work, built up in layers to group factors, and eventually to illustrate hypothesised or proven links between factors, including causative relationships. The model development was vital for seven inter-connected reasons:

1. As a basis to structure the system architecture
2. To support a user profiling tool built into the user interface
3. To enable a structured approach to scenario and user requirements development with respect to the act of collaboration (as distinct from engineering/design task performance)
4. To underpin iterative development, evaluation and implementation of CoSpaces systems within user partners and subsequently more widely
5. As a basis for development of a company collaboration readiness profiling tool
6. To fill a gap in the human factors literature with a structured descriptive model of the key factors of collaboration
7. To later predict and test interactions between sub-factors at one level or between levels of the model.

Before the CCWM could be developed we needed a framework of factors of collaborative work based on the state of the art and our own observations as these emerged, and it is this framework that we describe in this paper.

3. Framework of factors of collaborative work

CoSpaces technology will support collaboration at different levels, from small teams of individuals through larger project or enterprise groups and up to international arrangements between organisations. Therefore, our understanding of what it means to

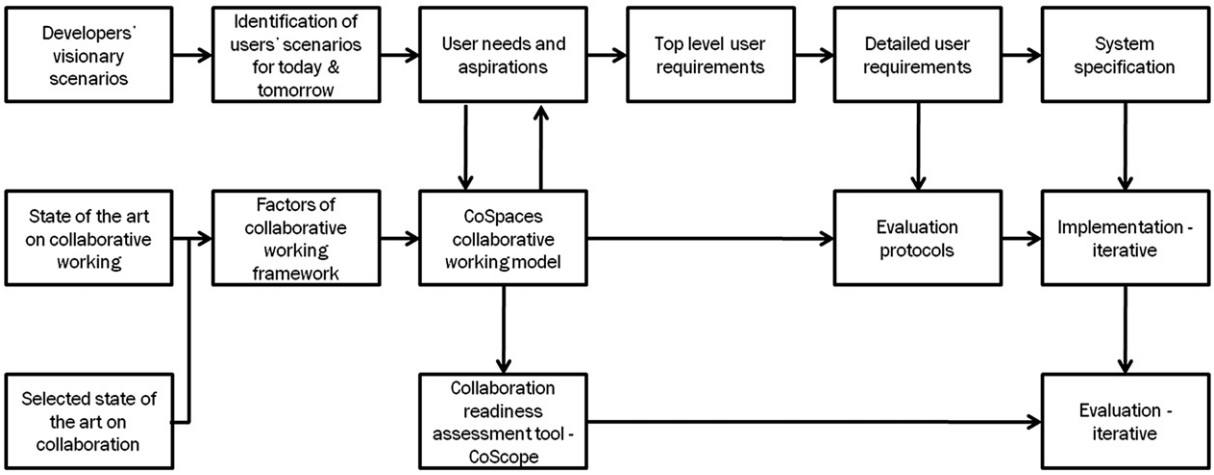

Fig. 1. Iterative process of developing collaborative technologies in the CoSpaces project.

collaborate had to have the flexibility to embrace interpersonal relationships and the factors that drive people to work together successfully, and also higher level organisational and more formal aspects of collaborative engineering and supply chain management. Work, collaborative or otherwise, is best understood in terms of the context in which people are working, and its influence and constraints on structures and processes, performance and success. With collaborative work we often find continually changing people, technology, information and space, and so collaboration is understood through people's interactions with each other, technology, information and the environment and not solely in terms of the cognitive skills of workers and organisational norms. All this needed to be accounted for in our framework.

Research into collaboration emerges from a large number of disciplines and professional fields. The total literature for all the factors and sub-factors relevant to collaboration is huge. Our way of managing the literature search was, in the main, to search from collaboration to factor X, rather than vice versa. That is, we identified and assessed the literature on collaboration, particularly collaboration in work systems, engineering and design, and noted evidence for factors, mechanisms, positive and negative effects. For instance, we looked for evidence of the role of culture, say, in papers on collaboration rather than searching the whole of the literature on culture for relevance to collaboration. There were some exceptions to this strategy, where we thought a particular general reference was key. The literature search was across CSCW (computer supported cooperative work), psychology, business and management science, organisational and social psychology, and ergonomics/human factors (including joint cognitive systems and distributed cognition). Application areas searched were primarily engineering, design, business, healthcare and education. The literature base was extended and tested through a programme of user interviews, user workshops, expert brainstorming sessions, and user requirements elicitation work with the CoSpaces industrial user partners (and earlier with other European companies on other projects) in the aerospace, automotive and construction sectors.

In the rest of this section we present summarised tables of the main factor groups that form the framework for our model of collaboration. At the top level (Table 1) the factor groups are: context, support, tasks, interaction processes, teams, individuals (these groups are consistent with team performance models and other frameworks of collaboration – e.g. Hackman, 1987; Harvey and Koubek, 2000; Neale et al., 2004; Salas et al., 2007). In addition we have identified a set of overarching factors relevant across all or most of the main factor categories. Each of the main factor groups contain a number of sub-factors, and Tables 2–8 provide a summary of the key findings from the literature on each of the sub-factors, their importance, and their impact on collaborative work. Sources are identified against sub-factors rather than against each of the key points as many references refer to several key points. Many of the factors can be collaboration enablers or inhibitors depending on how they are implemented and supported.

3.1. Context

Context (Table 2) usually determines the types of individuals and teams who are involved in the collaborative work, and the

Table 1
Factors (main and sub-factors) of collaborative work.

Main factors	Sub-factors								
Context	Culture	Environment	Business climate	Organisational structure					
Support	Tools	Networks	Resources	Training	Team building	Knowledge management	Error management		
Tasks	Type	Structure	Demands						
Interaction Processes	Learning	Coordination	Communication	Decision making					
Teams	Roles	Relationships	Shared awareness/ knowledge	Common ground	Group processes	Composition			
Individuals	Skills	Psychological factors	Wellbeing						
Overarching factors	Trust	Conflict	Experience	Goals	Incentives	Constraints	Management	Performance	Time

Table 2
Factors related to the context in which collaboration takes place.

Context	Reference sources	Key points
Culture	Bornemann et al., 2003; Devine and Banahan, 1999; Dooley, 1996; Edwards and Wilson, 2004; Frost & Sullivan, 2006; Guest, 1996; Marttiin et al., 2002; Payne, 1996; Tyndale, 2003; Unsworth and West, 2000; Weiseth et al., 2006.	• Culture can be national/regional, organisational or professional (e.g. architects, facilities engineer, site supervisor, client). • Organisational or team culture comprises the attitudes, beliefs and values shared by employees, which impact on employee behaviour and morale. • Culture can influence the 'openness' of communication channels, willingness to change, the types of social interaction that take place between people, organisational trust and organisational effectiveness. • Organisational culture often emerges from the organisation's overall vision and objectives and thus management should be well placed to change organisational culture. • Culture can vary in its strength (i.e. the extent of acceptance of the culture by members), content (i.e. the topics that are focused on) and pervasiveness (i.e. the range of behaviours/values that organisations focus on influencing).
Environment	Détienne, 2006; Devine and Banahan, 1999; Dix et al., 2004; Edwards and Wilson, 2004; Espinosa and Carmel, 2003; Galve Górriz and Ortega Lapiedra, 2000; Hinds and McGrath, 2006; Hockey, 1996; Kiesler and Cummings, 2002; O'Driscoll and Cooper, 1996; Neale et al., 2004; Olson and Olson, 2000; Salas et al., 2005a; Wilson et al., 2003.	• Environment constitutes the physical space that individuals and teams work in (e.g. organisation of space, light, temperature, noise, and safety), socio-cultural aspects of the workplace, and work organisation (e.g. time pressured, competitive, rapidly changing, stable etc.). • Individuals and teams may work in a co-located, distributed or mobile setting and sometimes across different time zones. • Poor working conditions and environments (e.g. noisy, highly pressured) can negatively influence skilled performance, physical and mental wellbeing, and willingness to collaborate. • Separation across distance and time often places more reliance on asynchronous communication and can result in increased demands on coordination. • Co-located work facilitates informal communication, the maintenance of shared awareness and mental models which can facilitate group effectiveness. In addition, physical proximity and familiarity 'breed liking', and thus can facilitate collaborative work amongst individuals working in close physical proximity to each other. Being co-located can facilitate productivity; difficult problems may be better solved, and tightly coupled work more easily achieved.
Business climate	Hackman, 1990; Unsworth and West, 2000.	• Business climates may vary between countries, companies, and even locations, requiring different collaborative work strategies to produce optimum results. • The stability of the business climate may affect the business opportunities available and the team's and organisation's effectiveness. • Business climates influence the collaborative strategies and partnerships employed by an organisation to maintain a competitive edge, and can explicitly and implicitly encourage or discourage participation. This may be a particular issue in multinational, global collaboration which may be affected by both the overall business climate and national/regional climates.
Organisational structure	Buchanan and Badham, 2008; Burton et al., 2005; Campion et al., 1993; Conger and Kanungo, 1988; Edwards and Wilson, 2004; Frost & Sullivan, 2006; Hackman, 1990; Hinds and McGrath, 2006; Igbaria, 1999; Langfred, 2000; Mannix and Sauer, 2006; Parker and Wall, 1996; Payne, 1996; Pettigrew and McNulty, 1995; Suchman, 1987; Tyndale, 2003; Weiseth et al., 2006; West, 1996; Wilson et al., 2003.	• Organisations provide the foundation, structure and boundaries (functional responsibility and authority) to formal and informal individual/team roles. The organisational structure will define different departments, tasks, processes, policies, culture and norms, power relations, trust, learning, and incentives for participation. • An organisation's productive power and effectiveness has been associated with the degree of management sharing of power and control with employees. • Organisational structure can influence the level of autonomy teams have to structure, conduct and deliver their tasks and responsibilities, and for individuals and teams to participate in collaborative decision making. Self-organising and more autonomous teams are associated with improved work productivity and employee satisfaction, though high autonomy has been associated with increased effectiveness only for teams with high task interdependence. Team structures that match the tasks to be performed are associated with more effective team work. • Organisational structures and policies may be influenced by, and may also influence, the organisation's collaborative relationships with other companies. Organisational structures and work conditions should be designed in order to support and facilitate collaborative work. • High performance workplaces have been characterised as being more decentralised (in terms of responsibilities) than traditional work organisations, and are better at flexibly responding to rapidly changing demands, focused on the impact of the context of work, processes, and tools that facilitate people's work, and on increasing their employees' influence on the business.

Table 2 (*continued*)

Context	Reference sources	Key points
		• Decentralised organisations rely on expert power, i.e. decisions are made by those who best understand the issues rather than rely on a hierarchy of authority. This decentralisation can increase the role of political skills in gaining resources and support to further personal, team and organisational goals. • The power and influence of employees is determined by contextual factors such as organisational structure and its impact on status. Collaboration of individuals or teams with differing power and status can impact on the interaction between them, thus influencing communication, coordination, decision making, learning, conflict resolution and overall performance.

types of tasks that need to be carried out. It will also influence the type of support that is provided for collaborative work, and can have an impact on the actual process of collaboration itself and on team effectiveness. For example, the general business environment (e.g. co-located or distributed workspaces and relationships across the supply chain) has been found to strongly influence how people work. Other contextual factors, such as organisational structures which provide employees with team as well as individual autonomy, can increase employees' psychological involvement in their tasks.

3.2. Support

Collaboration within organisations requires effective and appropriate support (Table 3), which will usually make the difference between a successful collaboration and an unsuccessful one. Even well-designed teams with good people can perform poorly if they are not provided with the management support and resources they require in order to meet their goals, and collaborate with internal and external colleagues and clients as necessary. In the context of engineering and design activities a major element of support will be the (mainly technical) tools provided, whether basic such as teleconferencing and shared workspaces or sophisticated such as networks of virtual reality facilities like Cave Automatic Virtual Environments (CAVEs) or networks of location-aware handheld devices. Such tools can provide support but themselves need good support systems such as training (for attitudes and knowledge as well as skills), complementary job design and user supportive interfaces.

3.3. Tasks

Individuals and teams engage in collaborative processes at work in order to complete tasks (Table 4) to meet defined goals. Team task performance is as critical as collaborative performance. Task characteristics are thus identified as a main category of attributes affecting collaboration since the type of work task will interact with the technical support systems, interaction processes and team work.

3.4. Interaction processes

One view on collaborative working is that individuals and teams are part of a collaborative working environment within which they engage in interaction processes (Table 5), such as learning, coordination, communication, and decision making. Steiner (1972) defines process as consisting of 'the individual or collective actions of the people who have been assigned a task…process is a series of behaviours, one following another, each determined to some degree by those that have gone before and each, in turn, influencing those that will come later' (p. 8). Teams complete tasks and achieve goals, converting their resources into a product or service, through such processes.

3.5. Teams

Teams (Table 6) have a specified organisational function and contribute to organisational objectives. They are made up of individuals engaging in shared tasks with a common goal, for instance 'a small number of people with complementary skills who are committed to a common purpose, performance goals, and approach for which they hold themselves mutually accountable' (Katzenbach and Smith, 1994, p. 45). For our purposes, team work covers individuals involved in collective tasks and also individuals involved in interdependent tasks which are subsequently integrated, both as part of intra- and inter-group collaboration. We included understanding from co-located teams, teams which are distributed in time and space, and teams in which one or more members is mobile, including remote agents.

3.6. Individuals

Whilst collaboration is fundamentally a social activity, requiring interaction between two or more individuals, it is inevitable that some (possibly a large) degree of work and task-related effort remains at the level of the individual (Table 7). Individual performance – social and technical – is crucial to the performance of teams.

3.7. Overarching factors

Overarching factors (Table 8) are those we believe are relevant to, and interact with, the six main factors identified above and with sub-factors under those. To take just one example of an overarching factor, trust is central to team performance in terms of whether and to what extent they trust each other and their employers and the way they interact (e.g. trusting they are using the best methods of communication). Individuals and teams may have to trust that they are being given the best support available in order to perform their tasks, that these tasks are important, and that their organisational context provides the structure, security and environment required for optimum performance whilst showing a concern for individual and team needs. Trust is also needed in terms of the confidence that people have in the technology they use, the information it gives them and, in certain systems, the decisions it recommends. Finally, trust is strongly related to issues of security and commercial confidentiality, and to the context of business to business collaboration.

4. Evidence for the collaboration factors from CoSpaces user scenarios

We had an opportunity to test out the framework of factors for collaborative working, through the user company partners within

Table 3
Factors related to the support provided for collaborative work.

Support	Reference sources	Key points
Tools	Bolstad and Endsley, 2005; Cramton and Orvis, 2003; Daft and Lengel, 1986; Dix et al., 2004; Eason and Olphert, 1996; Edwards and Wilson, 2004; Frost & Sullivan, 2006; Graham et al., 2004; Hambley et al., 2007; Hammond et al., 2001, 2005; Harford, 2008; Harvey and Koubek, 1998, 2000; Herbsleb et al., 2000; Igbaria, 1999; Klein, 2001; Knutilla et al., 2000; McNeese and Rentsch, 2001; Monk, 1996; Nunamaker, 1997; Pinelle et al., 2003; Rogers, 1995; Seymour and Cowen, 2006; Sheehy and Gallagher, 1996; Sheldon, 2007; Skovholt and Svennevig, 2006; Sonnenwald et al., 2001; Sproull and Kiesler, 1986; Talbot, 1999; Warner et al., 2003; Weiseth et al., 2006; Wilson, 2006.	• Technologies provide some mechanisms for collaborating when people are co-located but are the medium for collaboration when they work virtually, separated by time or distance. Technologies (such as email, conferencing, scheduling tools, and knowledge management tools) can allow teams to work towards a common purpose by communicating information and coordinating across different time zones, locations, organisational settings and cultural backgrounds. • A distinction needs to be made between technologies for pure collaboration (where the simpler the better is often the key) and those task-related technologies such as may be required to share and modify 3D engineering models where more complexity is needed. • At their best, collaborative technologies can improve the efficiency and effectiveness of collaborative work, the quality of the end product, work processes, team/organisational relationships, individual and group satisfaction, reduce project costs, establish and maintain common ground. However, the potential benefits of collaborative technologies can be limited by the way they are implemented and used. Tools should be task- and function-appropriate, intuitive to use, support formal and informal communication, and offer clear added benefits. • Communication tools can reduce the social distances between distributed team members and facilitate the development of shared mental models. • Communication tools vary in the type of information they communicate (i.e. verbal, non-verbal), the collaboration processes and tasks they can potentially support, the collaboration characteristics they support (e.g. asynchronous/synchronous, planned/unplanned, co-located/distributed), the amount and speed of feedback they can generate, the extent and speed of message flow, ability to direct focus on task, the control of communication afforded, and privacy. • Technology-assisted communication varies in terms of ease of communication, practicality, richness of information afforded, accuracy, and the workload associated with its use. • Technology that is compatible with fundamental individual, group and organisational goals, needs, culture, structure, work practices, and values is more likely to be adopted. However, the choice of collaboration tools is often dictated by cost, availability, technical limitations, and integration with existing organisational systems. • Collaborative technologies do not necessarily remove the need for face-to-face contact; they can actually make such face-to-face work as occurs even more critical. However, technology can reduce the serendipitous nature of face-to-face meetings and increase opportunities to exchange and create new knowledge.
Networks	Campion et al., 1993; Devine and Banahan, 1999; Edwards and Wilson, 2004; Galve Górriz and Ortega Lapiedra, 2000; Hansen and Nohria, 2004; King, 2006; Krackhardt and Hanson, 1993; O'Driscoll and Cooper, 1996; Sheehy and Gallagher, 1996; Wilson et al., 2003.	• Personal and professional networks can provide a forum for the discussion of ideas and can generate awareness of possible collaborations. • Informal networks facilitate the effectiveness of daily work, allowing individuals and groups to know who to contact when information cannot be accessed through formal systems and who can accurately and reliably confirm information which is fed through formal channels. Informal networks can also help to accelerate progress on tasks and may be particularly important in dealing with unexpected issues. • Some companies promote the use of 'connectors', i.e. people who have a vast personal network, who know where experts are located and can connect people. • Social support, the ability to establish informal contacts and open communication with colleagues are associated with improved work productivity, communication flow, employee satisfaction and wellbeing. • Networks are more easily established in co-located than in distributed working environments. • Social networks are useful mechanisms for generating support for change, e.g. the adoption of new technologies.

Table 3 (*continued*)

Support	Reference sources	Key points
Resources	Cramton and Orvis, 2003; Hackman, 1990, 1998; Johnson and Hyde, 2003; Mattessich and Monsey, 1992; Robertson, 1996; Steiner, 1972; Waugh, 2005.	• Individuals and teams need access to adequate resources (finance, time, physical space, materials, equipment, tools, appropriately skilled personnel) in order to perform their tasks. Task demands will dictate the type and amount of resources required for optimum performance. • Any lack of commitment of required resources is a barrier to effective collaboration. • Different teams and team members within teams may compete for a limited amount of resources available to support their work. Since organisations are unlikely to be able to provide unlimited resources, it is important to anticipate and manage resource use according to demand.
Training	Anderson, 1993; Campion et al., 1993; Cooke et al., 2001; Cordery and Soo, 2008; Edwards and Wilson, 2004; Hackman, 1990, 1998; Salas et al., 2008; Stammers, 1996; Tesluk et al., 1997; Warr, 1996b; Weiseth et al., 2006.	• Training is required for work task completion, collaboration tool use and the act of collaborating itself. • Personal and professional development training opportunities are associated with improved productivity and employee satisfaction. Training provides opportunities for team members to acquire new skills or improve existing skills and develop shared mental models, and thus can improve overall organisational effectiveness. Organisations should be aware of the skills and behaviours required to perform particular collaborative tasks or functions and base training on task analyses. • Training activities are a crucial part of managing change within an organisation.
Team building	Anderson, 1993; Bradley et al., 2003; Edwards and Wilson, 2004; Hackman, 1990, 1998; Katzenbach and Smith, 1994; Salas et al., 2008; Unsworth and West, 2000.	• Team building activities include interventions to train in social or team skills (e.g. communication, assertiveness) and can include social activities outside the workplace – these activities are related to successful project outcomes by helping people to work together more effectively, boosting morale, improving motivation and cohesiveness, increasing commitment, addressing cultural barriers, and helping to build trust and relationships. • Team building interventions to address current team issues can help teams achieve their goals, by, for example, identifying and overcoming any barriers to effectiveness. Post-task coaching interventions can help teams formally review their performance and experiences, enabling members to share and consolidate lessons learnt. • Team building interventions can have a greater positive impact on organisational processes than technical skills training.
Knowledge management	Bornemann et al., 2003; Carneiro, 2000; Détienne, 2006; Edwards and Wilson, 2004; Hackman, 1990; Inkpen, 1997; Kelly, 2007; Marttiin et al., 2002; Weiseth et al., 2006.	• Individuals and teams should have access to the knowledge required in order to do their job. By the same token they need the motivation and support systems to conserve and make available their own knowledge. Managing and using knowledge well will enable individuals, teams and organisations to gain a better understanding of current or past activities and their outcomes, and improve future performance. • Organisations should ensure that knowledge is captured, structured, transferred, stored, made available, and utilised as necessary. An environment of trust in an organisational context is important in creating a knowledge sharing culture to ensure that knowledge is exchanged and utilised effectively in order to meet organisational goals. Organisations which are ready to collaborate are likely to invest in keeping knowledge spaces up-to-date. Clear guidelines, policy, information and documentation processes should be set to ensure that all team members are aware of the information they should be recording and communicating, and how they should do this. • Knowledge management initiatives must acknowledge that for many workers their knowledge is their currency or status and collaborative work systems which just assume that people will make available all they know may be avoided or worked around.
Error Management	Edwards and Wilson, 2004; Hockey, 1996; Rasmussen, 1986; Reason, 1990; Salas et al., 2005a, 2005b; Van Dyck et al., 2005; Viller et al., 1999.	• Errors made during collaborative work may result from ineffective coordination of individuals within teams, inappropriate normative and informational influences which may impact on team decision making, and poor leadership, in addition to high mental workload and external stressors. • Error management must account for both errors and violations. The procedures in place to identify and manage errors and violations may influence collaboration, productivity and costs. • Violations are deliberate deviations from safe or formal procedures or rules, often for performance and optimising benefits, because the rules cannot be worked to, or due to an ignorance of rules. Violations may be related to organisational procedures and organisational culture. They are particularly relevant to collaborative work where an element of group norms and groupthink may be of influence.

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Table 3 (*continued*)

Support	Reference sources	Key points
		• An error management culture (e.g. reporting errors and identifying why they have occurred, freely communicating about errors which allows others to assist when they occur and enabling errors to be detected and managed quickly) facilitates positive organisational learning when errors occur, which has been associated with organisational goal achievement. • Mutual performance monitoring is associated with effective teams and involves team members monitoring each others' work (depending on the task) whilst conducting their own work to prevent or quickly correct any errors or lapses. This can only occur if teams share an understanding of each others' roles, common ground, and mutually trust each other.

Table 4
Factors related to collaborative tasks carried out within the workplace.

Tasks	Reference sources	Key points
Type	Girard and Robin, 2006; Hackman, 1990; Harvey and Koubek, 2000; Higgs et al., 2005; Salas et al., 2005a, 2007; Unsworth and West, 2000; Watson and Michaelsen, 1988.	• Collaborative tasks can be routine or non-routine, predictable or unpredictable, complex or easy in nature. Tasks can be cognitive (e.g. conceptual tasks) or behavioural (e.g. executing work). • Task type and scope will impact on strategies and associated demands. • Task type may affect team performance, e.g. due to differences in the cognitive demands and the motivating characteristics of different tasks. • Task type influences the degree of collaboration experienced or necessary, and the extent of collaboration will differentially affect different types of tasks. • The type of task can increase the need for communication (e.g. for non-routine tasks and when there is task uncertainty), dictate the type and amount of support the team requires in order to accomplish goals successfully, make different requirements on the team's need to be cohesive, and influence team members' wellbeing and their relationships.
Structure	Arthur et al., 2005; Cordery and Soo, 2008; Détienne, 2006; Hackman, 1998; Harvey and Koubek, 2000; Klein, 2001; Neale et al., 2004; Pinelle and Gutwin, 2001; Salas et al., 2005a; Shea and Guzzo, 1987; Tesluk et al., 1997; Viller et al., 1999; Walsh and Maloney, 2007.	• Task structure should be appropriate to task demands, and may be affected by its complexity. It can be fixed or flexible (e.g. in terms of the order in which tasks are completed, or how) and some tasks may be relatively unstructured, with unstable, changeable sub-goals. Ideally, task structure should engage all team members, ensure clear, measurable boundaries for the tasks which the team members are individually and collectively responsible for, and avoid unnecessary duplication of work. • Individuals can contribute to tasks in different ways. Some tasks are structured as sequential sub-tasks, each with their own goals. Work may be performed by an individual working alone outside the context of a team, or by all team members separately, leaving the team without need for interaction between members (pooled/additive interdependence); or work may be 'loosely coupled', with low levels of task interdependence and thus minimum interaction between team members. Task structure can also dictate sequential interdependence (work flows uni-directionally from one team member to another), or reciprocal interdependence (where work flows dynamically back and forth between team members), or intensive interdependence (team members interact intensively to collaboratively perform the task). • Tasks involving collective activities requiring input from multiple individuals simultaneously, or frequent interaction between individuals or teams, are highly interdependent or 'tightly coupled' tasks. Tightly coupled work requires more coordination and communication, the effectiveness of which will impact on productivity, and may suffer more significant process losses in distributed settings compared with loosely coupled work.
Demands	Edwards and Wilson, 2004; Kyzlinková et al., 2007; O'Driscoll and Cooper, 1996; Salas et al., 2005a, 2005b; Van Fenema, 2005.	• Tasks differ in the demands they make on individuals, teams and processes. For example, highly pressured work can require more effort to ensure that communications are efficient. Potentially, team-workers may experience higher work intensity and pressure than when working individually, thus experiencing higher workload levels, which in turn can negatively affect their wellbeing and performance. • In times of high demand, successful teams employ 'back-up behaviours' (e.g. when team members are flexible enough to assist overloaded colleagues) to ensure performance is not negatively affected. Successful 'back-up behaviours' rely on high levels of shared awareness of task status, conditions, roles, responsibilities, etc.

Table 5
Factors related to the collaborative interaction processes within the workplace.

Interaction processes	Sources	Key points
Learning	Bornemann et al., 2003; Edwards and Wilson, 2004; Hackman, 1998; Hockey, 1996; Ilgen et al., 2005; Johnson and Hyde, 2003; Kyzlinková et al., 2007; Stammers, 1996; Unsworth and West, 2000; Wenger, 1998.	• Learning organisations expect individuals and teams to engage in ongoing learning to help achieve their goals and improve responsiveness to change. • The act of collaboration will give formal and informal learning opportunities (e.g. about other individuals, the team, processes within the workplace, the tasks, the support available and the context). • Individuals within a team can learn from each other and develop or improve skills, and increase knowledge through team task performance, including the important learning from their experiences of success and failure. • When informal learning is consolidated or formalised at a team or organisational level (to form part of their shared knowledge), lessons learnt can improve future work. • Formal task-specific training improves the team's ability to be flexible, contributes to the organisation's learning environment, and can improve the quality of working life.
Coordination	Devine and Banahan, 1999; Girard and Robin, 2006; Gutwin and Greenberg, 2000; Hackman, 1990; Klein, 2001; Montiel-Overall, 2005; Neale et al., 2004; Weiseth et al., 2006.	• Coordination is required to achieve shared goals. • Coordination involves goal setting, managing and integrating people and information, setting and managing time schedules, planning and managing the division of labour across different tasks, managing task dependencies, monitoring and evaluating work progress, standardising processes as necessary, managing resources, and providing feedback on the status of activities and on performance. • Coordination of work within and across different, multidisciplinary teams and organisations can be demanding and requires clear communication to optimise collaborative activities.
Communication	Breazeal et al., 2004; Cramton, 2002; Cuevas et al., 2006; Denise, 1999; Edwards and Wilson, 2004; Frost & Sullivan, 2006; Gutwin and Greenberg, 2000; Harvey and Koubek, 1998, 2000; Liebrich and Zink, 2006; Neale et al., 2004; Olson and Olson, 2000; Pinto and Slevin, 1987; Potter and Balthazard, 2002; Salas et al., 2005b; Sheehy and Gallagher, 1996; Swigger et al., 2004; Tyndale, 2003; Walsh and Maloney, 2007; Weiseth et al., 2006; Willaert et al., 1998.	• Communication in collaborative work underpins how people understand each other and how knowledge is transferred. • Communication takes place synchronously or asynchronously, and can be verbal or non-verbal, informal or formal, and can occur through a variety of media. • Open channels of communication enable informal and formal exchanges of task, social and contextual information to support collaboration. • The more that the right information is conveyed to the right people at the right time in the most appropriate way, the more effective collaboration will be. • Communication will help synchronise mutual beliefs, and maintain shared awareness and common ground - easier for co-located teams than distributed teams. • Co-located communication at its best can provide information through many verbal and non-verbal channels; convey nuanced information; allow rapid feedback; provide information on the characteristics of team members; provide opportunities for spontaneous informal exchanges; and allow team members to easily understand deictic references. • Cultural differences (e.g. national, professional, industrial sector) in people's communication styles and preferences may differentially affect enjoyment of working alone or with others, and communicating electronically rather than by telephone or even face-to-face. • Distributed collaboration technology may better support team members with poorer communication skills, giving an overall broader range of views and knowledge.
Decision making	Devine and Banahan, 1999; Hammond et al., 2001; Klein, 2008; Steiner, 1972; Unsworth and West, 2000; Viller et al., 1999; Weiseth et al., 2006; West, 1996.	• Collaborative decision making will involve both intellectual and judgement tasks, and both should be supported. • Although much decision making in practice is rarely formal or structured decision making, the information collection, alternative exploration and choice should be supported technically to allow real contributions from more than one participant. • Decision making in collaborative work is more likely to be naturalistic, relying on a blend of intuitive and analytical processes and heavily influenced by context. The recognition-primed decision model suggests that people match the situation with prior experience of similar situations to generate a satisfactory or acceptable course of action, running a mental simulation of this to test it against known facts. • Group decision making is subject to all the biases found in individual decision making, and uses many similar heuristics, but may also be subject to groupthink whereby individuals are reluctant to stand out from others even when they are clear on the poor decisions being made. Teams affected by groupthink are prone to making

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Table 5 (*continued*)

Interaction processes	Sources	Key points
		irrational decisions and fail to consider all alternatives when under pressure to maintain unanimity. • Participation in collaborative decision making can increase employee satisfaction and commitment. • Team members lower in any hierarchy may be less motivated or confident to propose and fight for ideas; the use of computer mediated communication may reduce this, leading to a greater number of ideas generated when compared to face-to-face brainstorming sessions. • Although in distributed settings a greater number of ideas can be generated using electronic media, participants may exhibit difficulty in reaching a consensus during decision making.

Table 6
Factors related to teams within the workplace.

Teams	Sources	Key points
Roles	Beddoes-Jones and Miller, 2004; Belbin, 1981; Hackman, 1990; Johnson and Hyde, 2003; Mattessich and Monsey, 1992; O'Driscoll and Cooper, 1996; Warner et al., 2003; Wilson, 2006.	• Both team members and teams themselves have specific responsibilities and positions or roles within the organisation(s), often performing multiple roles with their own sets of tasks. Roles can be functional (in terms of their technical ability) and team-based (behaviours of team members interacting with each other and team facilitation performance). • Collaboration is aided when individual roles are coordinated to meet team goals. • Inter-organisational collaboration requires particular effort for participating members to have an understanding of roles and responsibilities in the different organisations, which can be difficult to develop. • Preferences for different types of thinking style, different personality characteristics and cognitive abilities may influence behaviour and taking up different roles. • Collaborative groups may be put together on the basis of team role assessments during recruitment, considering the balance or flexibility of roles required. • Role ambiguity and role conflict can result in psychological strain and in poorer performance.
Relationships	Beddoes-Jones and Miller, 2004; Buchanan and Badham, 1999, 2008; Dix et al., 2004; Edwards and Wilson, 2004; Hackman, 1990; Harvey and Koubek, 2000; Hinds and McGrath, 2006; Kelly, 2007; Kiesler and Cummings, 2002; Mullen and Copper, 1994; Pettigrew and McNulty, 1995; Pfeffer, 1992; Potter and Balthazard, 2002; Robin et al., 2007; Salas et al., 2005a; Unsworth and West, 2000; Van Fenema, 2005; Walsh and Maloney, 2007; Watson and Michaelsen, 1988.	• Collaboration is enhanced when team relationships are good; including group dynamics, interpersonal cohesion, task cohesion, professional, social and personal relationships within the team, respect and trust between members and overall team morale. • Effective collaboration is facilitated by teams that are motivated and operating in good working atmospheres. Good team relationships can reduce communication and coordination demands by, for example, enabling members to predict and more fully understand colleagues' behaviour. • Distributed collaboration needs careful support to ensure that weaker connections and a lack of familiarity between team members do not reduce team commitment. • Cohesiveness can increase supportive behaviours and motivation to result in increased team effectiveness, and is itself an outcome of effective team performance. • Teams of friends have been found to be more productive than teams of people who are not friends. • Policy, culture and status differences may discourage employees from building relationships across teams. • Work demands should be managed to allow time and activity for building relationships between different teams, within or between organisations. • Team dynamics can be influenced by differences in power relations within a group, which may be situational or influenced by organisational structures. • Power is a relational phenomenon, created, sustained, increased or lost in the context of interpersonal relationships, and can be used positively to influence the behaviour of others, mobilise resources, and achieve social and organisational goals, or negatively for personal whim or advantage or corruptly. • Power through privileged access to information or knowledge can affect relationships between team members.
Shared awareness/ knowledge	Bolstad and Endsley, 1999; Bratman, 1992; Carroll et al., 2003; Cordery and Soo, 2008; Détienne, 2006; Drury and	• Shared knowledge and awareness allows team members to work together effectively, adjusting their activities as necessary through an

Table 6 (*continued*)

Teams	Sources	Key points
	Williams, 2002; Edwards and Wilson, 2004; Fischer et al., 2005; Hutchins, 1995; McNeese and Rentsch, 2001; McNeese et al., 2000; Neale et al., 2004; Rogers and Ellis, 1994; Salas et al., 2005a, 2005b; Warner et al., 2003; Wenger, 1998; Wilson, 2006.	understanding of colleagues' roles, responsibilities, expertise, skills, limitations, preferences, biases, social networks, intentions, and emotions. • Collaborative awareness is influenced by, and has an influence on, context, cohesion, participation, trust, conflict, communication, and coordination; e.g. high awareness can reduce coordination demands, enabling teams to function effectively in stressful situations when there may be less communication. • Task and activity awareness (e.g. of project status, availability of resources, whereabouts and actions of colleagues) influences coordination and task performance. • It is easier to establish shared knowledge in homogenous teams than in multidisciplinary teams, and in co-located teams than in distributed teams. • The development of shared knowledge relies on stable team membership.
Common ground	Carroll et al., 2003; Cramton, 2002; Détienne, 2006; Dix et al., 2004; Hackman, 1990, 1998; Harvey and Koubek, 1998, 2000; Katzenbach and Smith, 1994; Kelly, 2007; Klein, 2001; McNeese and Rentsch, 2001; McNeese et al., 2000; Neale et al., 2004; Olson and Olson, 2000; Salas et al., 2005a, 2005b; Waugh, 2005; Wenger, 1998.	• Common ground refers to the extent team members have a shared culture, vocabulary, values or interests, and a shared understanding of working practices and group norms (e.g. rules of conduct) – and are aware that they share this information in common. • Teams achieve common ground with effective communication and coordination, which in turn require that teams share greater common ground and mutual awareness. • Establishing and maintaining common ground can reduce communication demands, improve productivity, help to establish trust, and increase the team's adaptability. • A lack of common ground can lead to misunderstandings, task errors and poor decision making, each of which in turn can negatively impact on working relationships and interpersonal trust. • It is more difficult to establish and maintain common ground in distributed teams.
Group processes	Hackman, 1998; Harvey and Koubek, 2000; Mannix and Sauer, 2006; Steiner, 1972; Viller et al., 1999; Watson and Michaelsen, 1988; Weiseth et al., 2006; West, 1996.	• Social and psychological interactions are defined as group processes and influence behaviour including patterns of communication, patterns of influence, how teams make decisions (rational and non-rational) and their effectiveness. • The way that groups interact can result in the whole being greater (or less) than the sum of the parts, giving performance that is better (or worse) than the sum of individual performances or that of the best individual. • Group effectiveness can be improved by ensuring that all members have an opportunity to voice opinions which are then fairly discussed by the team, and if differences in status (with respect to hierarchical relationship with others, socioeconomic or minority status) are not allowed to constrain collaborative interaction and decision making.
Composition	Belbin, 1981; Campion et al., 1993; Cordery and Soo, 2008; Cummings and Kiesler, 2005; Denise, 1999; Devine and Banahan, 1999; Edwards and Wilson, 2004; Eisenhardt et al., 1997; Frost & Sullivan, 2006; Hackman, 1990, 1998; Hansen and Nohria, 2004; Harvey and Koubek, 1998, 2000; Herbsleb et al., 2000; Higgs et al., 2005; Katzenbach and Smith, 1994; Knutilla et al., 2000; Marttiin et al., 2002; Mattessich and Monsey, 1992; McNeese and Rentsch, 2001; Olk, 1997; Olson and Olson, 2000; Rothschild-Whitt, 1979; Salas et al., 2005a; Sheehy and Gallagher, 1996; Sheldon, 2007; Sonnenwald et al., 2001; Sproull and Kiesler, 1986; Unsworth and West, 2000; Walsh and Maloney, 2007; Weiseth et al., 2006; West, 1996; Willaert et al., 1998.	• Team composition – heterogeneity and size – can affect collaboration. • Team members may differ in age, gender, ethnicity, background, educational/professional background, experience, roles, personalities, strengths, attitudes, values, skills, and expertise. These differing attributes allow teams to be more adaptable and flexible at responding to task demands by using their individual and collective expertise, thus improving work effectiveness. • A key choice can be between teams where members are similar in experience and skills, and are therefore interchangeable, or where they are each a "one-off". • Individual and cultural differences (professional and national) can affect collaboration positively or negatively. For example, multidisciplinary teams can overcome organisational barriers to improve communication and productivity, and their diversity of perspectives can promote creativity. • There is evidence to suggest that heterogeneous teams perform better on complex tasks, but less well on tasks of low complexity. • Diversity within teams may result in conflict, communication difficulties, greater misunderstanding, difficulty in developing shared awareness, differences in risk taking, poor team cohesion and high staff turnover. Evidence suggests awareness of these differences and investing time to understand them, is vital to managing them. • Language – national or professional – does not simply involve understanding the spoken language; unless there is an understanding of the culture it is grounded in, misunderstanding can ensue. • Individuals may have different preferences for methods of communication, due to cultural or functional differences,

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Teams	Sources	Key points
		or personal factors including age, personality, physical health, and company position. • Highly effective collaboration can involve as few as 2–4 team members – it has been suggested that this is because collaborations are interpersonally determined and do not respond well to rules or structures and therefore thrive in very small groups. In large organisations, teams can involve 4–20 people, but the optimum number is 6–8. • Larger teams potentially have a greater skill set available and can cope flexibly with a greater workload. • Large teams are more likely to experience trust, cultural and information security problems, in addition to being more complex to coordinate and difficult to manage. Larger teams are likely to have complex communication channels, and experience a greater difficulty in maintaining shared awareness. • Working in large teams can allow diffusion of responsibility, whereby some individuals may not actively contribute as much as they would if working alone. This 'social loafing' effect can be countered if individuals feel that their roles are indispensable and that their work is visible to others. There is also evidence to suggest that teams perform best when there are slightly fewer members than are strictly necessary to complete the work, as social loafing is unlikely to go unnoticed.

Table 7
Factors related to individuals within the workplace.

Individuals	Sources	Key points
Skills	Bornemann et al., 2003; Fischer et al., 2005; Hockey, 1996; Johnson and Hyde, 2003; Salas et al., 2005a; Stammers, 1996.	• Individuals bring their own set of skills, knowledge (declarative, procedural, explicit and tacit) and experiences to collaborations. • Skill level is moderated by factors such as motivation thus collaborative performance may not reflect an individual's actual skill level.

Psychological factors	Beddoes-Jones and Miller, 2007; Fasel, 2001; Fischer et al., 2005; Folkard, 1996; Harvey and Koubek, 2000; Marttiin et al., 2002, Montiel-Overall, 2005; Norman, 1980; Salas et al., 2005a; Steiner, 1972; Wilson et al., 2003.	• The psychological characteristics of individuals, the mix of these in the team and the levels of compatibility can all impact on collaboration. In turn they may be moderated by outcomes of collaboration success or failure.
		• Psychological factors include:
		  • Needs, biases, perceptions, mood, motivation, attitudes, values, beliefs, expectations, preferences, personality, ambitions, confidence.
		  • Cognitive factors – attention, perception, memory, mental models, reasoning, thinking styles etc. Social interactions, culture, motivation and emotions can all influence cognition.
		  • Aspects of mental workload, situation awareness, working style and behaviour.

Wellbeing	De Jonge et al., 2000; Van Fenema, 2005; Hockey, 1996; Karasek, 1998; O'Driscoll and Cooper, 1996; Tyndale, 2003; Kyzlinková et al., 2007; Warr, 1996a.	• Physical and mental wellbeing is both input and output for collaborative work success, as those experiencing more wellbeing may be more inclined to collaborate (and vice versa), and the act of collaborating will impinge on wellbeing. • High levels of job stress can negatively impact on the individual's wellbeing, reduce organisational effectiveness and financial performance (e.g. due to absenteeism and high turnover), and may influence acceptance of new technology. • Characteristics of an individual (e.g. personality traits) play a role in wellbeing as they can influence how employees feel about their work and consequently how they collaborate. • Fatigue or stress can result in lowered attention and reduced cooperation with colleagues. Fatigue and emotionally aroused states can reduce skilled performance especially when task demands are high. • High job demands combined with low control over the situation (high strain jobs) can lead to adverse health outcomes but increasing job control can lead to positive outcomes such as high job satisfaction and job challenge. • Collaboration has been associated with improved employee wellbeing and productivity, perhaps due to the social benefits (e.g. sense of belonging to a group and interactions with other people). However some studies have shown that team-workers were more likely to have a poorer work-life balance – associated with psychological strain.

Table 7 (*continued*)

Individuals	Sources	Key points
		• Satisfaction can be enhanced through collaborative work designed to support skill use, variety of work, participation in decision making, role clarity, task feedback, physical security, interpersonal interaction, career development opportunities, positive communication with management, increasing autonomy and control over demands, valued social status, and perceived fairness in rewards.

Table 8
Overarching factors (which affect and/or interact with other factors).

Overarching factor	Source	Key points
Trust	Bergman and Baker, 2000; Carroll et al., 2003; Cordery and Soo, 2008; Détienne, 2006; Edwards and Wilson, 2004; Fasel, 2001; Handy, 1995; Harford, 2006; Ilgen et al., 2005; Katzenbach and Smith, 1994; Kelly, 2007; Krebs et al., 2006; Salas et al., 2005b; Talbot, 1999; Walsh and Maloney, 2007; Yates, 2007; Zolin et al., 2004.	• Good collaborative relationships are built on mutual trust and respect and these should be established early on in a new project or team. People are more likely to trust those who are similar to themselves (e.g. in age, status, cultural, professional and educational background). Trust is both personal/informal and impersonal/institutionalised; a climate of trust enables people to engage in business with each other, and is of high value to an organisation or an economy. • The manner in which power is expressed within an organisation and how employees respond to this power is an important factor in the levels of trust within an organisation. • Trust and a willingness to communicate and share information openly indicate an organisation's collaboration readiness. • When different individuals, teams or organisations are responsible for completing interdependent tasks, they rely on trust between them that each individual task will be accomplished as assigned or promised, with quality and on time, with confidence in team members' competence, their commitment to goals, not letting others down and sticking together. • It is challenging to build trust within and between teams, departments and organisations, and generally, face-to-face communication works best with higher levels of trust associated with frequent social interaction and regular communication. • Distributed working may make it difficult to develop trust among colleagues, but there is evidence that exchanging social information via interactive chat can make a start at establishing trust. • There is a security risk involved in transferring sensitive data via computers, PDAs, and mobile phones, and also other confidentiality and privacy issues associated with virtual working. High security engenders and maintains trust between partners at an organisational level but may have a negative effect on levels of trust felt by individuals due to frustration with firewalls, encryption, pass codes etc. The challenge in collaborative working is to encourage computer-assisted collaboration within rational levels of security.
Conflict	Anderson, 1993; Denise, 1999; Détienne, 2006; Devine and Banahan, 1999; Edwards and Wilson, 2004; Eisenhardt et al., 1997; Katzenbach and Smith, 1994; Mattessich and Monsey, 1992; McNamara, 2003; McNeese and Rentsch, 2001; Waugh, 2005.	• Conflict in collaboration can result when there is incompatibility between people's personalities, goals, values, opinions or perspectives, and may also be related to personal, social or work differences or to situations with high levels of uncertainty, ambiguity and high stakes. Differing views on how processes and tasks are carried out or on risk taking may also cause conflict. • Poorly established common ground at the outset of collaboration, a lack of shared understanding of each other's skills, knowledge and schemas, and poor social dynamics within and across teams can be a cause of conflict, and may be a particular issue when teams are multidisciplinary and multinational, and very challenging to manage when teams are distributed. • Conflict in itself is not necessarily bad as it can lead to more creativity, wider discussion and understanding of issues and alternatives, and increased participation in work and better decision making; very low levels of conflict have been associated with poor decision making. Divergent views and behaviours within organisations can be just as important as cooperation in improving group performance. Specifically, high conflict in senior management teams has been associated with high performance. • The impact of conflict on collaboration can be influenced by the overall context, trust, and the support that an organisation provides to identify and manage any conflict which threatens work effectiveness, efficiency and working relationships. Differences of opinion need to be managed effectively to ensure that they do not limit progress on a task, reduce the quality of task performance, lower morale, create bad feeling, affect the wellbeing of team members, or be responsible for 'adversarial collaboration'.
Experience	Flanagin et al., 2004; King, 2006; Mannix and Sauer, 2006; Marttiin et al., 2002; Mattessich and Monsey, 1992; Van Fenema, 2005; Warr, 1996b; Wilson et al., 2003.	• Experience relevant to collaboration is task- or team-related or general and incorporates any shared history of working together. The length of time teams have worked together, how well they know each other, how successfully they have worked together in the past, and their shared working and personal experiences can enable members to predict each other's behaviour, reducing the demand on communication, and workload; in addition, personal past experiences can be a driver for successful collaboration.

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Table 8 (*continued*)

Overarching factor	Source	Key points
		• Experience to support collaboration includes the sum of the individuals' and team's familiarity with the business, processes, tasks, and technologies, which they can draw on to complete mutual tasks. The length of time teams have been working together can have a positive impact on satisfaction of processes (e.g. decision making). • Experience is likely to have an impact on the way that social interactions take place between people to perform tasks and can engender trust in future collaborations.
Goals	Breazeal et al., 2004; Cohen et al., 2000; Devine and Banahan, 1999; Edwards and Wilson, 2004; Hackman, 1990; Howes and Payne, 2005; Johnson and Hyde, 2003; Katzenbach and Smith, 1994; Klein, 2001; Marttiin et al., 2002; Mattessich and Monsey, 1992; Pfeffer, 1992; Tyndale, 2003.	• A clear, common organisational vision and objectives can provide a framework within which to define collaboration strategies and goals, and determine the success of collaborative projects. • Good collaboration requires participants to have a clear understanding of task and organisational goals and objectives, and changes in priorities over time. • Clearly defined goals provide a common ground for better communication and structure about tasks and measurable target performance objectives. • Teams who are told what to do in general terms, but left to work out the details themselves, may not fare so well as those provided with clearer goals and targets, and underspecified goals are a potentially negative factor in a group's effectiveness. • Individuals and teams will have their own goals for taking part in collaborative work which may or may not be consistent with the task or organisational goals. Personal goals and needs have been highlighted as a potential driver for successful or unsuccessful collaboration. People may adapt work objectives to fit in with their own beliefs and needs, and they actively adapt their work requirements to fit their own objectives. • 'Adversarial collaboration' involves people with different or conflicting goals working together to achieve some common purpose. However, there is a tendency not to share all available information with others or to partially reveal information as necessary. Organisational, social and contextual factors can impact on whether team members focus on working together to maximise team outcomes or to maximise their individual outcomes.
Incentives	Bergman and Baker, 2000; Bohen and Stiles, 1998; Détienne, 2006; Edwards and Wilson, 2004; Hackman, 1990, 1998; Katzenbach and Smith, 1994; King, 2006; Mattessich and Monsey, 1992; Salas et al., 2005b; Shea and Guzzo, 1987; Unsworth and West, 2000; Willaert et al., 1998.	• To encourage collaborative work, organisations should place a greater emphasis on team goals rather than individual goals, and accordingly rewards biased towards teams rather than individuals, thus providing incentives and motivation for working together. If a group of people is referred to as a 'team' but in reality is managed as individuals, their effectiveness will suffer. • People respond to incentives and adapt their behaviour accordingly. There may be less of an incentive to communicate information freely to others if there are greater rewards for being an expert with knowledge which is not known by others. • Motivations to work collaboratively may include financial rewards, recognition of contributions to work, enhancing visibility or improving status within the workplace, more/shared responsibility, shared risks, interesting work, reduction of workload, building professional and personal relationships with others, and the satisfaction of having achieved something. • The quality of shared physical and/or virtual spaces may motivate people to collaborate with each other. • Recognising that their team is performing poorly and any resulting lack of confidence (especially if reinforced by management) can serve to de-motivate team members. • Incentives need particular thought if they are to support motivation to participate in inter-organisational collaboration.
Constraints	Cordery and Soo, 2008; Edwards and Wilson, 2004; Mannix and Sauer, 2006; Weiseth et al., 2006.	• Constraints on collaboration may be found at an individual and team levels (e.g. the skills available, cultural constraints which may be a barrier to effective communication), at a process and task level (e.g. limited flexibility to change work processes or how/when a task is conducted), at a support level (e.g. available resources of finance, personnel, materials, space and technology), and at an organisational level (e.g. existing infrastructure, contractual and legal constraints, business constraints). • Cultural issues, especially between organisations, are a source of potential constraints (e.g. differences in working hours, preferences for work methods, and mix of status within the organisation). • Time barriers, for example working across different time zones or working to tight deadlines, may hinder communication and be a constraint on collaboration.
Management	Campion et al., 1993; Cordery and Soo, 2008; Devine and Banahan, 1999; Edwards and Wilson, 2004; Guest, 1996; Hackman, 1990; Katzenbach and Smith, 1994; Parker and Wall, 1996; Salas et al., 2005b; Tyndale, 2003; Unsworth and West, 2000.	• Support from management is associated with improved work productivity, team effectiveness, employee satisfaction, and plays a large role in the success or failure of collaborative projects. • Managers should provide clear direction and guidance to individuals and teams, and communicate expectations and norms and any necessary constraints on team behaviour. Good leaders can inspire others to work collaboratively and bridge disciplinary boundaries and can overcome organisational and process weaknesses. • Collaborative project management includes setting and communicating goals and objectives, forming and maintaining teams, ensuring team members maintain shared team mental models (of goals, constraints, roles etc.), planning tasks, assigning tasks, setting deadlines, monitoring task and resources status, ensuring

Table 8 (*continued*)

Overarching factor	Source	Key points
		that work is delivered of the required quality and performance and within the allotted budget and time frame, monitoring and reviewing changes in the environment and adapting the team, objectives, tasks, processes and strategies as necessary, setting performance expectations, providing feedback on individual and team performance, coaching the team, creating a positive working atmosphere, and managing conflict. Consistent management is related to effective teams. • Collaboration may be enhanced in (semi) autonomous work teams which do not have a formal leader, with leadership emerging according to tasks. Such teams have been associated with improved work productivity and employee satisfaction. • Both transformational leadership (inspiring motivation to work together towards common goals) and transactional leadership (rewarding or punishing based on performance) have been associated with effective team performance, dependent on context.
Performance	Cordery and Soo, 2008; Delgado Piña et al., 2008; Edwards and Wilson, 2004; Hackman, 1990; Howes and Payne, 2005; Salas et al., 2005a; Steiner, 1972; Tesluk et al., 1997; Tyndale, 2003; Viller et al., 1999; Warr, 1996a; West, 1996; Wilson et al., 2009b.	• Evaluating collaboration effectiveness involves assessing how the team worked together to achieve outcomes and whether the team is able to work together in the future. • Working together effectively can increase team cohesiveness. • Performance relevant to collaborative working includes: keeping to project budgets and deadlines, profits, time saved, meeting or improving required quantity and quality of product/service, improving work processes, innovation, achieving goals, meeting requirements, improving relationships, extending professional networks, generating new business, learning, individual and team satisfaction and wellbeing, improving trust and commitment, reducing errors, high level of safety, low levels of absenteeism and staff turnover. • Evaluating collaborative performance may involve assessing individual as well as collective efforts, depending on the type of task, as both can have an important influence on overall performance. • Team performance will be influenced by type of task, levels of trust between members, the autonomy afforded to the team, training, and quality of management. • People work towards decreasing demands on their time and on balancing cognitive overheads of collaboration with performance outcomes, whilst taking into account individual and team/organisational rewards.
Time	Dix et al., 2004; Hackman, 1990; Hockey, 1996; Ilgen et al., 2005; Mannix and Sauer, 2006; Pettigrew and McNulty, 1995; Salas et al., 2005a, 2005b, 2007; Saunders and Ahuja, 2006.	• Almost all factors inherent to collaboration and the interactions between them will change over time, though some aspects (such as organisational structure) may be more stable, and others more dynamic (e.g. teams may adapt and team members will increase in their familiarity with each other, improving communication and coordination). • Although increased experience over time can be associated with positive gains, it may also be associated with negative change (e.g. when conflict 'snowballs'). • Time limits, cycles of activity, and work rhythms help to organise and structure how teams work, and influence the team climate (e.g. motivation), and the quality of individuals' experiences. Deadlines may help to structure work; however, time pressure may also have a detrimental effect on the quality of skilled performance. • Events when a team is first formed (e.g. when members meet for the first time and how their goals and tasks are communicated and discussed) have long lasting effects on team performance. • Collaborative teams inevitably change over time. Temporary teams and long-term teams may differ in structure, processes and task-related and wellbeing outcomes. Individuals' power sources may vary over time (e.g. with age, experience, time on the job and by expanding their professional and personal networks) and can alter interpersonal dynamics and their capacity to influence the context within which collaboration takes place. • Management of collaboration should focus on establishing the most conducive conditions for team prosperity which can remain in place as other things change over time.

the CoSpaces project. We had good access and close relationships with relevant groups in these companies, which either currently work collaboratively or have a requirement for improved collaborative structures and processes, and which therefore had a vested interest in helping to develop a model of collaboration. The human factors researchers were thus in a position to gain an understanding of how real companies, real projects and real people work collaboratively at present, what problems they face, the critical success factors, and so on.

We analysed collaborative working for selected activities at user partner sites through semi-structured interviews, carried out as a part of the process of user story, scenario, use case and requirements generation (Wilson et al., 2009a). Prior to the interviews, user partners were asked to complete a scenario template document. They were asked to describe activities of interest and importance to their companies, where current collaboration is deficient in some way or where the user company imagines that CoSpaces technologies (as described in the visionary digital presentations from developers) may bring demonstrable improvements in the future. The initial scenarios, primarily developed to inform use cases and requirements generation, formed a basis for discussion in the interviews to explore the collaboration factors. The scenario

Table 9
Collaborative challenges faced by teams and organisations within CoSpaces industrial work activity scenarios.

Industry	Scenario of work activities
Aerospace	*Digital Mock-Up (DMU) Review*: DMU integrators are experts on the DMUs of all aircraft in production. They liaise with personnel from different teams to resolve issues (e.g. missing data, overlapping data etc.) that emerge on the digital representations of planes, with the overall aim of detecting and rectifying design issues for individual aircraft before they enter production. *Challenge*: Improve communication between the integrators; better integrate existing tools; improve remote real-time collaboration; isolate and overcome the barriers to using real-time collaborative tools; and overcome data exchange issues caused by use of different systems at different sites. *Final Assembly Line (FAL)*: This scenario is concerned with how the engineering offices at the company (which undertake the conception of the aircraft components and provide the relative assembly procedures) respond to design queries and non-conformities (e.g. a component damaged before/during assembly, or a component which cannot be assembled etc.). Collaboration takes place between technicians assembling the aircraft on the FAL, technical support, quality departments, the manufacturing engineering office, and a team of representatives from each engineering office – all based on or near the FAL. *Challenge*: Improve remote collaboration by introducing real-time collaborative tools to communicate video streams from the FAL to the engineering offices; overcome data exchange issues caused by different tools being used internally; find an effective method to train older engineers on the use of 3D models; overcome trust barriers to remote desktop sharing. *Virtual and Physical Testing of Aircraft*: This scenario concerns the virtual and physical tests carried out on 3D models of the aircraft and the actual aircraft structures. The virtual test engineers carry out simulations on virtual models. From these models they define the various load cases for fatigue, static and dynamic tests. This information is communicated in the form of plans to the physical test engineer who puts them into practice. The results from the physical tests are used to verify the virtual, numerical simulations to see if the model behaves in the same way as the physical structure. *Challenge*: Overcome data compatibility issues caused by the use of different systems and analysis methods; overcome version control issues due to inefficient communication of data; improve the physical test and virtual test teams' understanding of each other's constraints; improve methods used to exchange information between the physical and virtual test teams; introduce real-time collaborative tools to exchange information and increase the efficiency with which they plan tests and make decisions and resolve problems; explore the use of 3D models instead of drawings and related training issues.
Construction	*Construction Design*: This scenario considers the challenges of constructing particular building sections in what is known as a design and build approach (i.e. detailed design of the building takes place in parallel with construction work). For some building sections this can be difficult, as they may face multiple constraints, which have to be addressed by many stakeholders under intense time pressures. *Challenge*: To bring stakeholders together – from the beginning and throughout the duration of a project – to address design issues, to evaluate various design configurations, and to implement proposed changes without delaying the construction process; explore the use of virtual prototypes in design; explore systems which enable information to be communicated as quickly as possible; explore the use of mobile devices to access central databases to address problems on-site. *Site Management*: This scenario concerns the activity of overseeing the construction process, managing the activities of the main contractor, who is in turn responsible for sub-contractors. Part of this activity includes managing the process by which changes to the proposed plans are assessed and authorised by all relevant personnel. *Challenge*: Explore the use of PDAs on-site to communicate real-time information; improve communication of design changes and site progress from the office to on-site and vice versa; address reliance on email to communicate which can cause delays; explore the use of 3D models in design. *Site Supervision*: The process of site supervision ensures that the building meets the standards and requirements of the client as determined at the start of a project, and that all changes to these have been fully agreed and documented. This activity is increasingly conducted by contractors in order to keep costs low. *Challenge*: Improve site supervisor's awareness of what is happening on-site; improve communication to arrange site supervision (e.g. by automatic electronic alerts); explore technology to allow access to design drawings to aid decision making on-site via the use of a PDA; explore the use of mobile devices on-site to allow information to be uploaded onto central project sites and to access central databases; explore the option of approving or denying changes during the construction process by the provision of real-time video or live updates to a 3D model instead of having to make site visits; address misunderstandings and miscommunications caused by professional differences.
Automotive	*Technical Documentation Production*: This company produces the technical documentation regarding the repair and maintenance of automobile parts. They have limited access to physical and digital prototypes which are available almost exclusively at the customer's base. *Challenge*: Overcome version control issues due to inefficient communication from their customers; push towards more frequent use of digital models to perform tasks. *Detailed Design of Automobile Parts*: This Tier 1 supplier collaborates with an established network of Original Equipment Manufacturers (OEMs), sub-contractors and suppliers to analyse and produce the detailed design of automobile components. *Challenge*: To optimise their use of new technology (e.g. in the prototyping phase), and integrate it within their working practices which could help reduce process losses; explore the use of mobile technology as well as simulation and real-time visualisation software with the aim of reducing the need to travel without overly compromising the benefits of face-to-face meetings. *Mirror Design and Manufacture*: The company is a Tier 1 subcontractor for vehicle mirror design and manufacture. The research and development team is involved in the initial and detailed design of mirrors on receipt of a functional specification from an OEM. Additionally, they are involved in the manufacturing process, testing and prototyping. *Challenge*: Explore more efficient methods for data sharing; address software incompatibility issues; improve collaboration (especially decision making) between distributed partners by exploring the use of new technologies and by addressing existing problems caused by cultural and professional differences; improve trust between partners; improve communication of decisions down the supply chain; address version control issues; reduce the reliance on email for problem resolution in order to increase efficiency; explore better systems for task management; explore systems for real-time sharing of visualisation data; explore knowledge management systems to record lessons learnt. *Design and Manufacture of Eco-Friendly Car*: This scenario concerns the process of taking conceptual sketches and designs for a new vehicle and beginning the process of transforming these ideas into an engineering reality. At this stage the focus is on styling the car and on the development of simulations. Early preparations are also being made for development of the engine, and the OEM (a non-profit making organisation) has selected potential Tier 1 suppliers and is currently in discussion with them with regards to the prototyping stage. *Challenge*: This is a relatively small scale project which will involve more stakeholders in the coming years and so the OEM needs to prepare for this by: continuing to establish the company culture and involve partners in their vision; exploring the use of new technologies to support distributed collaboration, in particular, decision making; establishing the best way to record design decisions; exploring real-time visualisation of data; implementing an effective data exchange solution; introducing higher levels of security.

Table 10
Evidence of collaboration factors in scenario descriptions.

Factor	Scenario	Supporting evidence from scenario
Individuals	Site Management	• Highlighted the importance of aligning work and personal goals as far as is possible. Construction projects often require personnel to relocate to a different site for a significant portion of time. In some cases this can mean long journeys to and from work, or even moving home within or outside the country. This situation potentially conflicts with personal motivations, goals and lifestyle. Staff, especially senior members, are often reluctant to make these changes.
	DMU	• Preferences for particular methods to complete tasks can sometimes introduce process losses. Some staff prefer to rely on email to resolve problems, however, this is not as efficient as using real-time collaboration tools to perform the same task.
	Detailed Design of Automobile Parts	• There is a general preference for regular face-to-face contact with customers and suppliers. However, this preference can lead to significant travel and potentially ineffective meetings if they are followed by a lengthy journey.
	FAL	• The interviewee understood the importance of motivating team members to work, for example, by taking staff to see the aircraft. Similarly, on a negative note, he anticipated that the motivation of sub-contractors was likely to be low due to an organisational restructure and a lack of resources which would lead to them losing their jobs in the near future – these effects are considered when assigning tasks and responsibilities.
Teams	Common issues across more than 2 scenarios	• Individuals' roles and responsibilities are clearly defined. • Many of the companies experience difficulties caused by cultural differences between team members, affecting their ability to interact and communicate. • Some companies were aware of the negative issues (e.g. misunderstandings, potential for conflict etc.) associated with multidisciplinary and multicultural work but maintained a relaxed approach to dealing with them. • The companies with smaller teams report that they work well together because they know each other very well. • Generally, it appears that good interpersonal relationships make it easier to understand and work through problems together and ensure performance even if the availability of support for work activities is poor.
	DMU	• They experience problems due to inconsistent role definitions between employees at their different international sites. • The cultural differences between teams have led to preferences for using different tools, with some teams reluctant to have face-to-face meetings.
	Construction Design	• They have a strong focus on developing good team relationships which are fostered through face-to-face meetings. The organisation is so committed to maintaining good team relationships that they will remove a team member if they are found to antagonise others, for whatever reason; the quality of team relationships takes precedence over any one individual. This is unsurprising considering the temporary nature of construction teams and the short length of time in which buildings are constructed.
	Site Management	• It is the site manager's responsibility to ensure a 'comfortable climate' within team meetings to enable open and honest discussion.
	Site Supervision	• There is a distinct lack of awareness between site supervisors and activities occurring on-site – supervisors have to rely on contractors contacting them when particular processes are about to take place, and they do not get access to reports on the contractor's own supervision procedures, which may give a fuller picture of activity on-site.
	FAL	• Records on a design query database are supposed to be kept in English; however, as most of the employees at the FAL do not speak English, records there are kept in their native language. This could be an issue if non-native speakers are required to access these records. • The younger team members would prefer working with 3D models in the design office; however, the older team members (over 50 years of age) are not able to use these models even after lengthy training because they are so used to working with 2D drawings. It would be more efficient to work with 3D models, and these would be easier to share between sites and partners than 2D drawings. By continuing to work with 2D drawings there is the risk of creating a new generation of designers who also become reliant on 2D drawings, instead of developing expertise in a more effective and efficient way of working.
	Detailed Design of Automobile Parts	• Strong relationships are maintained in project teams, within the company, and with those above and below them in the supply chain, through face-to-face meetings, workshops, and frequent email/telephone contact. Customers tend to work with this company for many years due to their shared knowledge and rapport.
	Mirror Design and Manufacture	• They find it difficult to establish a common language (in terms of establishing a common work culture) between employees at the different stakeholder sites in order to communicate effectively. Personnel sometimes lose focus on solving the problem at hand, instead viewing things as being about the different stakeholder countries. • They also face language barriers which could explain the preference for communicating with the other site via email instead of the telephone. Although providing a traceability of communications, the reliance on email as a mechanism to aid problem resolution often results in significant delays – with one partner waiting for a solution whereas the other partner is waiting for feedback on their email(s) so that they can solve the problem. The engineering manager reported that in the preceding 12 months he had not seen a single engineer use the telephone to discuss a particular issue or activity status. There is clearly a large barrier here which needs to be addressed to improve collaborative work and relationships between different partners. • On a positive note, they acknowledge the language barrier they are faced with and overcome it by using visual representations to aid communication. In doing so, they are sometimes able to make effective decisions without travelling between their partner sites.
Interaction processes	Site Management	• They document decisions formally and stress the importance of distributing meeting minutes as quickly as possible since any changes rely on receiving written permission. • The construction company experience difficulties in communicating the urgency of on-site problems to office-based staff.

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Table 10 (*continued*)

Factor	Scenario	Supporting evidence from scenario
		• They find it difficult to ensure that relevant information is communicated to all stakeholders. However, there is a good awareness of these issues within the teams. Contractors tend to factor in extra time within their project planning in order to cope with mistakes and setbacks.
	Construction Design	• They stress the importance of distributing meeting minutes as quickly as possible since any changes rely on receiving written permission. • They regularly experience a delay in communicating changes agreed during meetings since these changes must be made manually to drawings, which causes the added problem of incompatibilities within a design scheme not being identified until the construction process is in progress. • Decision making is not formally structured and appears to be relatively haphazard – sometimes decisions are made in meetings, sometimes later – and once decisions have been made, further decisions are required to assign the responsibility for instigating a change. • Similarly, the way in which problems are handled is not generally structured formally. The cumulative effect of these issues is not failure, but rather a more difficult process of collaboration, particularly given that the collaborative environment is one that is high-pressured, with a significant focus on minimising delays, resolving issues quickly, and avoiding extra costs.
	Detailed Design of Automobile Parts	• Staff work in small teams on specific projects, yet are encouraged to share information between teams where appropriate. Thus, staff feedback interesting information from other projects, conferences and exhibitions enabling their wider team to share their knowledge and learn from their experiences. • They have a working environment in which all team members have the ability to contribute significantly to design choices – critical decisions are often made in face-to-face meetings – and decisions are documented prior to production of parts. Indeed, communication levels are high, and remain so, from the very outset of a project. However, it can be challenging to coordinate large projects (e.g. involving up to 35 partners) and in these projects it can be difficult to communicate decisions and design changes up and down the supply chain. • They rely on face-to-face meetings for design discussions – these meetings are viewed as fundamental to building trust.
	DMU	• The personnel clearly understood which decisions they were responsible for and who to contact for decisions outside of their responsibility; and they had regular, scheduled meetings to coordinate activity, supplemented by frequent email and phone contact.
	Technical Documentation Production	• This company is not able to control its work activities – the work is initiated by the customer who retains overall control of the tasks. They must wait to receive information from their customer, much of which is redundant, requiring them to filter through extensive data. They regularly work with old versions of a part, or old prototypes, and therefore have difficulty establishing whether later design changes will have an impact on what they have produced. Further, their ability to communicate with their customer is normally restricted via a coordinator, with a long chain of command to get information to and from designers and engineers of component parts. They estimate that as much as 10% of project time could be wasted simply waiting for information.
	Mirror Design and Manufacture	• High level decision making is not communicated down the supply chain, and thus some partners may not receive information which is relevant to them. This could potentially result in delays as these supply chain partners could continue their work as planned, unaware of changes which could affect how they should proceed. • Not all design decisions are documented as they find that this is too time consuming. The decisions which are recorded are at the discretion of those with the correct access rights to edit their project management tool. Certain decisions may be more relevant to some people than others (and have consequences for their ongoing work), however insignificant they may seem to the person inputting the data into the management tool – there does not seem to be any mechanism in place to communicate these. • They organise tasks and teams in such a way to ensure everyone is up-to-date on task progress and that potentially there is a structure for efficient communication channels for effective collaboration between teams, tasks and projects. However, it seems that they are currently let down by the support provided to ensure that this process flows effectively. Currently, one of the coordinators manually logs information from hundreds of email communications in an Excel sheet to show task status. The stages and progress of tasks are not recorded in the database so it can sometimes take the coordinator hours to track down the current status of a particular issue. In addition, as an organisation they do not communicate efficiently between distributed and mobile partners, or between the OEM and supply chain partners. They report a number of technical issues and issues related to choice of communication medium. They currently have a slow, secured bandwidth of 2 MB/s which they must use for data transfer.
Tasks	Common issues across more than 2 Scenarios	• Tools at many of the companies provide an indication of task status and successful task completion.
	DMU	• Deadlines for resolving issues on the DMU appear to be unrealistically tight and are regularly exceeded (e.g. taking 6 weeks to complete a task that had been planned to take 3 weeks as it can take 10 days to convert data into a workable format). Although it is recognised that the activities are important and need to be resolved as quickly as possible, targets that are unrealistic, and therefore never met, could potentially lead to de-motivation within the teams, and may largely be ignored. However, on a positive note, tasks are well structured with clearly established goals.
	FAL	• There are clear deadlines set for problem resolution during production of the aircraft and these are generally met.
	Detailed Design of Automobile Parts	• Dependencies between tasks, goals and task structure are all determined during early project stages, and often in collaboration with the OEM.
	Site Supervision	• Tasks are well structured and it is clear what is expected at each stage.
Support	Common issues across more than 2 Scenarios	• For most of these companies more advanced collaborative tools may be useful for rapidly communicating key information across a group of widely dispersed people. • Many of the companies still rely on the use of physical prototypes which are costly to produce, more time consuming to work with, and it is cumbersome to clearly communicate decisions made using them. These companies are positive about exploring the use of 3D models to increase the efficiency of the design cycle and to support making and communicating design decisions. • The construction company and the aerospace company rely on drawings for detailed design. These are sometimes time consuming to access when decisions have to be made, or problems have to be solved on-site or on the FAL.

		• Most of the companies would like to explore the use of real-time video communication (e.g. from the FAL or the construction site) to support quicker problem resolution and decision making. • Problems of interoperability of technology internally, between partner sites and with the supply chain are common to all the industries. Most companies face lengthy data conversion tasks and subsequent, related version control issues due to these interoperability problems. Smaller companies who are contracted to work with OEMs face pressure to invest in the same software as the OEM and on the next working contract they may have to invest in alternative software. Some companies do not have systems in place to enable efficient sharing of large datasets between offices or transfer data to mobile devices for employees on the move.
	Construction Design	• Construction is a complicated process - to a certain degree each building is unique. Therefore, there is limited potential for the reuse of old solutions, which may be a more common feature in other industries. Despite this, dedicated personnel at the construction company maintain a reference database of 'best practice' solutions to facilitate work on projects.
	Site Management	• There is a reliance on personally held, expert knowledge. • They are generally positive about the use of advanced technology to make the dissemination of information more effective, replacing the current reliance on paper documents. Networked devices could enable real-time updating of documents and systems. • One of the interviewees commented that on-site, the construction industry is about 4–5 years behind other industries in terms of technology provision.
	Technical Documentation Production	• Employees are unable to directly access the designers and engineers responsible for parts at the customer sites. This is managed, instead, through a third party contact (usually a project coordinator). This can incur lengthy delays when they need clarification on matters.
	Mirror Design and Manufacture	• They believe that their decision making process is currently negatively affected by the types of tools used to present and analyse data. They have more tools available to support individual work than collaborative work. • There are knowledge management issues, for example, changes to the design made by engineers are not always documented, and therefore personnel are unable to reproduce changes based on the drawings as they have not been updated. However, they have a database of some standardised design solutions which allows them to reuse previous design/engineering concepts, enabling them to provide low competitive prices, speed up subsequent design processes and provide helpful information to new engineers. • Similarly, they have started to populate a lessons learnt database, but this is in the form of an Excel spreadsheet and is not really a practical tool as they have over 600 employees who could potentially contribute information. • One person provides training geared towards individual engineers, however, they do not have any paper-based training material available and so engineers are required to remember the information they have learnt. The entire training process also relies on the availability of this one person.
	Design and Manufacture of Eco-friendly Car	• They do not effectively record how design decisions are made, relying solely on meeting minutes which are lacking in detail. • As a non-profit making company, they have a lack of available resources, namely financial resources (they are currently funded by an EU project which supplements personal funding), but they also experience a shortage of experts available to work on the project.
	FAL	• They have a successful system in place to manage design queries and provide training on how to use this tool. This tool is also used to record a history of design queries for future reference. However, some of the partner companies do not use this tool and so queries are sent, monitored and closed via email. It is unclear whether a history is kept of these queries. The use of different methods for the same type of task increases the difficulty of monitoring their status. They effectively reduce the need for face-to-face meetings by using WebEx in conjunction with audio conferencing in order to remotely share visualisations of screens during meetings. They provide shuttle flights to make travel to different company plants as efficient as possible. An important resources related issue is the increasing number of personnel being made redundant, which may negatively affect the remaining employees by an increase in their workload, increasing difficulty in meeting deadlines, and the loss of expertise to support their work. • Older employees find it difficult to use 3D models and thus there is a continuing reliance on drawings.
	DMU	• They have encountered problems in establishing equivalent and interoperable tools between sites. • Staff are easily able to find and locate relevant experts, and have the benefit of collaborative tools to enhance communication. • There is a lack of effective training for the personnel on how to use the various collaborative tools available to them, with no written resources available for reference purposes. • They consider their current tools and reporting systems as ineffective in consistently capturing meeting decisions effectively. Communication between distributed workers is relatively inconsistent – some choose to rely on asynchronous communication tools, e.g. email, whereas others use synchronous tools, including desktop sharing and this latter group tends to resolve problems more quickly.
	Virtual and Physical Testing of Aircraft	• They store data from previous tests and development programmes for reuse. • The interviewee talked about the difficulties of moving from 2D drawings to 3D models – the personnel are not ready in terms of the skills required to use them. • They recognise the potential usefulness and necessity of collaborative tools to communicate with distributed team members, however, they stress the importance of maintaining the direct connections that they have between teams.
	Site Supervision	• They feel that there is a lack of business support for the site supervision process, with a growing trend to allocate more of the work to contractors, partly due to limited funds. • They often experience difficulties in obtaining expert advice at the construction site when required, leading to potential delays. • They would like access to drawings on mobile devices whilst they are on-site.
Context	Common issues across more than 2 scenarios	• The companies generally find that co-located working environments facilitate effective team working as it enables frequent face-to-face communication. • They are committed to creating an open culture for the company and the supply chain to establish good, close working relationships.

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Table 10 (*continued*)

Factor	Scenario	Supporting evidence from scenario
	Design and Manufacture of Eco-friendly Car	• The company is housed in an eco-friendly physical working environment which is consistent with the company ethos.
	DMU	• This company is a large and complex organisation, arranged into various parent and sub-companies, which is affecting the ability to standardise work processes across the organisation (e.g. in terms of role definition and tools used). Additionally, there is poor standardisation of working practices across collaborating organisations. • Despite an insistence on high levels of privacy and security, the employees do not appear to be significantly affected or limited by these controls in their day-to-day work. • There is no policy stating desktop sharing and videoconferencing should be used to resolve problems (although proven to save 2 weeks).
	FAL	• Despite an insistence on high levels of privacy and security, the employees do not appear to be significantly affected or limited by these controls in their day-to-day work. • Working on the FAL is noisy with all the constraints and health and safety issues that come from working outdoors.
	Virtual and Physical Testing of Aircraft	• They find that co-locating the virtual and physical tests is the most efficient way of working in the absence of sophisticated communication tools.
	Mirror Design and Manufacture	• They have a strong emphasis on security although their secure channels for data transfer are not of the required bandwidth.
	Construction Design	• Office staff members are situated in well-designed, open plan offices, which are re-configurable according to the demands of current projects – i.e. people are moved around so that they remain close to their current team – another indicator of the organisation's commitment to strong working relationships. However, on-site working is noisier with all the constraints and health and safety issues that come from working outdoors and in temporary offices. In particular, it can be difficult to manipulate large documents whilst outside. • Their organisational culture encourages changing working practices where possible to encourage efficiency.
	Site Management	• A potential hindrance to collaboration is that tight security restricts the provision of advanced network access on-site, e.g. links to main servers, and thus delays work.
Overarching factors (trust, conflict, experience, goals, incentives, constraints)	Common issues across more than 2 scenarios	• Teams at all the companies had well defined goals. • The main constraints that most of the companies have to deal with are technical constraints, time constraints, the inappropriateness of tools used for collaborative work, the interoperability problems caused by different tools being used at different sites, the cost of investing in tools to ensure compatibility with partner sites, cultural (professional and national) and language constraints. • Some of the companies who act as sub-contractors experience information availability constraints – they are not privy to up-to-date design information from the OEM and thus often end up working on obsolete models. • One constraint is that companies admit to often relying on one person's expertise which invites a multitude of problems when these people are unavailable.
	Virtual and Physical Testing of Aircraft	• The virtual testers and physical testers of aircraft components frequently interact with each other, however they do not understand each others' constraints, which often results in frustration and they blame each other when there are delays in the work.
	Site Supervision	• They are aware from the outset of a project that there will be potential for conflict but their approach is one of accepting this and try and be good friends with their partners anyway. • The supervision process at the construction company ensures that work is conducted according to certain standards and the records provide traceability of decision making which often proves to be useful for conflict management. • In the construction company, constraints come in the form of contractual difficulties in maintaining communication links between all relevant stakeholders. Since main contractors are responsible for sub-contractors, they may insist on extra levels of administration in the dissemination of reports.
	FAL	• At the aerospace company, one of their collaborative tools has the functionality for remote participants to control their computers to change viewpoints, however they do not use it even though there is no policy in place which restricts them from doing so – it is a trust issue that they do not want to relinquish control to external partners. This could potentially limit discussions as allowing remote collaborators to change viewpoints could help facilitate problem resolution, and potentially shorten meeting duration. • Frequent face-to-face meetings early on in an aircraft programme helps to build trusting relationships between the different teams.
	Technical Documentation Production	• They experience communication constraints, i.e. they are unable to directly communicate with the OEM, instead they must communicate with a long chain of command to get necessary information to and from designers and engineers.
	DMU	• They are consistently set unrealistic targets for problem resolution which are almost never met. This can lead to de-motivation or ignoring targets altogether.
	Site Management	• The management structures at the construction company are clearly defined within individual projects.
	Mirror Design and Manufacture	• They experience trust issues when working with people from different professional and international cultures.
	Construction Design	• One of the negative issues highlighted in association with multidisciplinary collaboration is that individuals are all viewing the same problem with different goals. For example, the objective for contractors may be to minimise costs, whereas the client or user representatives are concerned that the design fully meets the requirements of the end users of the building. In particular, there seems to be a focus on the 'cost' of problems, leading to situations where team members seek to apportion blame and work out who should pay for a change, thus deviating from the actual task in hand. Awareness of these issues is the first step to managing and resolving potential conflicts. • There is a strong focus on face-to-face meetings particularly in the early design stages during which personal relationships are developed and a sense of trust between team members can emerge.

structure included: current practices; identified stakeholders; collaborative functions and processes; current needs/problems and successes in collaborative working; the goals (business, operational and human); individual and group issues; the setting (physical, social, organisational, cultural, infrastructure, business climate, procurement and contracting, security); and task level descriptions (considering the key activities, decisions, communications and collaborations that take place).

Interviews took place at user partner sites and lasted between two and three hours. Two researchers were present at each interview, carried out with between one and three company or project representatives. Interviews took place in either dedicated meeting rooms or with interviewees in their normal working environment. In the latter case, interviewees were able to demonstrate their usual actions and routines. Extensive notes were taken during the interviews, which were also audio recorded and fully transcribed later, with the two researchers taking it in turn to be the convenor and note taker.

For the purposes of this paper, the results from the in-depth interviews with real company representatives and champions of collaborative working are summarised in two tables. Table 9 provides information collapsed from the original extended scenarios and summarises the work activities within the scenarios and the challenges faced by the teams and organisations to optimise work, save time and money, and/or improve quality.

Analysis of the scenarios provided good examples of the factors from the framework, and evidence that successful collaboration emerges as a result of multiple interactions between these factors. In the context of working with systems developers and user engineers, architects and designers, the analysis supports the view that collaborative technologies need to consider more than just the development of new technology solutions when aiming to improve collaborative design and engineering activity. Table 10 summarises examples of the influence of the factors on the collaborative situations as recorded in the scenarios, and suggests some barriers to collaboration (expanded on in the Discussion section).

5. Discussion

5.1. Framework and model development

It is clear that collaborative work is an inherently complex phenomenon. The factors and issues which constitute collaboration are multiple, their relative importance and interactions are variable and may change during different phases of the team, project or organisational lifecycle. As demonstrated in our scenario analysis within the user companies, a collaborative working situation is likely to display a mixture of positive influences (e.g. good team spirit, high levels of skill) and negative/constraining influences (e.g. tough deadlines, poor tool support); often the positive influences help to limit the negative impact of some of the barriers to collaboration. Whilst the effectiveness and quality of collaborative (and especially distributed) work can be enhanced through good technology support, this is only part of the story. Many of our CoSpaces user partners understood the importance of not solely relying on technology to maintain collaboration and the need to focus on interpersonal relationships between different teams and the work system processes in place to conduct tasks. They welcomed the idea of a technology-independent model of collaborative working to help feasibly manage the various factors involved.

Earlier in the paper we explained the seven reasons why we set out to develop a model (CCWM) of collaborative working, based on the framework reported in this paper. We return to these reasons now and briefly examine how we have satisfied them. The first two were to meet the needs of our developer partners for a system architecture (1) and a user profiling interface front end (2). There was of course considerable debate within the project about the form of a collaboration model. The engineers' and developers' bias was for formal, computational, predictive and implementable models, akin to the systems architecture they needed for the reconfigurable software system. The human factors experts' (and user companies') preference was for a model or models which are informal, explanatory and descriptive. In particular we wanted to give a better understanding of what is collaboration and collaborative working in and of itself, and the attributes which influence and form part of collaborative work. We wanted to distinguish support of collaborative working from support for the engineering tasks – that is work *as* a team as distinguished from work *of* a team. In the event the human factors team worked with the system architects and the CCWM was used as a first specification for the architecture (Jørgensen et al., 2010). The interface designers also drew from the model factors to populate their user profile registration front end to the interface, used during first and subsequent logins for the system to understand an appropriate technology and interaction set up matching the task needs and user preferences.

The third reason (3) was to underpin the human factors systems analysis effort. The CCWM even in its early stages of development provided a framework within which to capture and define user requirements (Wilson et al., 2009a). It also enabled rationale specification for design guidance for collaborative technologies (Pettitt et al., 2009). As a direct consequence it became the basis for protocols and measures to be used in the systems evaluation process, for evaluation of the degree and quality of the collaboration supported as well as evaluation of the interfaces and tools' usability and of the engineering and design performance outcomes. This latter was an iterative process, as a part of the technology implementation process and the change management strategies. We followed a Living Labs procedure (Active Distributed Development Space (ADDS) – Wilson et al., 2008), specially developed to make the most of having real users as well as pseudo users in the developers' laboratories and in drawing on the collaboration factors framework satisfied the fourth reason for developing the CCWM (4).

An extension of our work, and the fifth reason for developing a model (5), was that it could be used as a basis to assess the current and future collaboration capability of organisations. Any tool developed should focus on the extent to which the fundamental conditions for collaboration are created, sustained and standardised across teams and organisations, and help to establish strengths, weaknesses and areas where change is required to enable the successful implementation of collaborative technologies. Our experience with the CoSpaces user partners was that in the first instance it was of value to show employees the model factors and sub-factors, stimulating discussion between employees about the critical issues for them and about how different tools could be used to support different aspects of collaboration. We wanted to go beyond this, to support effective assessment and understanding of collaborative working to improve performance across a range of dimensions and to evaluate collaborative work systems and technologies. This has been addressed by development of a profiling tool, CoScope, built on the basis of detailed questions and prompts across the collaboration factors taken from Tables 2–8, and designed for use in structured workshops with small numbers of company or project representatives. A pilot study has shown the usefulness of CoScope in enabling a structured assessment of different companies' infrastructure and processes in order to determine whether improvements need to be made before collaborative technologies can be implemented effectively (Patel et al., 2010). Such a tool will eventually support benchmarking so that companies can assess themselves against others in the same

sector, or can assess projects against each other or against themselves over time.

The final two reasons to develop the CCWM were the longer term and more fundamental ones, connected with advancing the human factors knowledge base in this area (6 and 7). There is a dearth of models in this field and the CCWM is intended to fill a gap, supporting both practical implementations of collaborative working and also further development of theory, drawing from experimental and quasi-experimental programmes. The model gives a framework within which to experimentally study the interrelationships between small sub-sets of factors (e.g. Saikayasit, 2011); for instance how might the degree of trust and variations in professional culture interact to influence shared awareness or coordination. Thus the model, when we have further developed and verified it, will help to advance theory in collaboration and collaborative working.

5.2. Barriers to collaboration

The general tenor of the scientific and, especially, the professional and business literature is positive with regards to collaboration. After all, who could argue against better communication, cooperation, team working and so on. Reflecting this, our own work with engineering and design companies, and also our framework for a collaboration model, tends to stress the positive aspects of collaboration. However, we must recognise and be open about the problems and difficulties, and especially the barriers which must be overcome in a well thought out and implemented collaboration initiative. Such barriers, identified from the literature (e.g. Barratt, 2004; Caruso et al., 2009; Cordery and Soo, 2008; Edwards and Wilson, 2004; Hansen and Nohria, 2004; Mannix and Sauer, 2006; Margolis and Runyan, 1998) and within the CoSpaces user companies, are summarised in Table 11. To be clear about the wide range of human factors contributions to understanding and managing any such barriers, an early quote from a senior manager associated with CoSpaces, from a supply chain partner of country A was: "it doesn't matter if we work with CAVEs or smoke signals, those people (in country B) will not even respond to say that they are there". We have excluded from Table 11 those barriers found at the individual and team levels. The reasons why people may not collaborate and get involved, effectively or at all, and why teams can fail, are well known from the literature in many fields including participation, implementation of change and team working. Also, the roots of many of the individual- and team-level barriers lie in problems at the context, support, task and interaction process levels.

5.3. Potential limitations of the collaboration framework and model

In any exercise such as the one reported here there are bound to be a number of compromises made, and limitations to what it is

Table 11
Potential barriers to collaborative working.

Type of barrier	Relevant levels of collaborative work framework	
Non-supportive organisation	Context Support Interaction processes Overarching factors	• No culture of collaboration; systems geared to individual work • Weak senior management • No commitment of resources to collaborative working • Poor communication and low levels of trust • Non-participatory structures and processes • Lack of support through training, supervision etc.
Inadequate supply chain and partnering arrangements	Context Support Interaction processes Overarching factors	• Mismatch or conflicts in leadership styles, culture, performance measures and goals • Inability to see constraints faced by partners, or others' perspectives • Differences in technical support, networks, systems availability • Reduced or no face-to-face time • Poorer coordination, communication and trust • National or cultural differences
Weak management	Context Support Overarching factors	• Weak team identity and weak identification with company/project goals • Sub-optimality – prioritisation of function or department performance at expense of total company performance • Concentration on technical skills rather than collaboration skills • Allowing divisions to grow and conflicts to remain unresolved; avoidance of issues • Allowing knowledge not to be shared, or people to opt out of collaboration
Poorly conceived, planned or managed projects	Context Support Interaction processes Overarching factors	• Lack of project goals definition • Rigid organisational hierarchies • Poor transfer of collaboration experiences from other projects • Poor choices in personnel mix in project team selection • Lack of care over face-to-face and especially virtual team meetings • Little organisational support for project
Technology orientation	Support	• Reliance on technology fix • Collaboration which is technology availability push-led rather than user needs pull-led • Overly optimistic views on technology capabilities • Overly pessimistic views on technology capabilities • Poor technology interfaces • Poor technology implementation
Inadequate knowledge management	Support Interaction processes	• Different knowledge held by different partners without clarity • Inadequate project central knowledge store • Lack of clarity on confidentiality of knowledge for different partner companies • Reluctance of individuals to release, or even share, their own (tacit) knowledge
Unacceptable costs	All levels	• High start up costs, including technology cost • Unknown or out of control running costs • Cut backs on technical/communications support • Attempts to collaborate across too many business units • No examination of cost-benefit and opportunity cost of collaboration

possible to achieve. One top level criticism which might be levelled is over the whole enterprise – is it possible to capture such a multi-faceted notion as collaborative working in a model? It is perhaps instructive that the few other such published collaboration models concentrate on only a few factors (e.g. Harvey and Koubek, 2000; Weiseth et al., 2006).

A second potential limitation lies in the approach we took to developing the model. An alternate approach would have been to draw up the first framework entirely from empirical evidence gained via our close collaboration with the project user companies, and then to test this against the literature. However, to fit with the development timetable we needed to short cut somewhat, starting with a template of issues and factors from the literature, in order to inform the developers about general requirements in a timely fashion. Also early on we realised that we would get the best out of the fantastic access we had been given to the user companies if we had a framework of issues around which to structure our workshop and interview sessions on scenario and requirements elicitation. In part mitigation, our first framework did draw upon earlier work on a range of projects (including one author [HP] being a researcher-in residence) with a number of other European companies, as well as the literature.

The literature review focused on papers written in the context of collaborative or team working in the engineering and construction sectors, with some input from other domains such as healthcare and education. There is a very large literature related to collaboration in other domains, for instance the military, aerospace, civil planning, disaster management and community projects. We did follow down useful leads in this literature where these were identified, but nothing found leads us to believe that our framework and factors/sub-factors would be very much different had the original search been much wider. We found recurring themes with respect to collaborative work in general and collaboration enablers or inhibitors (e.g. communication, shared awareness, etc.).

As a final limitation, the background literature, and hence our framework and model, are most applicable to work within Europe, North America and Australasia. Elsewhere, there are likely to be differences in factors or the relative influence of these, related to culture and linguistic ability, affordability of new collaborative technologies, political and technical infrastructures, team or individual orientations in different cultures, and different power structures and the organisation of politics and industry.

5.4. Verification and value of the collaboration framework and the CCWM

Use of our framework of collaboration for practical collaborative work implementation or for advances in collaboration theory and models will require that it is acceptable to the industrial and scientific worlds. Does it meet the tests of theoretical justification, practicality and robustness, and eventually validation as a model? Some initial verification has taken place. We have presented the framework and CCWM in workshops and seminars and within papers at conferences and meetings of the CSCW and ergonomics/human factors communities, as well as at specialist European Commission workshops for collaborative working. Reactions from our peers and potential users have been positive, accepting the need for such a structured comprehensive framework, and broadly in agreement with the range and clustering of factors. In practical terms, the model has also been widely accepted by our broad range of industrial user and ICT developer partners, and by a wider industry and developer audience through training workshops that we have run at key conferences associated with the collaborative engineering and ICT communities (e.g. CSCW 2008; International Conference on Concurrent Enterprising, 2008; International Conference on Advanced Research in Virtual and Rapid Prototyping, 2007). Continuing work with user partners to re-assess the CoSpaces scenarios in terms of the collaboration factors and development and use of CoScope (see above) suggested that the CCWM is meaningful in terms of practical instantiations of collaborative work and technologies.

Our focus within the CoSpaces project was to examine collaboration in design and engineering work. However, our model highlights factors which we believe are of relevance to collaborative work in any setting. Recent discussions with medical professionals have indicated that the same basic elements from our model are relevant when examining how well surgical teams collaborate and identifying where improvement or support is required to increase patient safety. Of course, further work is required to formally assess the usefulness of our model in different settings. As well as developing the CCWM, the human factors team in CoSpaces were responsible for ensuring that user needs were addressed, and met where feasible, within the system development process. This process was greatly aided by the model itself, as a framework and communication focus. We hope and expect the model to be useful in other similar systems development projects in the future.

6. Conclusions

In this paper we have presented the structured outcomes of a review of collaboration, in the form of a framework of factors and sub-factors of collaboration as a basis for the CoSpaces Collaborative Working Model. This work has been carried out in the context of new collaborative engineering tools and a platform for use with the aerospace, automotive and construction sectors, but we believe the framework has much more general relevance. As discussed earlier, collaboration is a complex phenomenon with many interactions between factors which contribute to performance at any one point in time. What the model does provide is a description of relevant factors which companies can use to think about how they currently collaborate, and identify where and how they do things well and where there is room for improvement.

Our next objective is to build on this work for three complementary and interlinked purposes. The first is the further development of the descriptive model (CCWM), to provide a conceptual understanding of collaboration and of the constituent factors, and to identify testable relationships. This will allow hypotheses to be drawn up for experimental work to assess the interaction of small sets of factors, as independent or dependant variables; for instance as just one question, how do professional culture and trust in technical systems interact to influence coordination of team activities, and how does any effect interact with levels of technology support? Second, the CCWM will also be useful for researchers in the future in providing a framework within which to assess collaborative performance, design new collaborative working structures, and evaluate collaborative working solutions. Third, we will use the collaboration factors and model to further develop our collaboration readiness profiling tool CoScope, and extend its use within companies across Europe. The aim is to support them in establishing where they are now with respect to collaborative working and how to get to where they want to go.

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References

Anderson, R.E., 1993. HRD's role in concurrent engineering. Training & Development 47 (6), 49–54.

Arthur Jr., W., Edwards, B.D., Bell, S.T., Villado, A.J., Bennett Jr., W., 2005. Team task analysis: identifying tasks and jobs that are team based. Human Factors 47 (3), 654–669.

Barratt, M., 2004. Understanding the meaning of collaboration in the supply chain. Supply Chain Management: An International Journal 9 (1), 30–42.

Beddoes-Jones, F., Miller, J., April 2004. The Psychology of Teams [online]. Available from: http://www.cognitivefitness.co.uk/documents/psychology_of_teams/psychology_of_teams.pdf (accessed 10.03.09).

Beddoes-Jones, F., Miller, J., 2007. Short-term cognitive coaching interventions: worth the effort or a waste of time? The Coaching Psychologist 3 (2), 60–69.

Belbin, R.M., 1981. Management Teams: Why They Succeed or Fail. Heinemann, London.

Bergman, R., Baker, J.D., 2000. Enabling collaborative engineering and science at JPL. Advances in Engineering Software 31, 661–668.

Bohen, S.J., Stiles, J., 1998. Experimenting with models of faculty collaboration: factors that promote their success. New Directions for Institutional Research 100, 39–55.

Bolstad, C.A., Endsley, M.R., 1999. Shared mental models and shared displays: an empirical evaluation of team performance. In: Proceedings of the 43rd Annual Meeting of the Human Factors and Ergonomics Society 43rd Annual Meeting, Texas. Human Factors and Ergonomics Society, Santa Monica, CA, pp. 213–217.

Bolstad, C.A., Endsley, M.R., 2005. Choosing team collaboration tools: lessons from disaster recovery efforts. Ergonomics in Design 13, 7–14.

Bornemann, M., Graggober, M., Hartlieb, E., Humpl, B., Koronakis, P., Primus, A., Ritsch, K., Rollett, H., Sammer, M., Tuppinger, J., Willfort, R., Wöls, K., 2003. An Illustrated Guide to Knowledge Management [online]. Wissensmanagement Forum, Graz, Austria. Available from: http://www.wm-forum.org/ (accessed 10.03.09).

Bradley, J., White, B.J., Mennecke, B.E., 2003. Teams and tasks. Small Group Research 34 (3), 353–387.

Bratman, M.E., 1992. Shared cooperative activity. The Philosophical Review 101 (2), 327–341.

Breazeal, C., Hoffman, G., Lockerd, A., 2004. Teaching and working with robots as a collaboration. In: Proceedings of the Third International Joint Conference on Autonomous Agents and Multiagent Systems (AAMAS), New York. IEEE Computer Society, Washington, DC, pp. 1028–1035.

Buchanan, D., Badham, R., 1999. Politics and organizational change: the lived experience. Human Relations 52 (5), 609–629.

Buchanan, D.A., Badham, R.J., 2008. Power, Politics, and Organizational Change. Winning the Turf Game. Sage Publications Ltd.

Burton, B., Casonato, R., Logan, D., Knox, R.E., Cain, M.W., Lundy, J., Austin, T., Mario Smith, D., Holincheck, J., Harris, K., 2005. The High Performance Workplace Defined [online]. Available from: http://www.microsoft.com/business/peopleready/innovation/insight/hpworkplace.mspx (accessed 11.11.07).

Campion, M.A., Medsker, G.J., Higgs, A.C., 1993. Relations between work group characteristics and effectiveness: implications for designing effective work groups. Personnel Psychology 46 (4), 823–850.

Carneiro, A., 2000. How does knowledge management influence innovation and competitiveness? Journal of Knowledge Management 4 (2), 87–98.

Carroll, J.M., Neale, D.C., Isenhour, P.L., Rosson, M.B., McCrickard, D.S., 2003. Notification and awareness: synchronizing task-oriented collaborative activity. International Journal of Human–Computer Studies 58, 605–632.

Caruso, H.M., Rogers, T., Bazerman, M.H., 2009. Boundaries need not be barriers: leading collaboration among groups in decentralized organizations. In: Pittinsky, T.L. (Ed.), Crossing the Divide: Intergroup Leadership in a World of Difference. Harvard Business Press, pp. 113–126.

Cohen, A.L., Cash, D., Muller, M.J., 2000. Designing to support adversarial collaboration. In: Proceedings of CSCW'00, Philadelphia, PA. ACM, New York, pp. 31–39.

Conger, J.A., Kanungo, R.N., 1988. The empowerment process: integrating theory and practice. Academy of Management Review 13 (3), 471–482.

Cooke, N.J., Stout, R.J., Salas, E., 2001. A knowledge elicitation approach to the measurement of team situation awareness. In: McNeese, M.D., Salas, E., Endsley, M. (Eds.), New Trends in Cooperative Activities: Understanding System Dynamics in Complex Environments. Human Factors and Ergonomics Society Press, Santa Monica, CA, pp. 114–139.

Cordery, J.L., Soo, C., 2008. Overcoming impediments to virtual team effectiveness. Human Factors and Ergonomics in Manufacturing 18 (5), 487–500.

Cramton, C.D., Orvis, K.L., 2003. Overcoming barriers to information sharing in virtual teams. In: Gibson, C.B., Cohen, S.G. (Eds.), Virtual Teams that Work: Creating Conditions for Virtual Team Effectiveness. Jossey-Bass, San Francisco, pp. 214–229.

Cramton, C.D., 2002. Finding common ground in dispersed collaboration. Organizational Dynamics 30 (4), 356–367.

Cuevas, H.M., Costello, A.M., Bolstad, C.A., Endsley, M.R., 2006. Facilitating distributed team collaboration. In: Koningsveld, E. (Ed.), Proceedings of the International Ergonomics Association (IEA) 16th World Congress on Ergonomics, Maastricht, The Netherlands. [CD-ROM]. Elsevier Science, New York.

Cummings, J.N., Kiesler, S., 2005. Collaborative research across disciplinary and institutional boundaries. Social Studies of Science 35 (5), 703–722.

Daft, R.L., Lengel, R.H., 1986. Organizational information requirements, media richness and structural design. Management Science 32 (5), 554–571.

De Jonge, J., Dollard, M.F., Dormann, C., Le Blanc, P.M., Houtman, I.L.D., 2000. The demand-control model: specific demands, specific control, and well-defined groups. International Journal of Stress Management 7 (4), 269–287.

Delgado Piña, M.I., Romero Martínez, A.M., Gómez Martínez, L., 2008. Teams in organizations: a review on team effectiveness. Team Performance Management 14 (1/2), 7–21.

Denise, L., 1999. Collaboration vs. C-three (cooperation, coordination, and communication). Innovating [online], 7 (3). Available from: http://www.lwdt.org/filelibrary/Collaboration%20vs%20The%Other%20%20C%20Words.pdf (accessed 20.07.07).

Détienne, F., 2006. Collaborative design: managing task interdependencies and multiple perspectives. Interacting with Computers 18 (1), 1–20.

Devine, M., Banahan, E., 1999. The virtual project: managing teams in distributed environments. In: Wognum, N., Thoben, K.-D., Pawar, K.S. (Eds.), Proceedings of the 5th International Conference on Concurrent Enterprising, The Hague, The Netherlands. University of Nottingham, UK, pp. 425–432.

Dix, A., Finlay, J., Abowd, G., Beale, R., 2004. Human–Computer Interaction, third ed. Englewood Cliffs, Prentice Hall, NJ.

Dooley, B., 1996. At work away from work. The Psychologist 9, 155–158.

Drury, J., Williams, M.G., 2002. A framework for role-based specification and evaluation of awareness support in synchronous collaborative applications. In: Proceedings of the Eleventh IEEE International Workshops on Enabling Technologies: Infrastructure for Collaborative Enterprises (WETICE'02), Pittsburg, PA. IEEE Computer Society, pp. 12–17.

Eason, K., Olphert, W., 1996. Early evaluation of the organisational implications of CSCW systems. In: Thomas, P. (Ed.), CSCW Requirements and Evaluation. Springer, London, pp. 75–89.

Edwards, A., Wilson, J.R., 2004. Implementing Virtual Teams: A Guide to Organizational and Human Factors. Gower, Aldershot, England.

Eisenhardt, K.M., Kahwajy, J.L., Bourgeois III, L.J., 1997. Conflict and strategic choice: how top management teams disagree. California Management Review 39 (2), 42–62.

Espinosa, J.A., Carmel, E., 2003. Modeling coordination costs due to time separation in global software teams. In: Proceedings of the International Workshop on Global Software Development, International Conference on Software Engineering. Oregon, Portland, pp. 64–69.

Fasel, D.K., 2001. Partnering in Action: a Guide for Building Successful Collaboration across Organisational Boundaries. Cromwell Press, Oxford.

Fischer, G., Giaccardi, E., Eden, H., Sugimoto, M., Ye, Y., 2005. Beyond binary choices: integrating individual and social creativity. International Journal of Human–Computer Studies 63, 482–512.

Flanagin, A.J., Park, H.S., Seibold, D.R., 2004. Group performance and collaborative technology: a longitudinal and multilevel analysis of information quality, contribution equity, and members' satisfaction in computer-mediated groups. Computer Monographs 71 (3), 352–372.

Folkard, S., 1996. Body rhythms and shiftwork. In: Warr, P. (Ed.), Psychology at Work. Penguin Books, London, pp. 39–72.

Frost & Sullivan, 2006. Meetings around the world: The impact of collaboration on business performance [online]. A Frost & Sullivan white paper sponsored by Verizon Business and Microsoft. Available from: http://newscenter.verizon.com/kit/collaboration/MAW_WP.pdf (accessed 4.09.08).

Galve Górriz, C., Ortega Lapiedra, R., 2000. Equipos de trabajo y performance: un análisis empírico a nivel de planta productiva. M@n@gement 3 (4), 111–134.

Girard, P., Robin, V., 2006. Analysis of collaboration for project design management. Computers in Industry 57, 817–826.

Graham, J., Schneider, M., Bauer, A., Bessiere, K., Gonzalez, C., 2004. Shared mental models in military command and control organizations: effect of social network distance. In: Proceedings of the 47th Annual Meeting of the Human Factors and Ergonomics Society, New Orleans, Louisiana, pp. 509–512.

Guest, D., 1996. Leadership and management. In: Warr, P. (Ed.), Psychology at Work. Penguin Books, London, pp. 254–278.

Gutwin, C., Greenberg, S., 2000. The mechanics of collaboration: developing low cost usability evaluation methods for shared workspaces. In: Proceedings of IEEE 9th International Workshop on Enabling Technologies: Infrastructure for Collaborative Enterprises (WETICE '00), Gaithersburg, MD, pp. 98–103.

Hackman, J.R., 1987. The design of work teams. In: Lorsch, J. (Ed.), Handbook of Organizational Behaviour. Prentice-Hall, Englewood Cliffs, NJ, pp. 315–342.

Hackman, J.R., 1990. Groups that Work (And Those that Don't): Creating Conditions for Effective Teamwork. Jossey-Bass, Oxford.

Hackman, J.R., 1998. Why teams don't work. In: Tindale, R.S., Heath, L., Edwards, J., Posavac, J., Bryant, F.B., Suarez-Balcazar, Y., Henderson-King, E., Myers, J. (Eds.), Theory and Research on Small Groups. Kluwer Academic, Hingham, MA, pp. 245–267.

Hambley, L.A., O'Neill, T.A., Kline, T.J.B., 2007. Virtual team leadership: the effects of leadership style and communication medium on team interaction styles and outcomes. Organizational Behaviour and Human Decision Processes 103 (1), 1–20.

Hammond, J., Koubek, R.J., Harvey, C.M., 2001. Distributed collaboration for engineering design: a review and reappraisal. Human Factors and Ergonomics in Manufacturing 11 (1), 35–52.

Hammond, J.M., Harvey, C.M., Koubek, R.J., Compton, W.D., Darisipudi, A., 2005. Distributed collaborative design teams: media effects on design processes. International Journal of Human-Computer Interaction 18 (2), 145–165.

Handy, C., 1995. How do you manage people whom you do not see? Trust and the virtual organization. Harvard Business Review 73 (3), 40–50.
Hansen, M.T., Nohria, N., 2004. How to build collaborative advantage. MIT Sloan Management Review 46 (1), 22–30.
Harford, T., 2006. The Economics of Trust [online]. Available from: http://www.forbes.com/home/technology/2006/09/22/trust-economy-markets-tech_cx_th.06trust_0925harford.html (accessed 01.09.07).
Harford, T., 2008. The Logic of Life: Uncovering the New Economics of Everything. Little, Brown, London.
Harvey, C.M., Koubek, R.J., 1998. Toward a model of distributed engineering collaboration. Computers and Industrial Engineering 35 (1–2), 173–176.
Harvey, C.M., Koubek, R.J., 2000. Cognitive, social, and environmental attributes of distributed engineering collaboration: a review and proposed model of collaboration. Human Factors and Ergonomics in Manufacturing 10 (4), 369–393.
Henneman, E.A., Lee, J.L., Cohen, J.I., 1995. Collaboration: a concept analysis. Journal of Advanced Nursing 21, 103–109.
Herbsleb, J.D., Mockus, A., Finholt, T.A., Grinter, R.E., 2000. Distance, dependencies, and delay in a global collaboration. In: Proceedings of CSCW'00, Philadelphia, PA, pp. 319–328.
Higgs, M., Plewnia, U., Ploch, J., 2005. Influence of team composition and task complexity on team performance. Team Performance Management 11 (7/8), 227–250.
Hinds, P., McGrath, C., 2006. Structures that work: social structure, work structure and coordination ease in geographically distributed teams. In: Proceedings of CSCW'06, Banff, Alberta, pp. 343–352.
Hockey, R., 1996. Skilled performance and mental workload. In: Warr, P. (Ed.), Psychology at Work. Penguin Books, London, pp. 13–38.
Howes, A., Payne, S.J., 2005. Being rational about collaborative activity: towards a framework for explaining the role of technologies in constraining collaborative work. In: Proceedings of ECSCW Workshop on Computer Support for Human Activity [online]. Available from: http://www.daimi.au.dk/~bardram/ecscw2005/ (accessed 06.09.07).
Hutchins, E., 1995. Cognition in the Wild. MIT Press, Cambridge, MA.
Igbaria, M., 1999. The driving forces in the virtual society. Communications of the ACM 42 (12), 64–70.
Ilgen, D.R., Hollenbeck, J.R., Johnson, M., Jundt, D., 2005. Teams in organizations: from input-process-output models to IMOI models. Annual Review of Psychology 56, 517–543.
Inkpen, A.C., 1997. An examination of knowledge management in international joint ventures. In: Beamish, P.W., Killing, J.P. (Eds.), Cooperative Strategies: North American Perspectives. The New Lexington Press, San Francisco, pp. 133–159.
Johnson, H., Hyde, J., 2003. Towards modelling individual and collaborative construction of jigsaws using task knowledge structures (TKS). ACM Transactions on Computer–Human Interaction 10 (4), 339–387.
Jørgensen, H., et al., 2010. D76: Final Publication of CoSpaces Reference Architecture. CoSpaces Deliverable for the European Commission. Available from: http://www.cospaces.org/downloads/D76%20Final%20publication%20of%20CoSpaces%20Reference%20Architecture.pdf (accessed 01.02.11).
Karasek, R.A., 1998. Demand/control model: a social, emotional, and physiological approach to stress risk and active behaviour development. In: Stellmann, J.M. (Ed.), Encyclopaedia of Occupational Health and Safety, fourth ed. ILO, Geneva, pp. 34.6–34.14.
Katzenbach, J.R., Smith, D.K., 1994. The Wisdom of Teams: Creating the High-performance Organization. Harvard Business School Press, McGraw-Hill, Boston, MA.
Kelly, C., 2007. Managing the relationship between knowledge and power in organisations. Aslib Proceedings: New Information Perspectives 59 (2), 125–138.
Kiesler, S., Cummings, J.N., 2002. What do we know about proximity and distance in work groups? A legacy of research. In: Hinds, P., Kiesler, S. (Eds.), Distributed Work. MIT Press, Cambridge, MA, pp. 57–80.
King, Z., 2006. The Determinants of Localised Knowledge Exchange: a Psychological Perspective Report for ESRC, RES-000-22-0867.
Klein, G., 2001. Features of team coordination. In: McNeese, M.D., Salas, E., Endsley, M. (Eds.), New Trends in Cooperative Activities: Understanding System Dynamics in Complex Environments. Human Factors and Ergonomics Society Press, Santa Monica, CA, pp. 96–113.
Klein, G., 2008. Naturalistic decision making. Human Factors 50 (3), 456–460.
Knutilla, A., Steves, M., Allen, R., 2000. Workshop on evaluating collaborative enterprises – Workshop Report. In: Proceedings of the IEEE 9th International Workshops on Enabling Technologies: Infrastructure for Collaborative Enterprises (WETICE), Gaithersburg, MD, pp. 79–85.
Krackhardt, D., Hanson, J.R., 1993. Informal networks: the company behind the chart. Harvard Business Review 71 (4), 104–111.
Krebs, S.A., Hobman, E.V., Bordia, P., 2006. Virtual teams and group member dissimilarity. Small Group Research 37 (6), 721–741.
Kyzlinková, R., Dokulilová, L., Kroupa, A., 2007. Teamwork and High Performance Work Organisation [online]. Available from: http://www.eurofound.europa.eu/pubdocs/2006/93/en/1/ef0693en.pdf (Accessed 28.11.08).
Langfred, C.W., 2000. Work-group design and autonomy: a field study of the interaction between task interdependence and group autonomy. Small Group Research 31 (1), 54–70.
Liebrich, A., Zink, K.J., 2006. Designing working conditions for virtual teams. In: Proceedings of the 16th International Ergonomics Association World Congress on Ergonomics, Maastricht, The Netherlands. [CD-ROM]. Elsevier Science, New York.
Mannix, E.A., Sauer, S.J., 2006. Status and power in organizational group research: acknowledging the pervasiveness of hierarchy. Social Psychology of the Workplace (Advances in Group Processes) 23, 149–182.
Margolis, L.H., Runyan, C.W., 1998. Understanding and reducing barriers to collaboration by academics with agencies and community organizations: a commentary. Injury Prevention 4, 132–134.
Marttiin, P., Lehto, J.A., Nyman, G., 2002. Understanding and evaluating collaborative work in multi-site software projects – a framework proposal and preliminary results. In: Proceedings of the 35th Hawaii International Conference on System Sciences, Big Island, Hawaii. IEEE Computer Society, pp. 283–292.
Mattessich, P.W., Monsey, B.R., 1992. Collaboration: What Makes It Work? a Review of Research Literature on Factors Influencing Successful Collaboration. Amherst H. Wilder Foundation, St Paul, MN.
McNamara, C., 2003. Field Guide to Leadership and Supervision for Nonprofit Staff. Authenticity Consulting LLC, Minneapolis.
McNeese, M.D., Rentsch, J.R., 2001. Identifying the social and cognitive requirements of teamwork using collaborative task analysis. In: McNeese, M.D., Salas, E., Endsley, M. (Eds.), New Trends in Collaborative Activities: Understanding System Dynamics in Complex Environments. Human Factors and Ergonomics Society Press, Santa Monica, CA, pp. 96–113.
McNeese, M.D., Rentsch, J.R., Perusich, K., 2000. Modeling, measuring and mediating teamwork: the use of fuzzy cognitive maps and team member schema. Similarity to enhance BMC3I decision making. In: Proceedings of IEEE International Conference on Systems, Man and Cybernetics, Nashville, TN. IEEE Computer Society, NY, pp. 1081–1086.
Meads, G., Ashcroft, J., Barr, H., Scott, R., Wild, A., 2005. The case for Interprofessional collaboration. In: Health and Social Care. Blackwell Publishing, Oxford.
Monk, A., 1996. Human–computer interaction. In: Warr, P. (Ed.), Psychology at Work. Penguin Books, London, pp. 95–120.
Montiel-Overall, P., 2005. Toward a theory of collaboration for teachers and librarians. School Library Media Research [online], 8. Available from: http://www.ala.org/ala/aasl/aaslpubsandjournals/slmrb/slmrcontents/volume82005/theory.htm (accessed 15.09.07).
Mullen, B., Copper, C., 1994. The relation between group cohesiveness and performance: an integration. Psychological Bulletin 115, 210–227.
Neale, D.C., Carroll, J.M., Rosson, M.B., 2004. Evaluating Computer-supported Cooperative Work: Models and Frameworks. In: Proceedings of CSCW '04, Chicago, Illinois, pp. 112–121.
Norman, D.A., 1980. Twelve issues for cognitive science. Cognitive Science 4, 1–32.
Nunamaker, J.F., 1997. Future research in group support systems: needs, some questions and possible directions. International Journal of Human-Computer Studies 47, 357–385.
O'Driscoll, M.P., Cooper, C.L., 1996. Sources and management of excessive job stress and burnout. In: Warr, P. (Ed.), Psychology at Work. Penguin Books, London, pp. 188–223.
Olk, P., 1997. The effect of partner differences on the performance of R&D consortia. In: Beamish, P.W., Killing, J.P. (Eds.), Cooperative Strategies. North American Perspectives. The New Lexington Press, San Francisco, pp. 133–159.
Olson, G.M., Olson, J.S., 2000. Distance matters. Human–Computer Interaction 15 (2/3), 139–178.
Parker, S.K., Wall, T.D., 1996. Job design and modern manufacturing. In: Warr, P. (Ed.), Psychology at Work. Penguin Books, London, pp. 333–358.
Patel, H., Pettitt, M., Hansen, S., Wilson, J., 2010. A descriptive model of collaboration to underpin a collaboration profiling methodology. International Reports on Socio-Informatics 7 (1), 15–23 [online]. Available from: http://www.iisi.de/fileadmin/IISI/upload/IRSI/IRSIV7I1.pdf.
Payne, R., 1996. The characteristics of organizations. In: Warr, P. (Ed.), Psychology at Work. Penguin, London, pp. 73–94.
Pettigrew, A., McNulty, T., 1995. Power and influence in and around the boardroom. Human Relations 48 (8), 845–873.
Pettitt, M., Patel, H., Wilson, J., 2009. Design guidance for collaborative working environments. Design Principles and Practices: An International Journal 3 (3), 117–132.
Pfeffer, J., 1992. Managing with Power: Politics and Influence in Organizations. Harvard Business School Press.
Pinelle, D., Gutwin, C., 2001. Group task analysis for groupware usability evaluations. In: Proceedings of IEEE 10th International Workshop on Enabling Technologies: Infrastructure for Collaborative Enterprises (WET ICE '01), Cambridge, MA. IEEE Computer Society, pp. 102–107.
Pinelle, D., Gutwin, C., Greenberg, S., 2003. Task analysis for groupware usability evaluation: modelling shared-workspace tasks with the mechanics of collaboration. ACM Transactions on Computer-Human Interactions 10 (4), 281–311.
Pinto, J.K., Slevin, D.P., 1987. Critical factors in successful project implementation. IEEE Transactions on Engineering Management 34 (1), 22–27.
Potter, R.E., Balthazard, P.A., 2002. Virtual team interaction styles: assessment and effects. International Journal of Human-Computer Studies 56, 423–443.
Rasmussen, J., 1986. Information Processing and Human-Machine Interaction. An Approach to Cognitive Engineering. North-Holland, Amsterdam.
Reason, J., 1990. Human Error. Cambridge University Press.
Robertson, I., 1996. Personnel selection and assessment. In: Warr, P. (Ed.), Psychology at Work. Penguin Books, London, pp. 121–160.
Robin, V., Rose, B., Girard, P., 2007. Modelling collaborative knowledge to support engineering design project manager. Computers in Industry 58 (2), 188–198.
Rogers, Y., Ellis, J., 1994. Distributed cognition: an alternative framework for analyzing and explaining collaborative working. Journal of Information Technology 9 (2), 119–128.
Rogers, E., 1995. Diffusion of Innovations. The Free Press, New York.

Rothschild-Whitt, J., 1979. The collectivist organization: an alternative to rational-bureaucratic models. American Sociological Review 44 (4), 509–527.
Saikayasit, R., 2011. The influence of communication modality and shared visual information on collaboration in virtual teams. Unpublished PhD thesis, University of Nottingham.
Salas, E., Guthrie Jr., J.W., Wilson-Donnelly, K.A., Priest, H.A., Burke, C.S., 2005a. Modeling team performance: the basic ingredients and research needs. In: Rouse, W.B., Boff, K.R. (Eds.), Organizational Simulation. John Wiley, Hoboken, NJ, pp. 185–228.
Salas, E., Sims, D.E., Burke, C.S., 2005b. Is there a "Big Five" in teamwork? Small Group Research 36, 555–599.
Salas, E., Stagl, K.C., Burke, C.S., Goodwin, G.F., 2007. Fostering team effectiveness in organizations: toward an integrative theoretical framework. In: Shuart, J.W., Spaulding, W., Poland, J. (Eds.), Modeling Complex Systems. Nebraska Symposium on Motivation, vol. 52. University of Nebraska Press, Lincoln.
Salas, E., Cooke, N.J., Rosen, M.A., 2008. On teams, teamwork, and team performance: discoveries and developments. Human Factors 50 (3), 540–547.
Saunders, C.S., Ahuja, M.K., 2006. Are all distributed teams the same? Differentiating between temporary and ongoing distributed teams. Small Group Research 37 (6), 662–700.
Schmidt, K., 1991. Riding a tiger, or computer supported cooperative work. In: Proceedings of the Second European Conference on Computer Supported Cooperative Work, Amsterdam, pp. 1–16.
Schrage, M., 1990. Shared Minds: The New Technologies of Collaboration. Random House, New York.
Seymour, G.E., Cowen, M.B., 2006. A review of team collaboration tools for crisis response in the military and government. In: Proceedings of Command and Control Research and Technology Symposium. Available from: http://www.dodccrp.org/events/2006_CCRTS/html/papers/037.pdf (accessed 03.07.07).
Shea, G.P., Guzzo, R.A., 1987. Group effectiveness: what really matters? Sloan Management Review 28 (3), 25–31.
Sheehy, N., Gallagher, T., 1996. Can virtual organizations be made real? The Psychologist 9, 159–162.
Sheldon, S., 2007, An Investigation into Collaborative Technologies: The implementation and Usability Issues Encountered by Teams in Industry. Master of Engineering Dissertation. University of Nottingham, unpublished results.
Skovholt, K., Svennevig, J., 2006. Email copies in workplace interaction. Journal of Computer-Mediated Communication 12, 42–65.
Sonnenwald, D.H., Maglaughlin, K.L., Whitton, M.C., 2001. Using Innovation Diffusion Theory to Guide Collaboration Technology Evaluation: Work in Progress. In: Proceedings of IEEE 10th International Workshop on Enabling Technologies: Infrastructure for Collaborative Enterprises (WET ICE '01), Cambridge, MA. IEEE Computer Society, pp. 114–119.
Sproull, L., Kiesler, S., 1986. Reducing social context cues: electronic mail in organizational communication. Management Science 32 (11), 1492–1512.
Stammers, R., 1996. Training and the acquisition of knowledge and skill. In: Warr, P. (Ed.), Psychology at Work. Penguin Books, London, pp. 73–94.
Steiner, I.D., 1972. Group Process and Productivity. Academic Press, New York.
Suchman, L.A., 1987. Plans and Situated Actions: The problem of Human–Machine Communication. Cambridge University Press.
Swigger, K., Alpaslan, F., Brazile, R., Monticino, M., 2004. Effects of culture on computer-supported international collaborations. International Journal of Human–Computer Studies 60, 365–380.
Talbot, K.D., 1999. The virtual company. Engineering Management Journal 9 (2), 65–70.
Tesluk, P., Mathieu, J.E., Zaccaro, S.J., Marks, M., 1997. Task and aggregation issues in the analysis and assessment of team performance. In: Brannick, M.T., Salas, E., Prince, C. (Eds.), Team Performance Assessment and Measurement: Theory, Methods, and Applications. Erlbaum, Mahwah, NJ, pp. 197–224.
Tyndale, P., 2003. The evaluation of critical success factors for IT projects. In: Proceedings of the 10th European Conference on Information Technology Evaluation, Madrid. MCIL, Reading, UK, pp. 641–651.
Unsworth, K.L., West, M.A., 2000. Teams: the challenges of cooperative work. In: Chmiel, N. (Ed.), An Introduction to Work and Organizational Psychology: a European Perspective. Wiley-Blackwell, Oxford, pp. 327–346.
Van Dyck, C., Frese, M., Baer, M., Sonnentag, S., 2005. Organizational error management culture and its impact on performance: a two-study replication. Journal of Applied Psychology 90 (6), 1228–1240.
Van Fenema, P.C., 2005. Collaborative elasticity and breakdowns in high reliability organisations: contributions from distributed cognition and collective mind theory. Cognition, Technology & Work 7, 134–140.
Viller, S., Bowers, J., Rodden, T., 1999. Human factors in requirements engineering: a survey of human sciences literature relevant to the improvement of dependable systems development processes. Interacting with Computers 11, 665–698.
Walsh, J.P., Maloney, N.G., 2007. Collaboration structure, communication media, and problems in scientific work teams. Journal of Computer-Mediated Communication [online] 12 (2) article 19. Available from: http://jcmc.indiana.edu/vol12/issue2/walsh.html (accessed 15.10.07).
Warner, N.W., Letsky, M., Cowen, M., 2003. Structural Model of Team Collaboration [online]. Office of Naval Research, Human Systems Department, Arlington, VA. Available from: www.au.af.mil/au/awc/awcgate/navy/model_of_team_collab.doc (accessed 03.03.08).
Warr, P., 1996a. Employee well-being. In: Warr, P. (Ed.), Psychology at Work. Penguin Books, London, pp. 224–253.
Warr, P., 1996b. Younger and older workers. In: Warr, P. (Ed.), Psychology at Work. Penguin Books, London, pp. 308–332.
Watson, W.E., Michaelsen, L.K., 1988. Group interaction behaviors that affect group performance on an intellective task. Group & Organization Studies 13 (4), 495–516.
Waugh, R., 2005. Communication, Cooperation, Collaboration [online]. Available from: http://www.neglected-delinquent.org/nd/resources/spotlight/spotlight200502b.asp (accessed 15.05.06).
Weiseth, P.E., Munkvold, B.E., Tvedte, B., Larsen, S., 2006. The wheel of collaboration tools: a typology for analysis within a holistic framework. In: Proceedings of CSCW'06, Banff, Alberta, pp. 239–248.
Wenger, E., 1998. Communities of Practice: Learning, Meaning and Identity. Cambridge University Press.
West, M., 1996. Working in groups. In: Warr, P. (Ed.), Psychology at Work. Penguin Books, London, pp. 359–382.
Willaert, S.S.A., de Graaf, R., Minderhoud, S., 1998. Collaborative engineering: a case study of concurrent engineering in a wider context. Journal of Engineering and Technology Management 15, 87–109.
Wilson, J.R., Jackson, S., Nichols, S., 2003. Cognitive work investigation and design in practice: the influence of social context and social work artefacts. In: Hollnaegel, E. (Ed.), Handbook of Cognitive Task Design. Lawrence Erlbaum Associates, New Jersey, pp. 83–98.
Wilson, J., Patel, H., Pettitt, M., Saikayasit, R., 2008. ADDS: living labs for collaborative engineering. In: Schumacher, J., Niitamo, V.-P. (Eds.), European Living Labs: a New Approach for Human Centric Regional Innovation. Wissenschaftlicher Verlag Berlin.
Wilson, J.R., Patel, H., Pettitt, M., 2009a. Human factors and development of next generation collaborative engineering. In: Proceedings of the Ergonomics Society Annual Conference, London, U.K. Taylor and Francis, London, pp. 39–48.
Wilson, J.R., Ryan, B., Schock, A., Ferreira, P., Smith, S., Pitsopoulos, J., 2009b. Understanding safety and production risks in rail engineering planning and protection. Ergonomics 52 (7), 774–790.
Wilson, J.R., 2006. Collaboration in mobile virtual work: a human factors view. In: Andriessen, J.H.E., Vartiainen, M. (Eds.), Mobile Virtual Work: a New Paradigm? Springer, Berlin, pp. 129–151.
Yates, N., 2007. An Investigation into Trust and Privacy Issues within Industrial Collaboration. Master of Engineering Dissertation. University of Nottingham, unpublished results.
Zolin, R., Hinds, P.J., Fruchter, R., Levitt, R., 2004. Interpersonal trust in cross functional, geographically distributed work: a longitudinal study. Information and Organisation 14, 1–26.