



A novel systematic method to evaluate computer-supported collaborative design technologies

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Abstract

Selection of suitable computer-supported collaborative design (CSCD) technologies is crucial to facilitate successful projects. This paper presents the first systematic method for engineering design teams to evaluate and select the most suitable CSCD technologies comparing technology functionality and project requirements established in peer-reviewed literature. The paper first presents 220 factors that influence successful CSCD. These factors were then systematically mapped and categorised to create CSCD requirement statements. The novel evaluation and selection method incorporates these requirement statements within a matrix and develops a discourse analysis text processing algorithm with data from collaborative projects to automate the population of how technologies impact the success of CSCD in engineering design teams. This method was validated using data collected across 3 years of a student global design project. The impact of this method is the potential to change the way engineering design teams consider the technology they use and how the selection of appropriate tools impacts the success of their CSCD projects. The development of the CSCD evaluation matrix is the first of its kind enabling a systematic and justifiable comparison and technology selection, with the aim of best supporting the engineering designers collaborative design activity.

Keywords Computer-supported collaborative design (CSCD) · Engineering design · Computer-aided engineering and design · Collaboration · Educational tools

1 Introduction

Computer-supported collaborative design (CSCD) is the application of technologies to support a design process involving several parties and usually in distributed locations. Technologies which support CSCD and the technology functionalities which facilitate collaborative design are essential for distributed design in digital or mixed environments. These technologies provide innovative methods of communication, co-operation and co-ordination within an engineering design context with the potential to foster greater collaboration for internal teams, external collaborators and across boundaries (Hicks 2013; Sarka et al. 2014). In an increasingly globalised world, CSCD is essential to

support the increasingly complex product design process (Brisco et al. 2018a).

Technologies which support CSCD come in the form of software or a web application depending on the required features and functionality offered to users. The definition of CSCD can be extended to include hardware which makes CSCD functionality possible through innovative interfaces, e.g. cave automatic virtual environment (CAVE), virtual reality and augmented reality technologies and telepresence robotics (Ahram et al. 2011). Commercial technologies which support CSCD tend to focus on a certain type of media, functionality or subject to differentiate themselves from their competitors. Technologies might include everyday communication methods such as e-mail, video conferencing and messaging (Shen et al. 2015) or specialist technologies such as digital whiteboards, groupware systems and knowledge management systems (Hsu 2013; Borsato et al. 2015; Shen et al. 2015). These technologies have been adopted by the more general consumer with free technologies offering functionalities such as document versioning

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control, social networking, and electronic co-ordination systems (Brisco et al. 2016).

Engineering design teams can utilise CSCD technology functionality using, for example, a multi-threaded conversation for the tasks of commenting and replying, or tagging team members for increased awareness and liking posts to show agreement (Gopsill 2014). This functionality has the potential to improve teamwork and change the way engineers work in the future (Zhao and Rosson 2009). A change is beginning to be seen in the way small businesses and students use this technology for design project communication and decision-making (Gopsill 2014). Many technologies which support CSCD also support social communication in addition to professional (project related) communication which is beneficial for successful engineering design teams. Törlind and Larsson (2002) stated: “The highly informal, accidental, spontaneous communication that characterizes everyday work has an impact on a design that sometimes is even greater than that of formal communication”. This has been referred to as the *watercooler* moment in organisations which offer workers an opportunity to socialise and discuss work informally.

To fully support CSCD, a range of functionalities is required. These are often featured within different technologies, and consequently to fully support CSCD, a range of different technologies are required (Mamo et al. 2015). Issues arise when technologies have overlapping functionalities offering a choice of communication method. This can lead to confusion in the project progress and future direction, and social tension between team members (Brisco et al. 2017). To minimise these effects, it is necessary to carefully select technologies that support the requirements of the design project and the individual team members.

Methods for technology identification, evaluation and selection exist typically reported in computing journals detailing computer systems selection or in business management journals detailing the decision process in the technology management process. The process tends to be holistic in nature (Sivunen and Valo 2006; Shea et al. 2011; Bohemia 2013) guided by recommendations and sometimes guided by a framework (Chan et al. 2000) derived from previous experiences which may or may not be relevant. This can lead to inappropriate technologies being selected which do not offer the functionality to support CSCD projects. Technology selection also crosses over with the requirements of the project or task, and the team members (Gibson and Cohen 2004). This makes the selection process unique to each problem requiring specialist knowledge of the entire system. A gap in this research has been that selection methods focus on the requirements of the technology functionality and not of the individual team members, then requiring team members to be trained on the use of technologies.

Technology selection is important for both business and socio-technical interests. Appropriate technology selection has been demonstrated to improve both technology capacity and technology management capacity which in turn increases innovation performance (Hao et al. 2007). Torkeli and Tuominen (2002) reflected, “A company can waste its competitive advantage by investing in wrong alternatives at the wrong time or by investing too much in the right ones. It is more and more difficult to clarify the right technology alternatives because the number of technologies is increasing, and technologies are becoming more and more complex”. Since 2002, this observation has become increasingly prevalent and the number of technologies which can support CSCD has increased enormously requiring assistance in the best technology selection. Socially technology has the ability “to provide a more collaborative method of communication” (Gopsill 2014) by bringing people together in virtual environments where the alternative would be too expensive or time-consuming. However, this is not to say technology can and should replace face-to-face co-located working as this cannot be proven for all contexts (Hatem et al. 2012).

It is important to select the right technologies. When done correctly, a successful selection of technology has the potential to minimise risks resulting in great benefits to businesses (Rassias and Kirytopoulos 2014). The use of technology can either provide benefits for a company or could impose barriers if improperly conceived. Cross (2014) surmised, “... they (companies) may dive into using it (technologies) without forethought or proper risk assessment. On the other end of the spectrum, it may be treated as bleeding edge technology that is largely untried, untested, and/or poses a substantial threat”. In these cases, the response of large companies is to largely block access rather than to understand the potential benefits and devise ways to utilise this in a safe way. There is also the issues of protecting interests as part of using technology such as assets, copyrighted materials and other intellectual property (Cross 2014). This is especially important when selecting technologies for new product development teams as security features may not be suitable for collaboration.

Categorisation of the factors that influence successful collaboration has been well published in the literature over the years. Mattessich and Monsey (1992) first published a consolidated list of requirements for successful co-located collaboration based on the literature of the time. Some of the factors in this list are still relevant to co-located studies today, whilst others are not (McDonnell 2012; Fain et al. 2013; O’Riordan 2014).

Efforts to create similar lists for digital collaboration have been made including cross-cultural influencing factors based on the literature from 1977 to 2005 (Markus et al. 2007), risk management guidelines for distributed software development for design teams based on contemporary case

study data from 1995 to 2002 (van Grinsven and de Vreede 2002), collaborative product development factors based on case studies analysis and survey results around 2007 (Elfving 2007), collaborative product development characteristics for an agile product development system based on learning from collaboration with industry (Reich et al. 1999), key factors for successful collaboration in the integration of CAD/CAE environments based on case studies between two universities and an industry partner in 2006 (Maier et al. 2009), and many of the same efforts have been achieved in related concepts such as communication (Maier et al. 2006), co-ordination (Duffy 2002) and co-operation (Hosnedl et al. 2008). These lists of requirements stemming from each of these studies differ due to differences between the contexts, differences with the data sources, and differences between the periods of investigation, as a result of changes to design practice or technological capabilities.

However, contextually relevant recommendations may provide additional insight when developed over shorter periods of time such as iterations from year to year. Such attempts use case study data (Horváth 2012; Gopsill 2014; Borsato et al. 2015) from an individual source which should not be generalised or the teachings may be misinterpreted. If generalised, the outcomes may not be applicable. In addition, no one has attempted to conduct a systematic literature mapping of existing published work to build a larger picture of the factors which influence the success of CSCD projects.

There have been many decision-making frameworks developed towards the task of selecting technology over time (Yap and Souder 1993; Gibson and Cohen 2004; Sivunen and Valo 2006; Nicholas and Steyn 2017). Most require an in-depth knowledge of the technology application to be able to utilise successfully across a range of factors. Often the individual or team who are in the position to make the decision does not have this knowledge (Sivunen and Valo 2006). When this is the case it can result in substandard technologies being selected that do not meet the requirements of the work and additional technologies or protocols to satisfy the requirements (Sclater 2008). Within student projects, technologies are often chosen based on the popularity of a technology within a team, and not based on its merits to support design activities or the overall design process (Brisco et al. 2017). When the wrong types of technologies are selected, it can result in conflict between team members (Hinds and Bailey 2003) and inefficient working (Brown 2000).

Germani et al. (2012) describe a method to benchmark co-design tools based on systems architecture. A QFD-based method is detailed and tested with small and medium enterprise (SME) partners and case studies. The method is successful in identifying collaborative dimensions which support the SME projects and creating a structured approach to understand collaborative tasks and functionalities through case studies. The outcome of this was the development of

software which can *fully support* the collaborative dimensions according to the author. This method does not contribute towards the use of existing software to meet collaborative requirements which are typical in smaller start-up companies and student projects as examples (Ferro 2015; Brisco et al. 2018b). In addition, the SME case studies used to form the collaborative dimensions can only be applied to SME projects and not a wider range of potential CSCD projects which a wider literature search would bring.

The motivation behind this research was an observation of a change in student behaviour. This change was reflected with the use of social software and technologies in student engineering design teams (Gopsill et al. 2015; Mamo et al. 2015; Pektaş 2015) and as an emerging trend within industry (Margaryan et al. 2014; Sarka et al. 2014). This is a result of increased awareness amongst students of the disruptive technologies available, whereas educators have knowledge of previous successful projects using technology to impart to students (Brisco et al. 2018b). Currently, there is no formal method to combine these two factors. If students were empowered with the relevant knowledge, a method to make informed decisions based on the available technologies, and the factors which influence successful CSCD, then they would be able to make decisions to the benefit of their collaborative and technological requirements.

This highlights the importance of the method presented within this paper to be agile and updatable with respect to current popular technology use. In 2010, the proliferation of Web 2.0 websites and web services reached maturity as identified by Conole and Alevizou (2010), “We have seen a continual evolution of technologies and how they are used [...] and we are only beginning to develop an understanding of what the trajectory of this co-evolution will be”. This coincides with a change in social behaviour driven by the spread of social websites. In 2010, Facebook reached its position as one of the top five websites by user traffic in the US (Metrix 2010; Post 2014). This encouraged the spawn of other social network sites and a trend towards mobile social network sites with the proliferation of smartphones over feature phones in the US in 2010 (Butler 2010).

2 Approach overview

The aim of this research was to develop a method to allow those involved in CSCD projects to evaluate and select suitable technologies based on the existing knowledge of the requirements of successful CSCD. A four-phase process was created as illustrated in Fig. 1.

In this paper, Sect. 3 addresses Fig. 1—Step 1 the creation of the CSCD evaluation matrix, identification of known and missing knowledge required and selection of the known knowledge best suited for the matrix. Section 4 (Step 2)

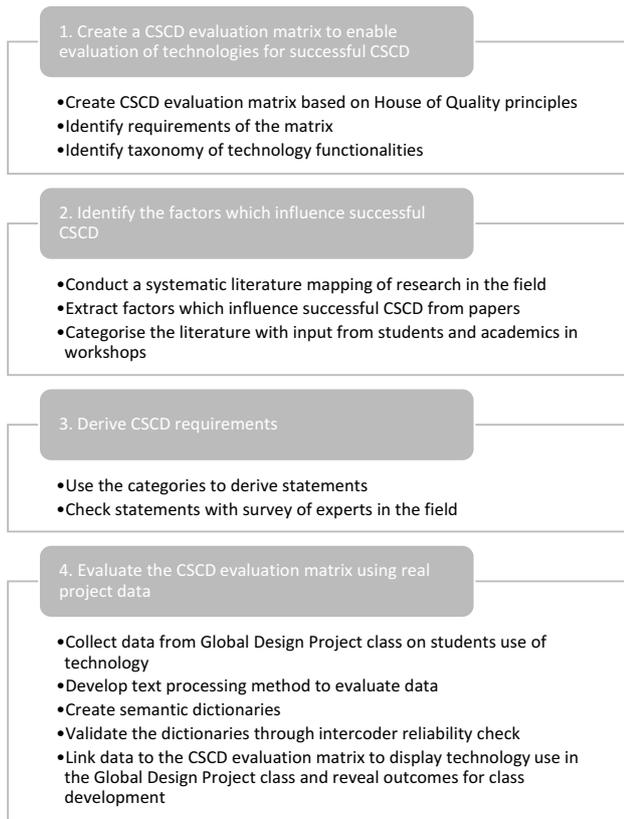
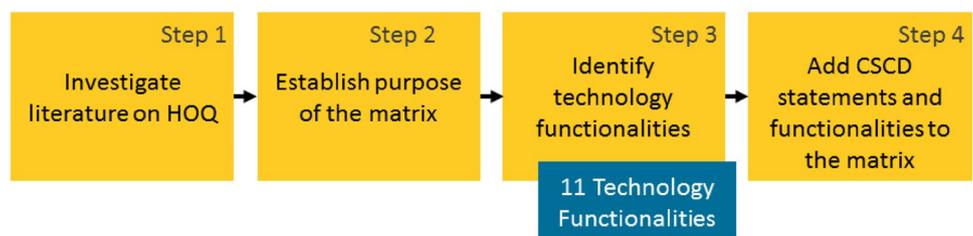


Fig. 1 Process adopted to create CSCD evaluation method

identifies the missing knowledge through a systematic literature mapping, extraction of factors which influence successful CSCD, categorisation of these factors and validation through workshops. Section 5 (Step 3) addresses the use of these factors for the purpose of the CSCD evaluation matrix by creating CSCD requirement statements and validation through a survey of experts. Section 6 (Step 4) pulls all the knowledge found and generated together into a complete CSCD evaluation matrix and discusses the creation of an automated text processing method requiring the input of three researchers to create dictionaries and coding to auto-evaluate reports and diaries of CSCD projects. Section 7 discusses the results of using the matrix to evaluate and develop a global design class, and Sect. 8 discusses the potential of the CSCD evaluation matrix in greater details.

Fig. 2 Approach for creating and populating the CSCD matrix



3 Creating the CSCD evaluation matrix

The CSCD evaluation matrix was developed to enable the selection of the most suitable technology to support a CSCD project. The CSCD evaluation matrix allows the technologies which support CSCD to be profiled and then compared against CSCD requirements. This is achieved through the identification of functionalities of each individual technology and evidence that the functionality helps achieve the requirement. The method would also enable a discourse analysis technique to be utilised to automate the population of matrix cells.

A summary of the methodology used in this section is displayed in Fig. 2. An investigation was made into House of Quality (HoQ) literature (Step 1), the purpose of the CSCD evaluation matrix was established and relevant HoQ literature extracted (Step 2), a taxonomy of technology functionalities was found to complete the knowledge requirements of the CSCD evaluation matrix (Step 3) and the CSCD requirement statements were added to the completed CSCD evaluation matrix (Step 4).

The CSCD evaluation matrix was initially inspired by the HoQ matrix from Quality Function Deployment knowledge (Germani et al. 2012). This approach was selected for HoQ's suitability for a competitor and product comparison analysis. There are structural similarities between the HoQ and the CSCD matrix, and the inputs, outputs and data processing were analogous. As the needs of the evaluation matrix developed, certain parts of the HoQ matrix were adapted, for example, there is no need to compare the CSCD requirements against each other, or for perception measurements towards the aim of this paper.

In the HoQ, customer requirements are compared against technical requirements. Both these aspects need to be represented within the new CSCD evaluation matrix. Customer requirements, in this case, are translated to CSCD requirements, and technical requirements are translated to technology functionality. In addition, there is also a need to define the technology and its available functionalities. This hierarchy is displayed in Fig. 3. Technologies afford functionalities which satisfy requirements.

Technical requirements are satisfied by the functional abilities of a product. In this case, the functional abilities are

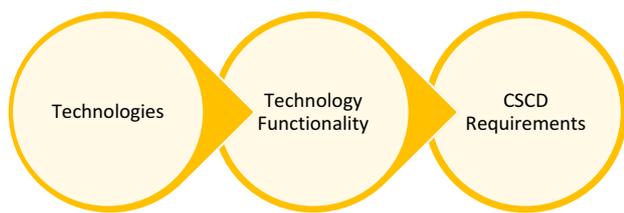


Fig. 3 Summary of the CSCD evaluation matrix logic in comparison

already established as the functionalities of the technology, which can be used analogously with the technical requirements of the HoQ. To identify what the technology functionalities are, a taxonomy of the functionalities of CSCD technology was required. This was identified and selected from Mittleman et al. (2015), where the core competencies of collaboration technology were appropriately listed. The core competencies are generic descriptions for the functionalities which are available on technologies which support CSCD and this term is used synonymously with technology functionality. Mittleman et al. (2015) split these into three high-level categories: jointly authored pages (shared editors, group dynamic tools, conversation tools, polling tools), streaming media (desktop/application sharing, audio conferencing, video conferencing), and information access tools (shared file repositories, social tagging systems, search engines, syndication tools). The core competencies were extracted, and descriptions inserted into the CSCD evaluation matrix.

CSCD requirements represent the conditions necessary to support successful CSCD projects. This has been investigated sporadically in the past through case studies, but no unified or co-ordinated effort to systematically define using published research a complete list of requirements has been made. The requirements are unknown and need to be found to complete the matrix.

To compare technology to functionality, and then functionality against CSCD requirement statements, two matrices were created which were linked through the functionalities of the technology. This formed the layout of the CSCD evaluation matrix (Fig. 4), the technology matrix allows a comparison of technology with functionality, whilst the requirements matrix compares functionality with CSCD requirement statements.

An automated method to populate the matrix was conceived to determine which technologies offered which functionalities, and subsequently how the CSCD requirements were satisfied and are discussed in Sect. 6. This method utilises existing data from a CSCD project and through a discourse analysis analyses the text and sorts into categories linked to the cells within the CSCD matrix. This enables the automated profiling of technologies for comparison or as a representation of a team’s CSCD abilities.

Technology	Technology 1						
	Technology 2						
	Technology 3						
	Technology N						
	Technology Functionality						
		Core competency 1					
		Core competency 2					
		Core competency 3					
		Core competency N					
CSCD Requirements	Requirement 1					0	0
	Requirement 2					0	0
	Requirement 3					0	0
	Requirement N					0	0
		0	0	0	0		
		0	0	0	0		

Fig. 4 Structure of the CSCD evaluation matrix

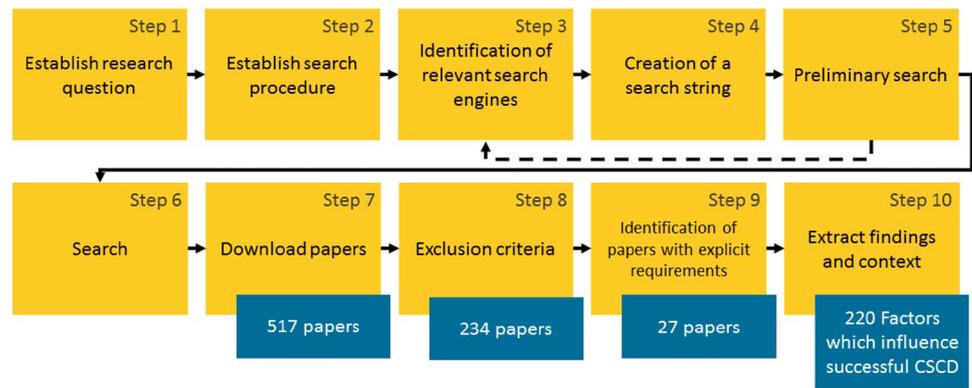
4 Identifying CSCD success factors

4.1 Methodology for identifying CSCD success factors

The procedure for identifying the factors which influence successful CSCD is described within this section and illustrated in Fig. 5. These factors were collected from the literature using a systematic literature mapping. The list reflects the state-of-the-art of factors which influence success in CSCD projects.

The research question was established (Step 1) to focus the mapping, followed by a search procedure (Step 2) to guide a systematic approach for paper search and mapping. An iterative approach of identifying relevant search engines (Step 3), creating the search string (Step 4), and conducting the search (Step 5) was conducted until the papers that were consecutively collected met the research question. The literature search was conducted (Step 6), and papers downloaded (Step 7). Exclusions were implemented to ensure only relevant papers were included in the systematic literature mapping (Step 8). Papers which featured statements of successful CSCD were identified through a review of the papers (Step 9), and the findings were extracted from the papers including the context of the paper (Step 10).

Fig. 5 CSCD success factor identification procedure



4.1.1 Establishing the research question

The research question was created to focus the study on answering one single question and to ensure the exclusion criteria were fair and consistent. The research question established for the systematic literature mapping was “What are the factors which contribute towards successful CSCD in engineering design teams?”

4.1.2 Search procedure

There are many types of search possible to collect and utilise the literature. The type of search used for this project was a systematic literature mapping (Grant and Booth 2009). The reason this was chosen was first to systematically collect literature based on search terms and second to allow the collected literature to be mapped which enables the future objective of categorisations of successful CSCD factors. In comparison, a typical systematic literature review is more suited to the examination of the recent and current literature.

Guidelines adapted from Moher et al. (2009) on *Preferred Reporting Items for Systematic reviews and Meta-Analyses* (PRISMA) were used to ensure a systematic collection and recording of literature. PRISMA was developed for conducting systematic reviews in the medical field but has the flexibility to ensure a systematic process for all potential fields including engineering design research (Hay et al. 2017). The PRISMA guidelines were adapted to remove the meta-analysis stage as this is not required for a systematic literature

mapping. All other sections including protocol search, eligibility, identification of information sources, search, data processing and exclusions, and synthesis of results were retained.

4.1.3 Identification of relevant search engines

The literature search was conducted using academic search engines in the fields of engineering, technology, computing and education as seen in Table 1. The search was conducted in June 2017 and spanned published journal articles, conference papers and books between 2010 and 2017. The reason to limit the systematic literature search to research published in 2010 and onwards is related to the motivation of this work as an observable change in student behaviour. Students demonstrated the ability to conduct global design projects using social media tools and a preference towards them. The example within this paper to demonstrate the method including the CSCD requirements and completed CSCD matrix reflect this decision as they are applied to the Global Design Project class. 2010 was chosen due to the popularity of social network sites, proliferation of Web 2.0 technologies and mobile device sales as detailed in Sect. 1.

Literature outside these dates was excluded to ensure factors which influence successful CSCD were based on the use of recent technology with the current functionality and to reduce the number of papers which theorise on how CSCD features and functionalities might be used.

Table 1 Search engines and their relevance to this study

Search engine	Database—topic
Proquest	All databases—engineering amongst others
Engineering village	Compendex—engineering
IEEE Xplore	All—computer-supported and technological engineering
Scopus	All—science and technology amongst others
EBSCO	All—education
ACM digital library	Full-text collection—computing

Google scholar was not used as it does not have the required Boolean search functionality. ISI Web of Knowledge was not included as it did not identify any papers not already identified.

4.1.4 Creation of search string

The search terms were created during a preliminary search as seen within Steps 3–5 of Fig. 5. Terms were collected and tested iteratively over approximately 1 month until relevant papers were consistently collected.

Towards the objective of identifying *factors which influence successful CSCD in engineering design teams*, the systematic literature mapping was split into three categories. These were to identify synonyms of *factors which influence, successful CSCD* and *engineering design teams* within categories. These categories became technology, field and domain as represented in Table 2. *Factors which influence* refers to a technology’s stimulus, then *technology* was established as a search category. *Successful CSCD* refers to the *field* of collaborative design and this was established as a search category. Finally, *engineering design teams* refers to the research *domain* of interest and this was included as a search category. Synonyms of these were tested using the academic search engines (Sect. 4.1.3) and added to the search string if papers were returned which met the objective.

Whilst the *field* and *domain* categories would identify all papers on the theories within the research area, the *technology* category was included to meet the motivation of the work in a change in students’ behaviour towards using social software.

A paper was considered relevant to the study if it could satisfy a search term in each of the three categories within the body of the text, title, keywords or abstract. The Boolean terms N/1 and W/1 were used to find words near other words in a specific order and words near other words irrespective of order. Searches for *engineering N/1 design* would return papers containing the phrase *engineering design* and *design engineering* or with a variable such as *design manufacture engineering*. Searches for *computer W/1 supported* would

only return searches within that order, e.g. *computer-supported* or *computer software supported*. Names of software were not included in the search terms as this study does not focus on specific software but focuses on the functionality of technologies which support CSCD. In addition, during a preliminary systematic literature mapping, these terms did not result with any additional relevant papers.

These categories defined the scope of the investigation, for example, a search for *collaborative design AND engineering design AND social software* would identify papers related to the goal of understanding how *social software* can support *engineering designers* to conduct *collaborative design activities*.

4.1.5 Exclusion criteria

Three stages of exclusion were performed in line with PRISMA guidelines:

1. Non-accessible, non-English papers, non-peer-reviewed and all duplicate papers were excluded for practical reasons. To achieve this on search engines themselves, English language and accessibility were given as search criteria on each academic search engine and manually reviewed for each paper. A duplicate search was conducted automatically by Mendeley and manually reviewed.
2. Data collected before 2010 were excluded. This was implemented to ensure factors which influence successful CSCD were based on modern technological use with current competencies. This ensured papers published post-2010 only utilised data from 2010 onwards. This was manually reviewed in each paper using Covidence (Cochrane 2017), a technology for systematically reviewing papers. These criteria removed many theories of CSCD systems which are now inaccurate or outdated compared to modern implementations of the software.
3. Any papers that did not explicitly report factors which influence successful CSCD on the use of CSCD technologies by engineering design teams were excluded. Explicit statements were reporting on the benefits of

Table 2 Search terms and categories

Technology	Field	Domain
Computer W/1 Supported	“Collaborative Design”	Engineering N/1 Design
Social W/1 Network	“Design Teamwork”	“Product Design”
Social W/1 Software	Cooperative Design	“Industrial Design”
Mobile W/1 Device	AND	AND
Mobile W/1 Phone		“Design Studies”
Smart W/1 Phone		
Tablet W/1 Computer		
OR	OR	OR

CSCD technology use, overcoming barriers to CSCD technology use, requirements of CSCD technology use, or opportunities towards better CSCD technology use. This was manually identified, checked and tagged in Covidence.

4.2 Results of identifying CSCD success factors

The systematic literature mapping revealed 517 papers which meet the search criteria and exclusion criteria 1 (Sect. 4.1.5). Exclusion criteria 2 and 3 aided the reduction of papers to meet the research question. Exclusion criterion 2 reduced the number of relevant papers from 517 to 234. Exclusion criterion 3 further reduced the number of papers from 234 to 27.

Within these 27 papers, the factors that influence successful CSCD by engineering design teams were identified. The relatively small number of papers reflects the lack of reporting of successes in this area despite the widespread use of CSCD technologies. Factors which influence successful CSCD were extracted from distinct statements on the use of CSCD technologies by engineering design teams in these papers during exclusion criteria 3. For example, in Gopsill et al. (2013) a table is presented with the requirements of technology to support teams using social media. This table was extracted and added with other findings to a table listing all factors from the systematic literature mapping which influence successful CSCD and is reported in Table 5 in “Appendix”.

The systematic literature mapping has revealed that no single paper included a complete list of CSCD factors and 220 factors exist in total. Many authors have chosen to focus on specific areas, picking and choosing outcomes, rather than revealing a complete list of the factors which influence successful CSCD. For example, Gericke et al. (2010) focussed on data storage and reuse factors, whereas Vyas et al. (2010b) focussed on supporting design activities such as creativity and innovation factors. Other authors such as Xie et al. (2010) presented a range of outcomes which could be categorised as a human to human factors and technological factors. This investigation has revealed a list of CSCD success factors from peer-reviewed and state-of-the-art published research. However, it is important to identify if further CSCD requirements exist which are not known or reported in the literature.

Once the factors that influence successful CSCD were identified, they contributed towards the technology evaluation and selection process. This was achieved by categorising the factors to look for similarities across published research and to create CSCD requirements which simplify the success factors into declarations of successful CSCD.

5 Establishing CSCD requirements

5.1 Methodology for establishing CSCD requirements

The list of 220 CSCD factors was verified using experts and those experienced in CSCD to assess the completeness of the list. Factors were then categorised and converted into requirement statements to simplify the analysis within the CSCD evaluation matrix. Finally, these requirement statements were validated with expert opinions. The process of transforming the CSCD factors into requirements for success is illustrated in Fig. 6.

Workshops were conducted to investigate the completeness of the list of factors which influence the success of CSCD (Step 1) and the factors were checked iteratively (Step 2). On completion, the 220 factors were categorised into five high-level categories (Step 3) and 19 sub-categories (Step 4) and sub-categories were redefined (Step 4). The 19 CSCD requirement statements were created to represent the factors within each of the 19 sub-categories (Step 5). A survey was created and distributed to discover if experts agreed with the 19 CSCD requirement statements (Step 6). Finally, the sub-categories were re-established based on the opinions of experts from survey feedback (Step 7).

5.1.1 Verifying the list of factors which influence CSCD success

The 220 factors were verified through a series of seven workshops to identify any factors which influence success

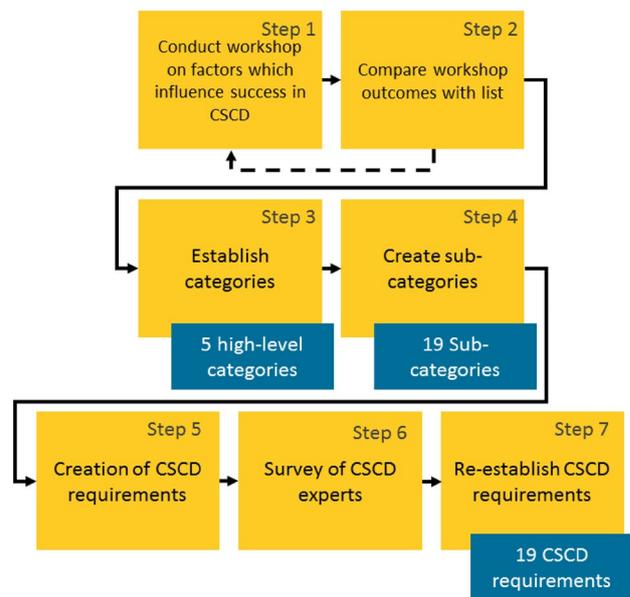


Fig. 6 Methodology for deriving CSCD requirements

in CSCD projects not captured through the systematic literature mapping.

Three workshops were held with representatives from academia and industry at the 18th International Conference on Engineering and Product Design Education (E&PDE 2016) with 12 participants, the 21st International Conference on Engineering Design (ICED'17) with 22 participants and at the 15th International Design Conference (Design 2018) with 21 participants. These workshops had a common theme on collaborative design and asked: “*What are the challenges in supporting successful collaborative design?*” Findings on the use of technology were extracted and compared with the 220 factors.

Four workshops were held with students experienced in CSCD during The Global Design Project (GDP) in 2016 with 18 participants, and in 2017 with 26 participants, and during the Global Studio class in 2016 with 26 participants and 2017 with 28 participants. The student workshops were all on the topic of technology use in global CSCD projects and asked students to reflect on successful collaborative practices. Example outcomes from the workshops are reported in. GDP students were all final year master students within the department of design manufacture and engineering management at the University of Strathclyde. Students of the Global Studio class were all undergraduates within the design school at Loughborough University. The workshops asked participants to share their knowledge on CSCD topics, discuss success in collaboration and current and future barriers to collaboration, and how these barriers might be overcome through research. The knowledge collected from these workshops was used to iteratively develop the coding scheme until 19 distinct sub-categories emerged. All outcomes from the workshops were collated and compared to the list of 220 factors to ensure no factors were missing from the list.

Following the workshops and comparing the outcomes with the list of 220 factors, there were no additional factors which could be added to the list to make it more complete. This demonstrated the success of the systematic literature mapping method in collecting the factors.

One major outcome from the workshops was an awareness that experts wished to discuss the differences and definition of co-ordination, co-operation and collaboration and that many did not have a definition of each. Many academics argued that co-ordination is inherent to co-operation and collaboration and so perhaps it is a sub-category of both. Students and academics argued that co-operation and collaboration are not distinct enough and so they should be contained under the same category or a joint category.

It has been well discussed in the literature that collaboration is more complex than co-operation in that it involves shared risk of failure and opportunities for shared success (Adams 2015). Collaboration is mutually beneficial and

requires a common goal somewhere in the process towards a shared outcome, whereas co-operation only requires the sharing of knowledge and resources towards a shared activity (Kvan 2000). Success is not defined by the outcomes of the project, but by the relationship and how well it was managed (Brewer 2015). Perhaps this insight from the workshops explains why there has not been a list of factors which influence the success of CSCD presented before and why the creation of a CSCD evaluation matrix has not previously been possible.

5.1.2 Creating CSCD requirements through categorisation

Each of the 220 factors which influence successful CSCD was assigned a category, and then a sub-category was derived. The categories were based on those reported by Mattessich and Monsey (1992): communication channels, collaborative environment, process and structure, team member characteristics, and resource management.

Sub-categories were iteratively created using a coding scheme based on benefits of CSCD technology use, overcoming barriers to CSCD technology use, requirements of CSCD technology use, or opportunities towards better CSCD technology use. NVivo 11 was used to create this coding scheme and code each factor.

The 5 categories and 19 sub-categories which emerged from the categorisation activity are described as follows:

Communication channels refer to the many ways in which a team can communicate and how they can be supported through technology use. The three areas identified in the literature which influence engineering design teamwork are

- artefacts, the use of digital representations of physical objects and digital work,
- feedback, on previous work to influence future development, and
- social, including networking to reduce interpersonal barriers.

The *collaborative environment* refers to how collaboration is supported within an organisation, team or group. The two areas identified in the literature which influence engineering design teamwork are

- access to information, how and where the knowledge and data can be accessed for transparency and ease of use, and
- corporate structure, for clear hierarchy and procedures.

Process and structure are put in place to ensure systematic practices and minimise loss of data. The three areas identified in the literature which influence engineering design teamwork are

- decision-making, the ability to share opinions and make informed decisions,
- knowledge capture, techniques and technologies to create comprehensive data stores, and
- productivity, to support readiness with the right skills at the right time.

The *team member characteristics* of a design team have influence over ensuring the right team members are involved with the project. The five areas identified in the literature which influence engineering design teamwork are

- commonality, consideration of differences in language, culture, social and time zones,
- motivation, of critical team members to ensure sustained interest in a project,
- shared understanding, of the problems, concepts and techniques,
- team co-operation, awareness of work and contribution towards co-construction activities, and
- trust, of the quality and completeness of the work of others.

Resource management refers to knowledge and skill assignments towards a common goal. The five areas identified in the literature which influence engineering design teamwork are

- competency, ensuring the best team member completes the appropriate work,
- co-ordination, of work, and team members time efficiently,
- innovation, promoting techniques for creativity and exploration,
- knowledge management, of all stakeholders and awareness of the whole life of the product,
- managing the sharing of data refers to how information can be sent to others, where it is hosted and the mechanism to send it, and
- communication refers to the different communication methods available through technology. Whether a conversation is synchronous or asynchronous communication to suit the message context and other factors such as multi-threaded conversations and multi-channel communication.

The categorised factors were subsequently summarised into statements which represent CSCD requirements. A total of 19 statements were created, one for each sub-category. An issue arose during the creation of the statements that some factors inferred the same outcomes such as *avoid miscommunication* (Cho and Cho 2014) and *avoid uncertain misunderstandings* (Luck 2013). In these instances, they

were included in the same requirements as they related to the same context. Another example is *discuss problems with a common context* (Hirlehei and Hunger 2011) and *Communicate context* (Wangsa et al. 2011). In this example, the requirement became R2. Encourage a *shared understanding* by defining and framing conversations within a *common context* which makes it easy to understand information, clarify meaning and *reduce miscommunications*. The full list of CSCD requirements was created as follows.

CSCD technology:

- R1. Supports complexity managing the *sharing of data* through integration with data storage systems, reduced file compatibility issues and synchronous live document working with automated tracking and versioning to enable co-creation of documents.
- R2. Encourages a *shared understanding* by defining and framing conversations within a common context which makes it easy to understand information, clarify meaning and reduce miscommunications.
- R3. Encourages *co-operation* by enabling increased awareness and connectivity to encourage equal participation, support design activities by anticipating needs and opportunities for peer learning.
- R4. Supports *knowledge management* through the organisation of information and communication, the ability to easily search and retrieve knowledge, and autonomy in the distribution of knowledge.
- R5. Allows for *feedback from stakeholders* to support reflection on past communication and concepts dependent on the context, knowledge, experience and competency of the stakeholders.
- R6. Allows for *social communication* which encourages team synergy, knowledge sharing and serendipitous communication by supporting networking and building interpersonal skills.
- R7. Supports *knowledge capture* through the recording of information, decisions and artefacts to document the design process and contribute to decision-making and reuse of knowledge.
- R8. Supports *communication* through synchronous and asynchronous multi-threaded and multi-channel software for prompt discussion in a way which supports the context of the message.
- R9. Enables team members to *overcome boundaries of access* to easily view and edit files when required.
- R10. Encourages the *building of trust* to support conflict resolution through increased accuracy, clarity and transparency of communication between team members.
- R11. Supports *co-ordination* through a shared space for organisation of work and communication, easy mecha-

- nisms for scheduling meetings and to support the even distribution of work.
- R12. Allows for *artefact-mediated communication* which are high-quality digital representations of physical work and ideas.
 - R13. *Reduces the barriers* of physical proximity, language and time zones, and enable a greater awareness of culture and the global community.
 - R14. Supports *decision-making* through concept ranking functionality, increased opportunities to develop negotiation skills and express opinions.
 - R15. Allows for *greater productivity* through fast objective focused communication, organisation of work and a greater quantity of output to promote collaboration readiness, reflection and reduced rework time.
 - R16. Encourages *innovative thinking* through agile systems to support exploration, creativity and quality of outputs.
 - R17. Encourages the development of *greater competency* through increased accessibility of team and non-team skills and experience, reduction of unnecessary information and supporting the completeness of messages.
 - R18. Encourages *motivation* through mechanisms of social incentivisation, positive reinforcement, gamification or

encouraging moral decisions to ensure long-sustained interest in the project and if implemented correctly can help avoid conflict and support conflict resolution.

- R19. Integrates with *company structure* through the implementation of procedures, policies and agreements to ensure clear roles and responsibilities, reducing the sense of lack of control and optimising team negotiation cycles.

5.1.3 Validating CSCD requirements

To verify the CSCD requirements, a survey was sent to 94 experts in CSCD. These experts were identified as notable authors through the systematic literature mapping. 24 experts responded to the request by completing the survey. The survey asked if the expert agreed with each of the CSCD requirements (agree, disagree in full, or disagree in part) and in addition, how important the requirement was towards success in CSCD (high, medium or low importance) so that they could be ranked from most to least important. Figure 7 is an example of the first question asked and all others follow the same format.

Fig. 7 Question 1 of 19 in the survey of CSCD experts

1/19 CSCD technology allows for **artefact-mediated communication** which are high-quality digital representations of physical work and ideas. These elaborate on text-based communication in the design space.

Do you agree with this statement?

Agree
 Disagree in full
 Disagree in part

If you disagree in full or in part, please indicate why.

How important is this in supporting collaborative engineering design team work?

Low Importance Moderate Importance High Importance

<<
>>

Table 3 Expert assessment of the developed CSCD requirements

Statement category	Agree	Agree in part	Disagree
Sharing of data	16	7	1
Shared understanding	18	5	1
Co-operation	17	6	1
Knowledge management	20	3	1
Feedback from stakeholders	16	7	1
Social communication	19	5	0
Knowledge capture	20	3	1
Communication	19	5	0
Overcome boundaries of access	13	9	2
Building of trust	13	8	3
Co-ordination	22	2	0
Artefact mediated	14	10	1
Reduce the barriers (commonality)	12	11	1
Decision-making	17	6	1
Greater productivity	12	10	2
Innovative thinking	12	10	2
Greater competency	12	9	3
Motivation	11	12	1
Company structure	11	13	0

Table 4 Expert opinion on importance of CSCD statement

Statement category	Low	Med	High	Rank
Sharing of data	0	5	19	67
Shared understanding	0	7	17	65
Co-operation	1	5	18	65
Knowledge management	0	7	17	65
Feedback from stakeholders	2	4	18	64
Social communication	1	6	17	64
Knowledge capture	0	8	16	64
Communication	0	9	15	63
Overcome boundaries of access	2	6	16	62
Building of trust	0	10	14	62
Co-ordination	0	10	14	62
Artefact mediated	3	6	16	61
Reduce the barriers (commonality)	0	11	13	61
Decision-making	0	11	13	61
Greater productivity	0	11	13	61
Innovative thinking	3	6	15	60
Greater competency	3	9	12	57
Motivation	4	10	10	54
Company structure	1	16	7	54

The survey was e-mailed to experts with a link and instructions on how to complete the survey. Tables 3 and 4 display the results of the questionnaire.

Most experts agreed with the CSCD requirements either in full or in part as displayed in Table 3. Where disagreement in full or in part was selected, the comments were used to understand why there was disagreement and how the statement might be changed to better represent the views of the experts. One main change suggested by the experts was that the requirements should not focus on the positive outcomes. Instead, they should say that CSCD *could* have these outcomes. The technology category was also split representing the management of shared data, and communication.

Experts ranked the CSCD requirements in order of importance as displayed in Table 4. One prominent comment was that although some lower ranked statement categories are very important for collaboration, they are perhaps less important for computer-supported collaboration. This could be because barriers are overcome using technology or more fully supported making the topic of the statement less important.

6 Automatic population of the CSCD evaluation matrix

The 19 CSCD requirements were included in the CSCD evaluation matrix with the 11 technology functionalities as illustrated in Fig. 8. The CSCD evaluation matrix supports an assessment of how well an individual technology satisfies successful CSCD, how multiple technologies compare against each other, and how a combination of technologies can satisfy an organisation's CSCD requirements by profiling.

A binary code is used to populate the matrix: if a technology functionality satisfies a CSCD requirement an entry is marked 1, or if they are not related, marked 0. The rows and columns are summated to establish the suitability of the functionality towards the CSCD requirements. The summation of the 1s in the rows and columns provides an indication of requirement or functionality fulfilment and is presented in the green summary box. A summation of the 0s in the red summary box represents that lack of requirement or functionality fulfilment for any given technology. A larger score signifies that the functionality has satisfied the CSCD requirements to a greater extent and that little changes are required to fully satisfy the factors for successful CSCD. Where a low score exists, there are opportunities for alternative or a combination of technologies or techniques to satisfy the CSCD requirements.

Two technologies can be evaluated by comparing the cells (the profile) or the total scores for requirement or functionality fulfilment. A team's technology (summary of all technologies used) can be profiled by including multiple technologies.

Fig. 8 CSCD evaluation matrix

Technology	Technology 1																	
	Technology 2																	
Technology 3																		
Technology N																		
Technology Functionality		Conversation Tools	Shared Editors	Group Dynamics Tools	Polling Tools	Desktop/Application Sharing	Audio Conferencing	Video Conferencing	Shared File Repositories	Social Tagging Systems	Search Engines	Syndication Tools						
CSCD Requirements	A shared understanding												0	11				
	Co-operation												0	11				
	Co-ordination												0	11				
	Building of trust												0	11				
	Integration with company structure												0	11				
	Decision making												1	10				
	Knowledge capture												0	11				
	Knowledge management												0	11				
	Development of greater competency												0	11				
	Motivation												0	11				
	Greater productivity												0	11				
	Reduce the barriers of ... (Commonality)												0	11				
	Feedback mechanisms from stakeholders												0	11				
	Overcome boundaries of access												0	11				
	Complexity managing the sharing of data												0	11				
	Social communication												0	11				
	Artefact-mediated communication												0	11				
Communication												0	11					
Innovative thinking												0	11					
		0	0	0	1	0	0	0	0	0	0	0	19	19				
		19	19	19	18	19	19	19	19	19	19	19	19	19				

The CSCD evaluation matrix contains up to 209 relationships when featuring only one technology, which requires significant comprehension and background knowledge to populate. To complete this manually would be a considerable task completed by multiple people experienced in the technology to reach consensus. An automated population method was developed using a discourse analysis method to take reported information on technology use and filter it to populate the CSCD evaluation matrix. This offers a systematic way of populating the CSCD evaluation matrix. Figure 8 illustrates the population of the CSCD evaluation matrix where Technology 1 contains polling tool functionality which satisfies the CSCD requirement of decision-making (Fig. 9).

6.1 Systematic population of the CSCD evaluation matrix

The input data used to populate the matrix included student reports, and diaries on the use of technology to meet CSCD requirements and was collected from a GDP class over a 3-year period with 34 students in 2015, 45 in 2016, and 25 in 2017. The sample size for this study is 104. The reports were created by the students reflecting on the successes and failures of their projects. A diary was kept by the author on the action’s teams were taking and quotes from students on their technology use.

An automated text analysis system was created to populate the matrix using this data. The text analyses had to interpret the words of the given text and code it appropriately into

Fig. 9 Methodology for the population of CSCD matrix



categories. These categories related to the technology, the functionality of the technology, or the CSCD requirement. Semantic dictionaries were created for each category and sub-category and allow for the categorisation of sentences based on the words which build them. All possible synonyms were collected from student reports and included in the dictionaries.

When checking the data, the word or words which contributed to the coding of the sentences were extracted. These extracted words were used to create semantic dictionaries for each category. 19 dictionaries were created for CSCD requirements, 11 for technology functionalities, and 7 for technologies used during the GDP. These technologies were social network site, messenger, video conferencing, cloud document storage, project management groupware, e-mail and collaborative document editor. The completed dictionaries are contained within Table 7 in “Appendix”. A sentence discussing the benefits of Facebook® in supporting communication through conversation would be categorised in technology as “SNS”; in functionality as “conversation tool”; and in CSCD requirement as “communication”.

289 data points were collected. Data were split for coding (35%) and for testing (65%). Due to the controlled nature of the project and the limited nomenclature of the data, 35% was a sufficient coding sample. Whilst conducting a verification of the final 65% of the data, only two words were found across the 36 categories, in addition to approximately 486 found from the 35% coding data. Data coding was completed by three experienced CSCD practitioners to create semantic dictionaries. Three academics was the minimum required to achieve a representative consensus on decisions where disagreements may occur, i.e. if a disagreement occurred then one other person would be able to resolve it. In addition, three data points were required to identify that a connection is true and confidence is on trend. Academics took sentences involving the use of technology to support collaboration and identified three parts of these sentences: the *technology used*, the *functionality available* and the *CSCD requirement satisfied*. These three parts of the sentence correspond with the elements of data required to populate the CSCD evaluation matrix i.e. technology, technology functionality and CSCD requirements. Each academic created their own semantic dictionary based on the categories and the results from the sample data were compared between researcher, known as intercoder reliability.

For example, one GDP team member stated “Video conferencing facilitated design activities to send and receive documents”. This was coded as *Videoconferencing* in technology, *group dynamics tools* in technology functionality, and *complexity managing the sharing of data* in CSCD requirements. The evaluation was subjective and clarified the need for an intercoder method.

To satisfy the intercoder method used, disagreements were resolved by the third member of the coding team. In instances of a difference of opinion by all three, a discussion of the factors was held. The coding team agreed on 87% of the checked data in the first instance. Through discussion, the remaining 13% was agreed upon. Disagreements were due to differences in the interpretation of the data. For example, the use of slack® for multi-channel communication enabling sub-team communication was reported. This was coded by one academic as a *conversation tool* and by another as a *social tagging system*. Both can be applied as slack® is being used for conversations, but communications are being tagged to enable sub-team syndication. Through discussion, the decision was made to code this as tagging which enables multi-channel communication and was the intent of the sentence in its original context.

Following the creation of the semantic dictionaries, the dictionaries were included in an automated text processing method using the RapidMiner Studio software. Text processing enabled the sentences reserved for testing from student reports to be automatically filtered into a category based on the semantic dictionaries. Sentences which were filtered were awarded a score of + 0.1 based on the number of similar words also in the category. A value of 0.1 was selected to make significance calculations simple and follow general practice. The score acts as an automatically generated confidence indicator if the sentence could be categorised multiple ways and the top score is automatically progressed to the data output.

For example, the word *messenger* could refer to Facebook® Messenger coded as a social network site, or WhatsApp® referring to messenger applications or the inbuilt messenger technology in video conference technologies. In most cases, the word will refer to messenger technology and not social network sites or video conference. This can be confirmed by looking at other words in the sentence such as app, chat, instant and voice, amounts others included in the semantic dictionary. Where multiple words are detected, the confidence score increases.

Figure 10 illustrates the process of parsing a data set from the perspective of a word within the RapidMiner Studio system. A piece of data is a sentence containing many words. Each word of that sentence moves through the process individually and is joined with its sentence at the end. The score offers confidence of a word towards a category and in turn the sentence towards a category. If a category is matched, it is tagged with that category and its score incremented by 0.1 in that category. The scores are added at the end and the highest score is kept, removing all other possible categories. The output is the top-scoring category for technology, technology functionality and CSCD requirement for each sentence or data set.

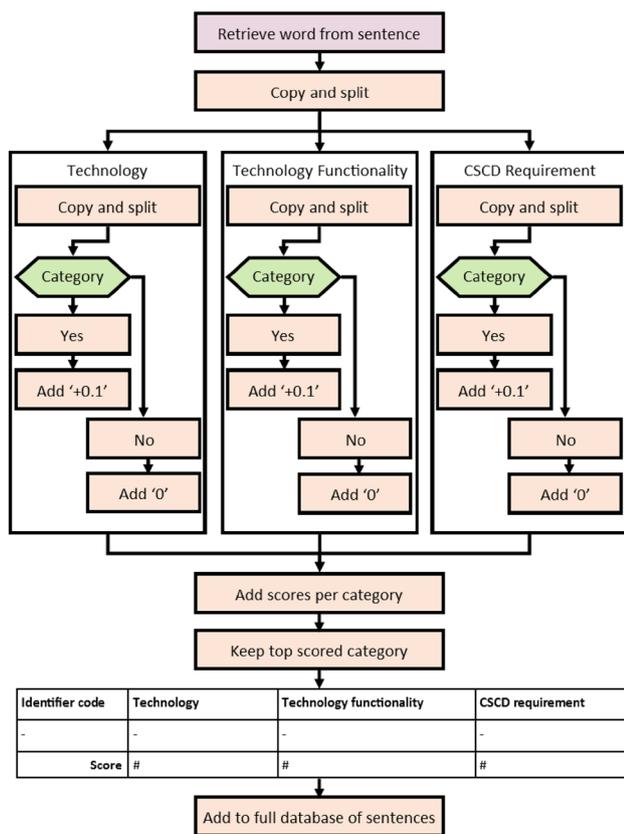


Fig. 10 Text processing steps as a flowchart

The output from RapidMiner Studio is a spreadsheet of all data points, their categories and their confidence scores. This spreadsheet is used to populate the matrix which was automated in excel. Where the data point has two or more categories it can populate a cell in the matrix. For example, the categories of communication and communication tools are linked and the data show examples of this, then the cell connecting both categories would be filled.

7 Results

The use of the CSCD evaluation matrix populated by the GDP data has revealed insights into the class that could help with the development of this class and demonstrates its value. The insights are discussed based on the populated CSCD evaluation matrix presented in Fig. 11.

The CSCD evaluation matrix was automatically populated with the output from RapidMiner Studio illustrating the relationships between the success factors and technology functionality. The nodes within the CSCD evaluation matrix provide a numerical indication of the confidence of the relationship between the two aspects. This illustrates the extent to which the functionality of the technology used within the

GDP addressed the CSCD requirements. The CSCD evaluation matrix provides insight into both project managers and computer scientists regarding the barriers in the collaborative process. The CSCD evaluation matrix also supports the identification of whether new or additional technology is required to fill gaps in the CSCD requirements. Within a newly formed team, the CSCD evaluation matrix could be used to select and build a toolkit of integrated technology that meets the CSCD requirements of the team, the project, and the processes.

In Fig. 11, it is visually demonstrated that there are gaps in the requirements of building trust, motivating team members, greater productivity, reducing barriers and feedback mechanisms. A team would then investigate why these requirements are not being fulfilled with additional technologies which encourage these practices.

Technology that supported conversation contributed towards almost all requirements relating to the success of the teams. This was expected as without conversation it would be difficult to perform any collaborative task. All technologies that were used within the GDP had some form of conversation tool. This is the only column which is fully populated which demonstrates the importance of conversation in all aspects of CSCD.

Mamo et al. (2015) posited that four areas of technology functionality would be most populated: conversation tools, video conferencing, group dynamic tools and shared file repositories. It was, therefore, expected that these functionalities would satisfy the requirements for success in CSCD fully. The CSCD evaluation matrix has revealed this to be true for conversation and the remaining three are more populated. The reason for this is due to the factors which influence CSCD which the technologies satisfy.

Group dynamic tools supported many requirements for successful CSCD which were unexpected. For example, company structure was not expected to be related to any requirement, but in reviewing the populated matrix, company structure relates to enabling all members of a team, no matter their position, the ability to contribute to discussion and decisions. Competency was not expected to be a contributor to group dynamic tools either as competency reflects a human’s ability to perform a task and not a computer’s ability. But in reviewing the populated matrix, competency relates to the functionalities that technologies offer enabling tasks to be completed in a simplified way. This relates to the availability of team members for a task and their suitability. Technology can support this by offering co-ordination and profiling functionalities.

Social communication was not expected to arise in group dynamic tools as the functionality typically refers to project work and professional communication. However, within design engineering, innovative thinking outcomes can arise from social interaction contributing to new ideas.

Fig. 11 Success in CSCD matrix with data populated from GDP class

Technologies	Technology Functionality												
	Conversation Tools	Shared Editors	Group Dynamics Tools	Polling Tools	Desktop/Application Sharing	Audio Conferencing	Video Conferencing	Shared File Repositories	Social Tagging Systems	Search Engines	Syndication Tools		
Social Network site													
Messenger													
Video Conferencing													
Cloud Document Storage													
Project Management Groupware													
Email													
Collaborative Document Editor													
CSCD Requirements	Complexity managing the sharing of data											5	6
	A shared understanding											4	7
	Co-operation											7	4
	Knowledge management											7	4
	Feedback mechanisms from stakeholders											1	10
	Social communication											2	9
	Knowledge capture											3	8
	Communication											2	9
	Overcome boundaries of access											3	8
	Building of trust											2	9
	Co-ordination											7	4
	Artefact-mediated communication											4	7
	Reduce the barriers of ... (Commonality)											3	8
	Decision making											5	6
	Greater productivity											2	9
	Innovative thinking											2	9
	Development of greater competency											7	4
Motivation											1	10	
Integration with company structure											4	7	
	18	3	11	3	4	0	12	9	2	1	3		
	0	15	7	15	14	18	6	9	16	17	15		

There were no data relating to knowledge capture with the functionality of video conferencing. This could be because the knowledge capture of video conferencing technologies is difficult to implement. Typically, video conferences can be recorded but this does not enable easy summaries to work from and if summaries are created in a text form this requires manual work. Transcriptions could be one alternative with text search, but none of the technologies used within the GDP offered this ability. This could be an opportunity for improving success in CSCD for design engineering if the technology used enables simple capture of work in a usable format. This demonstrates the abilities of the CSCD evaluation matrix to display why factors for success in CSCD were not met and clearly displays how they could be met in future technology development.

Syndication tools such as notification systems are often linked with building trust between team members (Carroll et al. 2003; O’Riordan 2014). Within the GDP data, this was not observed. The CSCD evaluation matrix indicates that this functionality is more linked with management in being able to co-ordinate people.

It is important to note that this method and its results cannot be generalised to all engineering projects using this

data. The data used is from an educational environment and deals with distributed engineering design. Many of the technologies considered have search functionality; however, the use of search was not reported in the GDP data. In addition, audio conferencing was not utilised within the GDP in favour of the use of video conferencing, however, the use of audio conferencing may be preferable in other projects. What can be inferred from this is a trend within the GDP that there is an expectation for functionalities such as search and subsequent a lack of reporting on its use. The results can be considered complete in terms of the use of technology within the GDP 2015–2017. And for examples outside this context further data collection would be possible.

8 Discussion

This method fills a gap within the GDP and the wider engineering design community where there is a lack of knowledge on CSCD tools to help teams select suitable technologies. To fill this gap in knowledge, the steps are taken for creating a matrix and identifying factors which influence success in CSCD, and an automated evaluation method has

demonstrated successful support in the creation of the CSCD evaluation matrix and the method used.

The contribution of the literature categorisation and the act of forming the CSCD requirements is a key contribution and component in the reported approach as this has never been achieved before in a systematic way using published literature. One respondent to the survey on CSCD requirement statements described the CSCD requirements as “CSCD dogma which once formalised through verification and publication will have a great impact on teaching”. Students can benefit from education in both the core knowledge in their field, but also the skills to be able to collaborate with others. The CSCD requirements form the basis for a framework representing the knowledge to build new techniques, tools and approaches. For engineering design as a collaborative process, the knowledge of CSCD requirements is important to learn and build skills.

In the creation of the CSCD requirements, there are implications for the development of new technologies to ensure the requirements are fulfilled, but this would require new partnerships between developers of these technologies and the knowledge holders in industry and academia. These types of relationships are prevalent in the development of CAD systems but less so for collaborative communication-based technologies.

If a major technology change were to happen to offer new functionality or new collaboration procedures, the CSCD evaluation matrix can be updated. The information within this paper on the development of the method offers the ability to recreate the knowledge required or adapt for alternative purposes. This method is robust in that it can be repeated, but it should not be generalised. If the method is to be applied to other situations such as CSCD success in the industry, industrial data must be used. If the method is to consider co-operation in greater detail for example, then the requirements must be changed to consider co-operation success factors. One way to ensure the continued development could be in the utilisation of a larger database of data to track trends and update over time rather than focusing on a single university class and these partnerships could be created or further developed across institutions.

Due to lack of training and disinterest by workers, attempts to integrate novel technology often fail (Garcia-Perez and Ayres 2010). The adoption of this technology is only visible between team member to team member communication and rarely in business to business communication with the exception of e-mail as an industry standard. For a paradigm shift in the industry on the magnitude of previous technology changes, such as the adoption of e-mail, would require rapid large-scale adoption (Ellison et al. 2007) which has not yet happened. Although, along with current trends in social communication, the use of CSCD can be expected

to increase in the future as students familiar with these technologies make their way to the workforce.

The next generation of workers choose to use social media platforms and social network sites for personal communication, and usage reveals they are active and engaged on these platforms. If this affinity can transfer to technologies used in industry, then they might also share in higher levels of engagement (Hank 2012). The CSCD evaluation matrix gives future workers the ability to understand and evaluate their technology based on the requirements of the project.

Considering future workers, it is not unreasonable for an employer to assume that newer technologies such as messengers and social network sites might become a basic technological skill along with e-mail and word processors. And if future workers are not able to use these in a professional setting, they may not have the opportunity to build these skills in the appropriate ways.

This study used student co-operation in its development and student data to evaluate. Considering industry applications this approach is yet to be validated. However, other studies of this nature had the same approach such as Gopsill (2014) who utilised student projects to develop an e-mail analysis technique before applying it to industrial applications. The benefits of this approach are the validation of the method in a familiar environment before industry partners get involved. The disadvantage is that major changes may be required to the text analysis, but with time this can easily be updated.

Whilst the systematic literature review was completed in a manner that aimed to capture all relevant published work, there is still a need to regularly check and expand the potential of the CSCD evaluation matrix. This study cannot infer on collocated or blended environments where students are collaborating whilst using technology. This is because the CSCD requirements may not be fully complete for these situations. If a systematic literature mapping of engineering teamwork was completed it might offer a wider impact on generalised engineering work and CSCD requirements.

In the future, a comparison of technology use over the years in terms of learning implications is possible using the CSCD evaluation matrix. This would be beneficial in mapping the changes in learning practice and predicting trends. Some expected outcomes were not seen within the GDP data such as e-mail use and audio-conferencing technologies. This is because the students of the GDP did not use e-mail after the first week and only utilised video conferencing in place of audio conferencing. However, in industrial contexts, it is likely that these types of technology would be more prominent. This relates to the change in student behaviour and a change in the skills of students. If students are restricted to older technologies with fewer functionalities, then perhaps their skills are not being fully utilised.

Partnerships with other similar classes would offer the data required to build a more complete picture of successful CSCD in student engineering design teams.

The creation of this evaluation method has never been attempted before. It was built in a systematic way but also offers a systematic method of evaluation. The knowledge utilised comes from peer-reviewed literature comparing a range of different experiences to make a large list of factors which influence success. The list of CSCD requirements created not only considers technological factors but also human interaction factors and social factors to give a more complete picture of CSCD evaluation. The method of working with the matrix has been developed using existing knowledge of HoQ matrix formulation for a simplified understanding, but also the automated population of cells means no prior expert knowledge is required to utilise the matrix. This also benefits new users such as students who are being introduced to evaluation methods. All these together or individually offer new avenues for further research which have not been seen before.

The next steps for this project are to develop an educational programme on the impact of technology selection based on CSCD requirements. The CSCD evaluation matrix will play an important part in this class and will act as a framework for student's decision-making. Feedback from the class will be used to evaluate how successful the CSCD evaluation matrix is as an evaluation tool and the data from this class will be used to evaluate how complete the CSCD evaluation matrix is for this purpose. This class is envisioned for further education level for university students and as a CPD course for industry. It would be worthy in the future to be able to compare the outcomes of the CSCD evaluation matrix with other similar classes and within an industrial setting.

9 Conclusion

This paper describes the development of a method to evaluate and select suitable technologies based on CSCD requirements and functionality which influence success in CSCD. The main contribution of this paper is the description, verification and validation of a method to evaluate technologies through a CSCD evaluation matrix. The matrix offers the ability to compare technologies and their functionalities against CSCD requirements. In addition to the main outcome of this research; factors which contribute towards successful CSCD, and the impact of technology used within a global design class were discovered. The impact of this method and the data collected is the potential to change the way students

and academics think about the technology they use and how it impacts the success of their CSCD projects. These outcomes suggest how the method can be used in an industrial environment to improve the process of selecting technology.

To create the method, a four-phase process was devised to create the CSCD matrix for the evaluation of technology. This involved a systematic literature mapping to identify the 220 factors which influence success in CSCD verified through workshops to ensure a robust list, categorisation of the 19 CSCD requirements validated through a survey of experts, and creation of a discourse analysis method developed in an intercoder structure to process design reports and automatically populate the CSCD evaluation matrix.

The development of the CSCD evaluation matrix introduces opportunities for students and educators towards the development of better learning experiences. With the development of classes on the evaluation method, students can be educated on the impact of technology selection with collaborative projects and with this knowledge and the CSCD matrix can evaluate technologies to pick the most suitable. This does not exclude the potential for education within industry which could be developed through future studies. If the gaps in the CSCD requirements are better known, then they can be filled and CSCD can be better supported. The details within this paper explain how the CSCD matrix can be updated or augmented for new purposes. The method developed is not generalisable but is a first step in building a better understanding of technology evaluation in CSCD. In addition, this paper discusses the impact of the findings as a framework to direct future research on the topic of CSCD and the CSCD evaluation matrix impact in its ability to track and predict trends through further research and partnerships.

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Appendix

See Tables 5, 6 and 7.

Table 5 The 220 factors which influence successful CSCD listed by author alphabetically

References	Factors which influence successful CSCD
Antunes et al. (2011)	Encourage synergy of team; be provided with positive reinforcement to encourage information flow; support contextualisation over distance; support contextualisation with relationships; share a global view in the aid of a shared understanding; share a global view to reduce information overload; reduce difficulties in co-ordination due to technical difficulties
Benolken et al. (2010)	Allow for shared visualisation of work; support the organisation of meetings; support audio and video conferencing; allow for messenger-style communication
Bittner and Leimeister (2013)	Convey individual personality; encourage team familiarity; organisational culture; authority; have an understanding for the impact of physical proximity; be incentivised in their work; be in good morale; performance (quantity of output); assist in the reduction of iterative loops; assist in the reduction of rework; support group member satisfaction; have a diverse range of skills; have individual skills; co-ordination; support innovation; performance (quality of output); support communication
Borsato et al. (2015)	Allow for serendipitous communication; encourage networking; support a pervasive experience; make team members aware of work; co-operate with each other; co-ordination; support collaboration
Cho and Cho (2014)	Enhance interpersonal skills; accept a sense of lack of control; avoid miscommunication; ensure equal participation by all; allow for greater opportunities to express opinions; learning negotiation skills; more thorough outputs; ensure efficiency in communication; productivity; enhance communication skills; ensure more capable employee skills; more creative outputs
French et al. (2016)	Be encouraged to have a long-sustained interest in the project; be made awareness of other team member's actions; allow for a constant connection; more opportunities for peer learning and training; greater retention of learning; encourage greater team trust when required; allow for improved decision-making; greater likelihood of catching mistakes; faster design through collaboration; reduced rework time; reduce complexities whilst sharing data
Fruchter et al. (2010)	Allow for feedback on ideas; support resolution of discussions; present information in an easy to understand way; allow for clarification of a statement; allow for explanation of a statement; allow for negotiation; allow for the asking of closed questions; assist in negating scheduling problems; support exploration; support problem solving; reduce technical problems
Gericke et al. (2010)	Allow for the capture of meeting information; support the reuse of data; integrate with data storage systems
Gopsill et al. (2014)	Allow response with high-quality representation examples; provide an electronic or physical reference for communication; allow team members to add comment to past communication; allow team members to define a response to communication; seek input from parties outside the design team; allow the ability to define the purpose of a conversation; allow for the capture of high-quality representation of artefacts; allow for the recording of modifications to the artefact; allow for text-based description; record and capture the focus of the conversation; limit the size of the response; include the ability to conclude a conversation thread; allow for the organisation of communication by grouping; allow for the response to be co-ordinated to the correct purpose; allow for the categorisation of communication; allow for referencing previous communication; allow for organisation of communications; allow for easy linking between communications; allow for pushing of information; support the answering of multiple threads through a single response; support multi-threading conversations
Hansen and Dalsgaard (2012)	Allow for the documenting of decisions; allow for the reflection on work and decisions; support an aligning effort of their team members; support the rapid transformation of ideas; support the proposition of design change; support design change
Herrmann et al. (2013)	Allow for the addition of artefacts to text-based ideation; allow access to edit documents; encourage team members through gamification; be made aware and notified; support rework after the fact; support easy switching between ideation topics; support synchronous working with live documents
Hirlehei and Hunger (2011)	Difference in time zone; have a cultural awareness for distributed team members; discuss problems with a common context; communicate on a common ground; collaboration readiness; technology readiness; coupling of work; contribute to the team experience
Horváth (2012)	Employ smart support of process control systems; allow for the mining of information; support knowledge elicitation methods; support intelligent asset management; integrate 3rd party program support, e.g. Cad; have an adaptive system interface; allow for model and document sharing; support multi-channel working; support co-creation in smart ways; communication channels; support virtual presence in smart ways
Iacob (2011)	Display summaries of work completed; have access to view and edit files freely; have freedom to collaborate with whoever is required; give an awareness of other team members work; ranking functionality; allow for annotations on existing artefacts; consistent interface; support device flexibility; allow for everyone to take part at once; support communication through an integrated chat client; support tracking work/versioning of documents; provide a private space to work; employ a mechanism to handle the resources; integrated tagging functionality
Jinghua et al. (2014)	Ensure work is completed by the most compliment member; support the even distribution of work

Table 5 (continued)

References	Factors which influence successful CSCD
Liu et al. (2014)	Articulate their completed work; give an awareness of team members activities; select appropriate technology or tools
Luck (2013)	Avoid ambiguous misunderstandings; avoid uncertain misunderstandings
Pavkovic et al. (2013)	Allow access to information; delegate clear roles and responsibilities; anticipate the needs of other team members; encourage regular project reviews; encourage mutual trust; give a visual overview of tasks; support the autonomy of tasks; support collaboration; reduce technical conflict
Rapanta et al. (2013)	Encourage knowledge sharing; support human to human connections; implement consistent corporate policies; support small team negotiation cycles; have appropriate training with groupware systems; overcome cultural barriers; overcome language barriers; encourage employees who are unwilling to co-operate; support co-construction activities; encourage employee trust; problems and solutions develop at the same rate and time; reduce file compatibility issues between groupware systems; reduce software incompatibility; be informed of the benefits of groupware
Shen et al. (2015)	Allow for monitoring of feedback from manufacturing and assembly; use standardised procedures; allow for direct supervision of team members work; encourage mediated co-ordination; support efficient decision-making; predictive behaviour; new strategies for efficient communication (ideas and comments); allow for ease of sharing; allow for the integration of software
van Dijk and van der Lugt (2013)	Encourage engagement; support single tasking
Vyas et al. (2010a)	Incorporate artefacts into the online design space; adapt to the social needs of the designer; artefact-mediated interaction; encourage social flexibility; allow for artefact-mediated interaction; explore creative solutions; utilize spatial resources
Vyas et al. (2012)	Support innovative thinking; integrate technology into the offline space
Vyas et al. (2010b)	Co-operate with each other; support creativity; support exploration; support multi-channel communication
Wangsa et al. (2011)	Support human-computer interactions; overcome boundaries of access; historical development; have an awareness for community differences; have an awareness for cultural differences; have an awareness for environmental differences; communicate context; minimise conflict; be objective oriented; ensure a hierarchical structure of activity
Xie et al. (2010)	Reduce interpersonal barriers; effectiveness of procedure; support the understanding of information; avoid poor communication; accuracy of information; conflicting information; not distort the meaning of the message; assist in overcoming logistic barriers; minimise information overload; ensure completeness of communication; avoid a lack of co-ordination; act as a gatekeeper to communication channel; act in a timely way; assist in reducing information overload
Zheng and Feng (2012)	Allow for reflection on customer feedback; allow easy access to product data; support the synchronisation of data

Table 6 Full table of factors which influence successful CSCD, their sources and categorisation

Top-level category	Sub-category	Requirement	References
Communication	Artefacts	Allow response with high-quality representation examples	Gopsill et al. (2014)
		Allow for the addition of artefacts to text-based ideation	Herrmann et al. (2013)
		Artefact-mediated interaction	Vyas et al. (2012)
		Incorporate artefacts into the online design space	Vyas et al. (2010a, b)
		Provide an electronic or physical reference for communication	Gopsill et al. (2014)
	Feedback	Allow team members to add comment to past communication	Gopsill et al. (2014)
		Allow team members to define a response to communication	Gopsill et al. (2014)
		Allow for reflection on customer feedback	Zheng and Feng (2012)
		Allow for feedback on ideas	Fruchter et al. (2010)
		Allow for monitoring of Feedback from manufacturing and assembly	Shen et al. (2015)
	Social	Adapt to the social needs of the designer	Vyas et al. (2010a, b)
		Display summaries of work completed	Iacob (2011)
		Allow for serendipitous communication	Borsato et al. (2015)
		Encourage knowledge sharing	Rapanta et al. (2013)
		Encourage networking	Borsato et al. (2015)
		Enhance interpersonal skills	Cho and Cho (2014)
		Support human computer interactions	Wangsa et al. (2011)
		Support human to human connections	Rapanta et al. (2013)
		Convey individual personality	Bittner and Leimeister (2013)
Environment	Access to information	Encourage synergy of team	Antunes et al. (2011)
		Reduce interpersonal barriers	Xie et al. (2010)
		Encourage social flexibility	Vyas et al. (2012)
		Encourage team familiarity	Bittner and Leimeister (2013)
		Allow access to edit documents	Herrmann et al. (2013)
	Corporate structure	Allow access to information	Pavkovic et al. (2013)
		Overcome boundaries of access	Wangsa et al. (2011)
		Have access to view and edit files freely	Iacob (2011)
		Use standardised procedures	Shen et al. (2015)
		Historical development	Wangsa et al. (2011)
		Implement consistent corporate policies	Rapanta et al. (2013)
		Organisational culture	Bittner and Leimeister (2013)
		Have freedom to collaborate with whoever is required	Iacob (2011)
		Seek input from parties outside the design team	Gopsill et al. (2014)
		Effectiveness of procedure	Xie et al. (2010)
Membership characteristics	Commonality	Accept a sense of lack of control	Cho and Cho (2014)
		Support small team negotiation cycles	Rapanta et al. (2013)
		Delegate clear roles and responsibilities	Pavkovic et al. (2013)
		Authority	Bittner and Leimeister (2013)
		Have appropriate training with groupware systems	Rapanta et al. (2013)
		Difference in time zone	Hirlehei and Hunger (2011)
		Have a cultural awareness for distributed team members	Hirlehei and Hunger (2011)

Table 6 (continued)

Top-level category	Sub-category	Requirement	References
		Overcome cultural barriers	Rapanta et al. (2013)
		Overcome language barriers	Rapanta et al. (2013)
		Have an awareness for community differences	Wangsa et al. (2011)
		Have an awareness for cultural differences	Wangsa et al. (2011)
		Have an awareness for environmental differences	Wangsa et al. (2011)
		Have an understanding for the impact of physical proximity	Bittner and Leimeister (2013)
	Motivation	Encourage team members through gamification	Herrmann et al. (2013)
		Encourage employees who are unwilling to co-operate	Rapanta et al. (2013)
		Encourage engagement	van Dijk and van der Lugt (2013)
		Be incentivised in their work	Bittner and Leimeister (2013)
		Be provided with positive reinforcement to encourage Information flow	Antunes et al. (2011)
		Be encouraged to have a long-sustained interest in the project	French et al. (2016)
		Support resolution of discussions	Fruchter et al. (2010)
		Be in good morale	Bittner and Leimeister (2013)
	Shared understanding	Support a pervasive experience	Borsato et al. (2015)
		Present information in an easy to understand way	Fruchter et al. (2010)
		Allow the ability to define the purpose of a conversation	Gopsill et al. (2014)
		Avoid ambiguous misunderstandings	Luck (2013)
		Articulate their completed work	Liu et al. (2014)
		Allow for clarification of a statement	Fruchter et al. (2010)
		Discuss problems with a common context	Hirlehei and Hunger (2011)
		Communicate on a common ground	Hirlehei and Hunger (2011)
		Communicate context	Wangsa et al. (2011)
		Support contextualisation over distance	Antunes et al. (2011)
		Support contextualisation with relationships	Antunes et al. (2011)
		Allow for explanation of a statement	Fruchter et al. (2010)
		Share a global view in the aid of a shared understanding	Antunes et al. (2011)
		Avoid miscommunication	Cho and Cho (2014)
		Avoid uncertain misunderstandings	Luck (2013)
		Support the understanding of information	Xie et al. (2010)
	Team co-operation	Anticipate the needs of other team members	Pavkovic et al. (2013)
		Make team members aware of work	Borsato et al. (2015)
		Be made aware and notified	Herrmann et al. (2013)
		Be made awareness of other team member's actions	French et al. (2016)
		Give an awareness of other team members work	Iacob (2011)
		Give an awareness of team members activities	Liu et al. (2014)
		Allow for direct supervision of team members work	Shen et al. (2015)
		Encourage mediated co-ordination	Shen et al. (2015)
		Encourage regular project reviews	Pavkovic et al. (2013)
		Allow for shared visualisation of work	Benolken et al. (2010)
		Co-operate with each other	Vyas et al. (2010a)
		Support co-construction activities	Rapanta et al. (2013)
		Allow for a constant connection	French et al. (2016)
		Avoid poor communication	Xie et al. (2010)
		More opportunities for peer learning and training	French et al. (2016)
		Co-operate with each other	Borsato et al. (2015)
		Greater retention of learning	French et al. (2016)

Table 6 (continued)

Top-level category	Sub-category	Requirement	References	
Process and structure	Trust	Ensure equal participation by all	Cho and Cho (2014)	
		Accuracy of information	Xie et al. (2010)	
		Conflicting information	Xie et al. (2010)	
		Not distort the meaning of the message	Xie et al. (2010)	
		Minimise conflict	Wangsa et al. (2011)	
		Encourage employee trust	Rapanta et al. (2013)	
		Encourage greater team trust when required	French et al. (2016)	
	Decision-making	Encourage mutual trust	Pavkovic et al. (2013)	
		Ranking functionality	Iacob (2011)	
		Support efficient decision-making	Shen et al. (2015)	
		Allow for greater opportunities to express opinions	Cho and Cho (2014)	
		Allow for improved decision-making	French et al. (2016)	
		Learning negotiation skills	Cho and Cho (2014)	
		Allow for negotiation	Fruchter et al. (2010)	
		Knowledge capture	Allow for annotations on existing artefacts	Iacob (2011)
			Allow for artefact-mediated interaction	Vyas et al. (2012)
			Allow for the capture of high-quality representation of artefacts	Gopsill et al. (2014)
			Allow for the capture of meeting information	Gericke et al. (2010)
			Allow for the documenting of decisions	Hansen and Dalsgaard (2012)
			Allow for the recording of modifications to the artefact	Gopsill et al. (2014)
			Allow for text-based description	Gopsill et al. (2014)
			Allow for the asking of closed questions	Fruchter et al. (2010)
	Productivity	Record and capture the focus of the conversation	Gopsill et al. (2014)	
		Greater likelihood of catching mistakes	French et al. (2016)	
		Allow for the reflection on work and decisions	Hansen and Dalsgaard (2012)	
		Collaboration readiness	Hirlehei and Hunger (2011)	
		Technology readiness	Hirlehei and Hunger (2011)	
		Faster design through collaboration	French et al. (2016)	
		Limit the size of the response	Gopsill et al. (2014)	
		More thorough outputs	Cho and Cho (2014)	
		Be objective oriented	Wangsa et al. (2011)	
		Performance (quantity of output)	Bittner and Leimeister (2013)	
Reduced rework time		French et al. (2016)		
Ensure work is completed by the most compliment member		Jinghua et al. (2014)		
Assist in overcoming logistic barriers		Xie et al. (2010)		
Coupling of work		Hirlehei and Hunger (2011)		
Ensure efficiency in communication		Cho and Cho (2014)		
Predictive behaviour		Shen et al. (2015)		
Productivity		Cho and Cho (2014)		
Resources	Competency	Assist in the reduction of iterative loops	Bittner and Leimeister (2013)	
		Assist in the reduction of rework	Bittner and Leimeister (2013)	
		Support the reuse of data	Gericke et al. (2010)	
		Support rework after the fact	Herrmann et al. (2013)	
		Support single tasking	van Dijk and van der Lugt (2013)	
		Support group member satisfaction	Bittner and Leimeister (2013)	
		Minimise information overload	Xie et al. (2010)	
		Ensure completeness of communication	Xie et al. (2010)	
		Include the ability to conclude a conversation thread	Gopsill et al. (2014)	

Table 6 (continued)

Top-level category	Sub-category	Requirement	References
		Enhance communication skills	Cho and Cho (2014)
		Have a diverse range of skills	Bittner and Leimeister (2013)
		Have individual skills	Bittner and Leimeister (2013)
		Ensure more capable employee skills	Cho and Cho (2014)
		Contribute to the team experience	Hirlehei and Hunger (2011)
	Co-ordination	Provide a private space to work	Iacob (2011)
		Allow for the organisation of communication by grouping	Gopsill et al. (2014)
		Give a visual overview of tasks	Pavkovic et al. (2013)
		Allow for the response to be co-ordinated to the correct purpose	Gopsill et al. (2014)
		Avoid a lack of co-ordination	Xie et al. (2010)
		Employ a mechanism to handle the resources	Iacob (2011)
		Co-ordination	Borsato et al. (2015)
		Co-ordination	Bittner and Leimeister (2013)
		Act as a gatekeeper to communication channel	Xie et al. (2010)
		Ensure a hieratical structure of activity	Wangsa et al. (2011)
		Support the organisation of meetings	Benolken et al. (2010)
		Assist in negating scheduling problems	Fruchter et al. (2010)
		Employ smart support of process control systems	Horváth (2012)
		Act in a timely way	Xie et al. (2010)
		Support an aligning effort of their team members	Hansen and Dalsgaard (2012)
		Problems and solutions develop at the same rate and time	Rapanta et al. (2013)
		Support the even distribution of work	Jinghua et al. (2014)
	Innovation	Explore creative solutions	Vyas et al. (2012)
		Support creativity	Vyas et al. (2010a)
		Support easy switching between ideation topics	Herrmann et al. (2013)
		Support exploration	Vyas et al. (2010a)
		Support innovation	Bittner and Leimeister (2013)
		More creative outputs	Cho and Cho (2014)
		Performance (quality of output)	Bittner and Leimeister (2013)
		Support the rapid transformation of ideas	Hansen and Dalsgaard (2012)
		Support innovative thinking	Vyas et al. (2010b)
		Support exploration	Fruchter et al. (2010)
		Support problem solving	Fruchter et al. (2010)
	Knowledge management	Integrated tagging functionality	Iacob (2011)
		Allow for the categorisation of communication	Gopsill et al. (2014)
		Allow for referencing previous communication	Gopsill et al. (2014)
		Allow for organisation of communications	Gopsill et al. (2014)
		Allow for the mining of information	Horváth (2012)
		Support knowledge elicitation methods	Horváth (2012)
		Support intelligent asset management	Horváth (2012)
		New Strategies for efficient communication (ideas and comments)	Shen et al. (2015)
		Support the autonomy of tasks	Pavkovic et al. (2013)
		Allow for easy linking between communications	Gopsill et al. (2014)

Table 6 (continued)

Top-level category	Sub-category	Requirement	References
	Managing the sharing of data	Assist in reducing information overload	Xie et al. (2010)
		Share a global view to reduce information overload	Antunes et al. (2011)
		Integrate 3rd party program support, e.g. CAD	Horváth (2012)
		Allow easy access to product data	Zheng and Feng (2012)
		Reduce file compatibility issues between groupware systems	Rapanta et al. (2013)
		Reduce software incompatibility	Rapanta et al. (2013)
		Have an adaptive system interface	Horváth (2012)
		Consistent interface	Iacob (2011)
		Reduce complexities whilst sharing data	French et al. (2016)
		Integrate technology into the offline space	Vyas et al. (2010b)
		Allow for ease of sharing	Shen et al. (2015)
		Allow for model and document sharing	Horváth (2012)
		Support the synchronisation of data	Zheng and Feng (2012)
		Integrate with data storage systems	Gericke et al. (2010)
		Support device flexibility	Iacob (2011)
	Communication	Allow for the integration of software	Shen et al. (2015)
		Allow for pushing of information	Gopsill et al. (2014)
		Support tracking work/versioning of documents	Iacob (2011)
		Be informed of the benefits of groupware	Rapanta et al. (2013)
		Support the answering of multiple threads through a single response	Gopsill et al. (2014)
		Support multi-channel working	Horváth (2012)
		Support co-creation in smart ways	Horváth (2012)
		Support synchronous working with live documents	Herrmann et al. (2013)
		Allow for everyone to take part at once	Iacob (2011)
		Select appropriate technology or tools	Liu et al. (2014)
		Support collaboration	Pavkovic et al. (2013)
		Support collaboration	Borsato et al. (2015)
		Support multi-threading conversations	Gopsill et al. (2014)
		Support audio and video conferencing	Benolken et al. (2010)
		Communication channels	Horváth (2012)
	Support communication	Bittner and Leimeister (2013)	
	Allow for messenger-style communication	Benolken et al. (2010)	
	Support multi-channel communication	Vyas et al. (2010a)	
	Support the proposition of design change	Hansen and Dalsgaard (2012)	
	Support virtual presence in smart ways	Horváth (2012)	
	Support communication through an integrated chat client	Iacob (2011)	
	Support design change	Hansen and Dalsgaard (2012)	
	Reduce technical conflict	Pavkovic et al. (2013)	
	Reduce technical problems	Fruchter et al. (2010)	
	Utilize spatial resources	Vyas et al. (2012)	
	Reduce difficulties in co-ordination due to technical difficulties	Antunes et al. (2011)	

Table 7 Symantec dictionaries

<i>Technology dictionary</i>	
SNS	Facebook; Group; Network; Page; Shared; Site; Social
Messenger	App*; Chat; Facebook; Instant; Memos; Messenger; Voice; Whats
Video conferencing	Conf*; Google; Hangouts; Skype; Video; Webcam
Cloud document storage	Box; Cloud; Doc*; Drive; Google; Share; Storage; Store
Project management groupware	Groupware; Management; Slack; Team; Tool; Trello
E-mail	Email; E-mail
Collaborative document editor	Doc*; Google; Live; Real; Share; Time
<i>Technology functionality dictionary</i>	
Conversation tools	Asynchronous; Chat; Comment; Communicat*; Convey; Decision; Discuss; Engaged; Familiar; Feedback; Informal; Information; Instant; Language; Making; Messages; Misunderstanding; Proactive; Rationale; Repetition; Reply; Response; Share; Sharing; Social; Speaking; Synchronous; Text; Translation; Understood; Update; Updating
Shared editors	Access; Concurrent; Live; Management; Overwritten; Real; Share; Simultaneous; Synchronous; Time
Group dynamics tools	3-6-5; Activities; Brainstorming; Breaker; CAD; Concept; Decision; Development; Exercise; Further; Ice; Ideas; Ideation; Iterate; Method; Research; Session; Sketch; Task; Turnaround; Visualisations
Polling tools	Activity; Consensus; Decision; Functionality; Mechanism; Pole; Vote; Voting
Desktop/application sharing	Animation; Augmented; CAD; Collaboratively; Draw; Ideas; Reality; Screen; Sharing; Technology; Whiteboard
Audio conferencing	Audio; Call; Memo; Phone; Voice
Video conferencing	Communication; Conf*; Conversation; Discussion; Face; Google; Hangouts; Resolve; Share; Skype; Synchronous; Understand; Video; Visual
Shared file repositories	Access; Allocations; Assign; Available; Capture; Co-ordination; Data; Decision; Doc*; Held; Information; Manage; Manage; Note; Overwritten; Photos; Receive; Record; Repository; Retrieval; Scanners; Send; Sent; Share; Sharing; Sketch; Storage; Store; Storing; Track; Uploaded; Versioning
Social tagging systems	Asynchronous; Aware; Channel; Feedback; Hashtag; Pinned; Rank; Starred; Tag
Search engines	File; Find; Search
Syndication tools	Asynchronous; Aware; Connected; Fast; Hyperlinks; Inform*; Integration; Notification; Notified; Notify; Pervasive; Progress; Reminding; Speedy; Update
<i>CSCD requirements dictionary</i>	
A shared understanding	Aware; Clarif*; Context; Dissemination; Others; Rational; Summary; Understand; Understood
Co-operation	Activities; Activity; Activity; Agreement; Confus*; Design; Goal; Issue; Missed; Notifications; Personal; Split; Support; Task; Team
Co-ordination	Allocations; Arrange; Arranging; Assign; Aware; Conduct; Coordinat*; Co-ordinat*; Could; Decide; Edit; Everyone; How; Interdependently; Manage; Multiple; Progress; Remind; Tasks; Teams; Version; Work; Working
Building of trust	Build; Built; Greater; Higher; Interpersonal; Issue; Lack; Levels; Relationship; Sense; Trust
Integration with company structure	Across; Between; Change; Delegated; Formal; Gatekeepers; Leaders; Professional; Progress; Regularly; Relevant; Responsible; Scheduled; Team; Willing
Decision-making	Apply; Consensus; Decision; Discuss; Knowledge; Mechanism; Organisation; Voting
Knowledge capture	Capture; Capturing; Difficult; Document; Record; Results; Share; Sketches; Take; Uploaded
Knowledge management	Cloud; Connected; Data; Decisions; Document; Found; Going; Held; Information; KM; Knowledge; Labelled; Location; Manage; Members; Missing; Requirements; Sections; Securely; Share; Store; Tag; Team; Tool; Well
Development of greater competency	Accountable; Capable; Competent; Complete; Completing; Compliant; Considered; Most; Perceived; Reliable; Share; Struggled; Suitable; Tasks; Unreliable; Use
Motivation	Cohesion; Contribute; Demotivated; Motivated; Respond; Response
Greater productivity	Access; Around; Complexities; Conven*; Convenient; Easier; Effectiv*; Faster; Improve; Notify; Pervasive; Productiv*; Real; Reduced; Response; Simultaneous; Time; Turn
Reduce the barriers of physical proximity, language and time zones (commonality)	Barrier; Boundaries; Communicate; Complete; Confidence; Cultural; Culture; Difference; Different; Difficult; Disagreement; Geography; Issues; Knowledge; Lack; Language; Overcome; Plans; Same; Socialise; Summarise; Time; Work
Feedback mechanisms from stakeholders	Comment; Communicat*; Discuss; Evaluat*; Feedback; Other; Question; Sketch; Team

Table 7 (continued)

Overcome boundaries of access	Access; Available; Constantly; Easy; Hosted; Inform*; Integration; Links; Manag*; Other; Programs; Share; Simple; Space; Understand; Uploaded
Complexity managing the sharing of data	Annotate; Avoid; Could; Data; Digitally; Document; Exchanged; Files; Finding; Idea; Image; Information; Knowledge; Live; Manag*; Outcome; Posted; Procedure; Research; Scan; Scanned; Share; Sharing; Showed; Sketch; Storage; Store; Storing; Uploaded; Various
Social communication	Activities; Activity; Breaker; Build; Communicat*; Discuss; Ice; Informal; Interpersonal; Meeting; Relationship; Social
Artefact-mediated communication	Communicat*; Concept; Drawing; Drew; File; Format; Idea; Image; Member; Over; Share; Support; Team
Communication	Based; Communicat*; Connection; Convey; Difficult; Discuss; Initial; Meetings; Messenger; Quick; Response; Summary; Team; Text
Innovative thinking	3-6-5; Brainstorming; Concept; Highest; Innovative; Lowest; Method; Number; Session; Thinki*

References

- Adams K (2015) Non-functional requirements in systems analysis and design. Springer, Berlin
- Ahram T, Karwowski W, Amaba B (2011) Collaborative systems engineering and social-networking approach to design and modelling of smarter products. *Behav Inf Technol* 30:13–26. <https://doi.org/10.1080/0144929X.2010.490957>
- Antunes P, Ferreira A, Zurita G, Baloian N (2011) Analyzing the support for large group collaborations using Google Maps. In: 15th international conference on computer supported cooperative work in design (CSCWD), pp 748–755
- Benolken P, Wewior M, Lang U (2010) A virtual workspace for distributed design and engineering tasks. In: 6th international conference on collaborative computing: networking, applications and worksharing (CollaborateCom). IEEE, pp 1–9
- Bittner EAC, Leimeister JM (2013) Why shared understanding matters—engineering a collaboration process for shared understanding to improve collaboration effectiveness in heterogeneous teams. In: 46th Hawaii international conference on system sciences (HICSS). IEEE, pp 106–114
- Bohemia E (2013) Design learning for tomorrow. In: Proceedings of the 2nd international conference for design education researchers, p 2
- Borsato M, Peruzzini M, Stjepandić J et al (2015) Collaborative engineering. *Concurrent engineering in the 21st century*. Springer, Berlin, pp 165–196
- Brewer PE (2015) Evaluating and maintaining effective global virtual teams. Wiley, Oxford, pp 158–181
- Brisco R, Whitfield RI, Grierson H (2016) Recommendations for the use of social network sites and mobile devices in a collaborative engineering design project. In: Proceedings of the 18th international conference on engineering and product design education (E&PDE16), design education: collaboration and cross-disciplinarity. The Design Society, pp 394–399
- Brisco R, Whitfield RI, Grierson H (2017) The use of social network sites in a global engineering design project. In: Proceedings of the 21th international conference on engineering design (ICED 17). The Design Society, pp 059–068
- Brisco R, Whitfield RI, Grierson H (2018a) Modelling the relationship between design activity and computer-supported collaborative design factors. In: Proceedings of the DESIGN 2018 15th international design conference. The Design Society, pp 193–204
- Brisco R, Whitfield RI, Grierson H, others (2018b) Are social network sites the future of engineering design education? In: DS 93: proceedings of the 20th international conference on engineering and product design education (E&PDE 2018), Dyson School of Engineering, Imperial College, London. 6th–7th September 2018. The Design Society, pp 400–405
- Brown P (2000) Technology and trust in teams. *Research Challenges, 2000 Proceedings Academia/Industry Working Conference* on 15–20. <https://doi.org/10.1109/aiworc.2000.843266>
- Butler M (2010) Android: changing the mobile landscape. *IEEE Pervasive Comput* 10:4–7
- Carroll JM, Neale DC, Isenhour PL et al (2003) Notification and awareness: synchronizing task-oriented collaborative activity. *Int J Hum Comput Stud* 58:605–632. [https://doi.org/10.1016/S1071-5819\(03\)00024-7](https://doi.org/10.1016/S1071-5819(03)00024-7)
- Chan F, Chan M, Tang N (2000) Evaluation methodologies for technology selection. *J Mater Process Technol* 107:330–337
- Cho JY, Cho M (2014) Student perceptions and performance in online and offline collaboration in an interior design studio. *Int J Technol Des Educ* 24:473–491. <https://doi.org/10.1007/s10798-014-9265-0>
- Cochrane (2017) Covidence (Systematic Review Software)
- Conole G, Alevizou P (2010) A literature review of the use of Web 2.0 tools in higher education. A report commissioned by the Higher Education Academy
- Cross M (2014) What is social media? Social media security, pp 1–20
- Duffy A (2002) Designing design. In: DS 29: Proceedings of EDIPROD 2002, Zielona Góra, Poland, 10.-12.10. 2002
- Elfving S (2007) Managing collaborative product development: a model for identifying key factors in product development projects
- Ellison NB, Steinfield C, Lampe C (2007) TOIL: the benefits of Facebook “friends.” Social capital and college students use of online social network sites. *J Comput Mediated Commun* 12:1143–1168. <https://doi.org/10.1111/j.1083-6101.2007.00367.x>
- Fain N, Kline M, Kline NF, Miro (2013) The dynamics of multicultural NPD teams in virtual environments. *Int J Technol Des Educ* 23:273–288
- Ferro T (2015) The importance of publicly available social networking sites (SNSs) to entrepreneurs. *CSCW* 15:917–928
- French DJ, Stone B, Nysetvold TT, Hepworth A, Red WE (2016) Collaborative design principles from minecraft with applications to multi-user computer-aided design. *J Comput Inf Sci Eng*. <https://doi.org/10.1115/1.4032667>
- Fruchter R, Bosch-sijtsema P, Ruohomäki V (2010) Tension between perceived collocation and actual geographic distribution in project teams. *AI Soc* 25:183–192. <https://doi.org/10.1007/s00146-009-0254-x>
- Garcia-Perez A, Ayres R (2010) Wikifailure: the limitations of technology for knowledge sharing. *Electron J Knowl Manag* 8:43–51
- Gericke L, Gumienny R, Meinel C (2010) Message capturing as a paradigm for asynchronous digital whiteboard interaction. In: 6th

- international conference on collaborative computing: networking, applications and worksharing (CollaborateCom). IEEE, pp 1–10
- Germani M, Mengoni M, Peruzzini M (2012) A QFD-based method to support SMEs in benchmarking co-design tools. *Comput Ind* 63:12–29
- Gibson CB, Cohen SG (2004) Virtual teams that work: creating conditions for virtual team effectiveness. *Pers Psychol* 57:243–246. <https://doi.org/10.1108/13665620210427294>
- Gopsill J (2014) A social media approach to support engineering design communication, p 243
- Gopsill J, Mcalpine HC, Hicks BJ (2013) A social media framework to support engineering design communication. *Adv Eng Inform* 27:580–597. <https://doi.org/10.1016/j.aei.2013.07.002>
- Gopsill J, Jones S, Snider CM et al (2014) Understanding the engineering design process through the evolution of engineering digital objects. In: DESIGN 2014 13th international design conference, pp 1773–1784
- Gopsill JA, Mcalpine HC, Hicks BJ (2015) Supporting engineering design communication using a custom-built social media tool. *Adv Eng Inform* 29:523–548
- Grant MJ, Booth A (2009) A typology of reviews: an analysis of 14 review types and associated methodologies. *Health Inf Lib J* 26:91–108
- Hank C (2012) Blogging your academic self: the what, the why and the how long? *Social media for academics*. Elsevier, New York, pp 3–19
- Hansen NB, Dalsgaard P (2012) The productive role of material design artefacts in participatory design events. In: Proceedings of the 7th Nordic conference on human–computer interaction: making sense through design. ACM, pp 665–674
- Hao S, Yu B, Wu W (2007) The impact of technology selection on innovation performance. *Wireless communications, networking and mobile computing, 2007. WiCom 2007*. International conference on, pp 5781–5783
- Hatem WA, Kwan A, Miles J (2012) Comparing the effectiveness of face to face and computer mediated collaboration. *Adv Eng Inform* 26:383–395. <https://doi.org/10.1016/j.aei.2012.01.001>
- Hay L, Duffy AH, McTeague C et al (2017) A systematic review of protocol studies on conceptual design cognition: design as search and exploration. *Des Sci* 3:2017
- Herrmann T, Nolte A, Prilla M (2013) Awareness support for combining individual and collaborative process design in co-located meetings. *Comput Support Cooper Work* 22:241–270
- Hicks BJ (2013) the language of collaborative engineering projects. In: ICED13: 19th international conference on engineering design, pp 1–10
- Hinds PJ, Bailey DE (2003) Out of sight, out of sync: understanding conflict in distributed teams. *Organ Sci* 14:615–632. <https://doi.org/10.1287/orsc.14.6.615.24872>
- Hirlehei A, Hunger A (2011) In designing an end-user tailorable synchronous groupware. In: 2011 international conference on collaboration technologies and systems (CTS). IEEE, pp 373–380
- Horváth I (2012) Recent developments in computer supported cooperative work in design: from group collaboration through global connectivity to informing apobetics. In: 16th international conference on computer supported cooperative work in design (CSCWD). IEEE, pp 2–13
- Hosnedl S, Srp Z, Dvorak J (2008) Cooperation of engineering and industrial designers on industrial projects. In: DS 48: proceedings DESIGN 2008, the 10th international design conference, Dubrovnik, Croatia
- Hsu C-M (2013) The construction of a web-based learning platform from the perspective of computer support for collaborative design. *Int J Online Pedagogy Course Des* 3:44–67. <https://doi.org/10.4018/ijopcd.2013100104>
- Iacob C (2011) Identifying, relating, and evaluating design patterns for the design of software for synchronous collaboration. In: Proceedings of the 3rd ACM SIGCHI symposium on engineering interactive computing systems. ACM Press, p 323
- Jinghua W, Liyi Z, Hongxiang X (2014) Simulation of project scheduling through the rule-based coordination in indirect collaboration design. *J Simul* 8:251–258. <https://doi.org/10.1057/jos.2013.25>
- Kvan T (2000) Collaborative design: what is it? *Autom Construct* 9:409–415. [https://doi.org/10.1016/S0926-5805\(99\)00025-4](https://doi.org/10.1016/S0926-5805(99)00025-4)
- Liu W, Pasman G, Taal-fokker J, Stappers PJ (2014) Exploring “Generation Y” interaction qualities at home and at work. *Cogn Technol Work* 16:405–415. <https://doi.org/10.1007/s10111-013-0269-4>
- Luck R (2013) Articulating (mis)understanding across design discipline interfaces at a design team meeting. *Artif Intell Eng Des Anal Manuf* 27:155–166. <https://doi.org/10.1017/S089006041300005X>
- Maier AM, Eckert CM, Clarkson PJ (2006) Identifying requirements for communication support: a maturity grid-inspired approach. *Expert Syst Appl* 31:663–672
- Maier AM, Kreimeyer M, Lindemann U, Clarkson PJ (2009) Reflecting communication: a key factor for successful collaboration between embodiment design and simulation. *J Eng Des* 20:265–287
- Mamo J, Farrugia P, Borg J et al (2015) Using engineering design tools in multidisciplinary distributed student teams. In: 17th international conference on engineering and product design education, pp 99–104
- Margaryan A, Boursinou E, Lukic D, Zwart HD (2014) Narrating your work: an approach to supporting knowledge sharing in virtual teams. *Knowl Manag Res Pract* 13:1–10. <https://doi.org/10.1057/kmrp.2013.58>
- Markus P, James T, Luc F, Udo L (2007) Cross-cultural collaboration in design engineering—influence factors and their impact on work performance. Guidelines for a decision support method adapted to NPD processes
- Mattessich PW, Monsey BR (1992) Collaboration: what makes it work. A review of research literature on factors influencing successful collaboration. ERIC, New York
- McDonnell J (2012) Accommodating disagreement: a study of effective design collaboration. *Des Stud* 33:44–63. <https://doi.org/10.1016/j.destud.2011.05.003>
- Metrix comScore M (2010) Ranks Top 50 U.S. Web Properties for May 2010 (PRESS RELEASE). 2010
- Mittleman DD, Murphy JD, Briggs RO (2015) Collaboration systems: concept, value, and use. In: Nunamaker Jr JF, Briggs RO, Romano Jr NC (ed) 1st ed. Routledge, New York, p 45
- Moher D, Liberati A, Tetzlaff J et al (2009) Preferred reporting items for systematic reviews and meta-analyses: the PRISMA statement. *PLoS Med* 6:e1000097
- Nicholas JM, Steyn H (2017) Project management for engineering, business and technology. Routledge, London
- O’Riordan S (2014) Exploring the relationship between social network sites and the consumption of cultural goods through the lens of affordances
- Pavkovic N, Štorga M, Bojetic N, Marjanovic D (2013) Facilitating design communication through engineering information traceability. *Artif Intell Eng Des Anal Manuf* 27:105–119. <https://doi.org/10.1017/S0890060413000012>
- Pektaş ŞT (2015) The virtual design studio on the cloud: a blended and distributed approach for technology-mediated design education. *Arch Sci Rev* 58:255–265. <https://doi.org/10.1080/00038628.2015.1034085>
- Post TW (2014) From Lycos to Ask Jeeves to Facebook: tracking the 20 most popular web sites every year since 1996
- Rapanta C, Maina M, Lotz N, Bacchelli A (2013) Team design communication patterns in e-learning design and development. *Educ Tech Res Dev* 61:581–605. <https://doi.org/10.1007/s11423-013-9306-5>

- Rassias N, Kirytopoulos K (2014) Evaluating risk factors in the operation of virtual teams in ICT projects. In: Industrial engineering and engineering management (IEEM), 2014 IEEE international conference on 1192–1197. <https://doi.org/10.1109/ieem.2014.7058827>
- Reich Y, Konda S, Subrahmanian E et al (1999) Building agility for developing agile design information systems. *Res Eng Design* 11:67–83
- Sarka P, Ipsen C, Maier AM et al (2014) Engineers are using social media for work purposes. In: 13th international design conference
- Sclater N (2008) Web 2. 0, personal learning environments, and the future of learning management systems. *Management* 2008:2008–2009
- Shea TP, Sherer PD, Quilling RD, Blewett CN (2011) Managing global virtual teams across classrooms, students and faculty. *J Teach Int Bus* 22:300–313. <https://doi.org/10.1080/08975930.2011.653911>
- Shen W, Barthès J-P, Luo J (2015) Computer supported collaborative design: technologies, systems, and applications. *Contemporary issues in systems science and engineering*. Wiley, New York, pp 537–573
- Sivunen A, Valo M (2006) Team leaders' technology choice in virtual teams. *Prof Commun IEEE Trans* 49:57–68. <https://doi.org/10.1109/TPC.2006.870458>
- Torkkeli M, Tuominen M (2002) The contribution of technology selection to core competencies. *Int J Prod Econ* 77:271–284
- Törlind P, Larsson A (2002) Support for informal communication in distributed engineering design teams. In: *Annals of 2002 Int'l CIRP design seminar*, pp 16–18
- Van Dijk J, van der Lugt R (2013) Scaffolds for design communication: research through design of shared understanding in design meetings. *Artif Intell Eng Des Anal Manuf* 27:121–131. <https://doi.org/10.1017/S0890060413000024>
- Van Grinsven J, de Vreede G-J (2002) Collaborative engineering: 'towards design guidelines for risk management in distributed software development'. In: *DS 30: Proceedings of DESIGN 2002, the 7th international design conference, Dubrovnik*
- Vyas D, Nijholt A, Heylen D et al (2010a) Remarkable objects: supporting collaboration in a creative environment. In: *Proceedings of the 12th ACM international conference on ubiquitous computing*. ACM, pp 37–40
- Vyas D, Nijholt A, van der Veer G (2010b) Supporting cooperative design through “living” artefacts. In: *Proceedings of the 6th Nordic conference on human-computer interaction extending boundaries—NordiCHI'10*. ACM Press, p 541
- Vyas D, Veer G, Nijholt A (2012) Creative practices in the design studio culture: collaboration and communication. *Cogn Technol Work* 15:415–443. <https://doi.org/10.1007/s10111-012-0232-9>
- Wangsa IT, Uden L, Mills SF (2011) Using activity theory to develop requirements analysis framework for collaborative working environments. In: *Proceedings of the 2011 15th international conference on computer supported cooperative work in design (CSCWD)*. IEEE, pp 756–763
- Xie C, Wu D, Luo J et al (2010) A case study of multi-team communications in construction design under supply chain partnering. *Supply Chain Manag Int J* 15:363–370. <https://doi.org/10.1108/13598541011068279>
- Yap CM, Souder WE (1993) A filter system for technology evaluation and selection. *Technovation* 13:449–469
- Zhao D, Rosson MB (2009) How and why people Twitter. In: *GROUP'09 proceedings of the ACM 2009 international conference on supporting group work*, pp 243–252
- Zheng J, Feng Y (2012) Study on the collaborative product design platform in the context of the internet of things. In: *2nd international conference on consumer electronics, communications and networks (CECNet)*. IEEE, pp 3538–3542

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