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Supporting Collaborative Design by Digital Tools – Potentials and Challenges

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Abstract

Modern product engineering is characterised by distributed teams working on different subsystems and components at different times in different knowledge domains. On the one hand, this distributed development enables flexibility with regard to experts' know-how; on the other hand, it results in an enhanced effort for coordination tasks and information exchange between the partners involved. However, these tasks are less supported in collaboration of small and medium size enterprises and therefore often result in an interface-based development rather than a collaborative design. The application of modern digital tools for information representation and exchange as well as the use of design methods in distributed teams can support a wide range of the tasks needed for a successful collaboration. However, new competencies with regard to technical or methodical issues as well as socio-emotional competencies of the designers are required to enable an efficient work among the team members and gain the advantages of collaborative design.

In order to develop a concept for the support of collaborative design using digital tools, this paper addresses the following research questions: what does the collaborative work look like, nowadays, and which potentials and challenges result from this increasing digitalisation of work? What kinds of competencies are required to ensure an effective collaboration from both the personal and the process point of view? Subsequently, this paper proposes an approach to support collaborative teams in a methodical way. This approach is based on a model including three views upon collaborative design, namely process-view, technical-methodical-view and personal view.

Keywords: Competencies, collaborative design, design methods, digital tools

1 Introduction

Since the complexity of modern products increases, there are often multiple disciplines (e.g. mechanic, electronic and software) involved in engineering. Knowledge of experts is needed as well as persons that are able to overview the total system, are able to evaluate consequences of changes and integrate all components into the system. This is one of the main drivers for collaboration, the sourcing of different know-how / creativity regarding design and manufacturing issues. On the one hand, this concerns people and people's knowledge; on the other hand, whole companies can be seen as knowledge owners (Vietor et al., 2015). As another main driver for collaborative design, flexibility regarding resources can be stated. Manpower can be shared and utilised flexibly, but so can production capacity. Finally, there are economic drivers as, e.g., the differing costs for manufacturing and assembly in different countries. Gaul (2001) points out eleven drivers for collaborative design complemented by possible (negative) consequences. Besides the drivers mentioned before, he also considers strategic aspects in more detail, like the proximity to customers, concentration on core competencies or the systematic usage of different mind-sets across the cultures (Gaul, 2001).

Against the background of increasing digitalisation within the working environment, these drivers can be seen as potentials since there are new technologies to share knowledge, exchange and represent information. However, various challenges concerning the collaboration remain unresolved.

1.1 Different understandings of collaborative design

Since in nearly every case, engineering design involves multiple people, it can be understood as a collaborative task per se. In order to specify the collaborative design addressed in this contribution, different understandings were analyzed resulting in a comprehensive model of collaborative design and different views on it (see section 2). There are different understandings of the term 'collaborative design' with regard to different dimensions, e.g. disciplines, locations and time zones (Schleidt, 2009). What is important about collaboration is the fact that various people work together to achieve a common purpose which is the development of a product (Lombard & Yesilbas, 2006). In general, these people provide diverse knowledge, are equipped with diverse skills and work in a multi-geographic environment, sometimes across enterprise boundaries (Lombard & Yesilbas, 2006). The last-mentioned case is also referred to as Cross Enterprise Engineering where different groups of employees interact locally separated, organisationally and or timely shifted to achieve a common task (Schleidt & Eigner, 2010). Due to the non-direct communication via information and telecommunication technologies, such teams are also named virtual teams (Schleidt & Eigner, 2010). As a result of the geographical distribution, further aspects are important for collaboration, e.g. the fact that different cultures and languages may hinder the proper communication between the persons involved (Petermann et al., 2007). Anderl et al. (1999) present a list of 15 characteristics of distributed design. Besides the dimensions mentioned above, they cite, e.g., the compatibility of methods and tools as well as the number of interfaces, the data access and competencies of the partners involved.

In this paper, the focus shall be lain on interdisciplinary, geographically distributed and virtual collaboration of teams in engineering design considering the specific competencies requested form humans within the process.

1.2 Focus of research

Although there are different research works dealing with the competencies requested for engineers in collaborative design and tools to support the application of engineering methods, an integrated concept to support collaborative design based on digital tools is missing. The aim of the research presented here is to support collaborative design by the application of appropriate methods and communications tools. In order to address the different aspects of collaborative design, interactions between methods, communication, and competencies of engineers are in the focus of the research presented. Taking into account the increasing digitalisation in private and working life, this contribution focuses on the following research questions:

- What does the collaborative design look like nowadays?
- Which potentials and challenges result from an increasing digitalisation of work?
- What are the additional competencies required?
- How can we support collaborative design within teams at different places by a methodical approach?

In order to specify different views upon collaborative design, in the following section a model is introduced, defining three perspectives and their interactions. Based on this model, existing tools and concepts to support collaborative design are analysed (section 3) and the potential and challenges of digitalisation are highlighted (section 4). In section 5, a concept for a holistic support of collaborative design is introduced and two examples of application are described. The paper closes with a discussion of the concept proposed and forecast on future work.

2 Different views on collaborative design

In order to highlight different fields to support the designers in collaborative design, in this section a model is introduced describing three views upon collaborative design. These views are based on established models (Bender, 2001; Schleidt, 2009), but explicitly involve the human and his competencies as part of collaborative design. There are interactions highlighting the need of a holistic approach between the different views when aiming to gain the potentials of collaborative design in practise.

The technical-methodical view focuses on the tools and methods used within the collaborative design process. These tools and methods aim to support the communication between partners, for instance via video conference, or the representation of product models via shared desktop as well as the generation or evaluation of design solutions at different stages of the design process. The availability of tools and application of methods is affected e.g. by the IT-infrastructure of the enterprise and the methodical know-how of the designers themselves and can differ among different locations. In order to support designers in collaborative work, support is needed to provide and share know-how about engineering design methods and assist appropriate use of communication and representation tools in correlation with the use of methods. An application of methods as well as the way of communication and representation of information is interlinked with the personal and process view upon.

The process view describes organisational aspects of the collaboration. Within this view, dependencies between the different components of the overall system and interactions are considered. Because of the strong interdependencies between design decisions, for instance concerning geometrical changes of interfaces made during the design process, the adequate processes are needed, defining higher-level decision-points as well as the exchange of information (moment and kind). These processes should avoid information deficits of the several development partners involved. To support collaborative design from process view, samples and basic types of processes and change, strategies are needed to plan and manage collaboration. Furthermore, integration of reflection processes can help to ensure an appropriate use of engineering methods and evolve the competencies requested form the persons involved.

The personal view focuses on the competencies of the persons involved in a collaborative design task. Due to the asynchrony of communication, new digital tools and virtual teams with additional new competencies are requested for collaborative working (see section 3.1). The change of competencies concerns communication skills, self-organisation as well as skills to handle stress, for instance caused by misunderstandings or traveling effort of the engineers. In order to accomplish high productivity and content of the individual engineers, support is needed to consider different competencies when choosing engineering methods and

communication tools. Furthermore, tools are needed to capture the mood of individual engineers as well as engineering teams within the design process and derive suitable measures to cope with challenging situations (Gaul, 2001).
Based on this model, the existing support for collaborative design focusing on the introduced views is described in the following section.

3 Supporting collaborative design from different views

This section deals with different means of support for collaborative design. We will point out that a lot of research is done to support collaborative design. However, there is a lack of a holistic approach. Wallace et al. (2001) state that the multiple points of view (technological, human, expertise, etc.) are rarely supported in collaborative design. Although many projects have tried to fill this gap, the results obtained were mainly disappointing (Robin et al., 2007).
Because of the focus of this paper, the literature review only addresses the personal and technical-methodical view.

3.1 Support from personal view

The engineer, as a person, is the central part of the design process. He influences the product by generating his ideas and also the development process in which he interacts (Rosenman & Gero, 1998). So, designing can also be seen as a social process (Bucciarelli, 1988). Therefore, the consideration of personal aspects is evident. As there are mainly multiple persons involved in engineering tasks, team building plays an important role when focusing on the personal view. Gaul (2001) states that distributed teams have to face the same challenges as normal teams, but appearing problems like dissatisfaction caused by dissimilar discussions result in major implications. However, other authors (e.g. (Schleidt & Eigner, 2010; Shin, 2004)) stress the dependency between the degree of virtuality of a team and the competencies required. This assumption is also supported by different governments who announce various programs to investigate on the human factor in increased digitalised working environment. The competencies a person possesses are an important psychological factor in the thinking and behaviour of this person. Competence means the individual disposition of a person to show a specific behaviour in a specific situation (Schleidt, 2009). In order to measure the competencies, there are different methods and techniques starting from questionnaires to diagnostic tools (e.g. In-K-Ha (Paulsen et al., 2016)). The objective is to identify certain competencies like professional, methodological, social competence or self-competence and to develop them subsequently. For instance, an online-tool called VICO (virtual qualification coach) was developed to identify special competencies needed in virtual teams. The tool assists persons who work in virtual teams (like free lancers that come together for a project) to identify their competencies (clustered in 14 groups) and to search for adequate competence development programs (Auffermann et al., 2007). Schleidt (2009) transfers this approach towards an engineering context and proposes the House of Engineering Competencies which correlates working conditions in Cross Enterprise Engineering processes and relevant competencies in virtual teams. The idea is to fit a person and the environment using this tool. A similar support is proposed by Rose et al. (2009). They developed a competencies matrix which is supposed to give an overview of the knowledge, the activity, the autonomy and quality of different persons within an enterprise. They focus on the difficulties arising when engineers of different domains are working together. With the aid of the PEGASE application, which integrates the above-mentioned matrix, the project manager can deploy his employees considering their competencies using a four-level scale. Besides, there are classic tools like Kick-Off-Meetings or other team building measures to get to know each other. Those tools become especially important when working in virtual or distributed teams (Gaul, 2001). In a cross-cultural context, intercultural training seems to be an adequate way to prepare the team members for collaboration.

3.2 Support from technical-methodical view

Supporting the technical-methodical view of a collaboration, it can be differentiated between the following dimensions: communication, coordination and collaboration (Teufel et al., 1995). Within the field of computer supported collaborative work (CSCW), the focus lies on communication features (messaging) and coordination (approval forms, work flows) (Robin et al., 2007). Typical systems and tools to support the communication are, e.g., e-mails, video-conference tools or phone calls; to support coordination, there are, e.g., workflow-management-systems. Grieb (2008) classifies media into three groups: traditional media (phone, fax, postage or face-to-face meetings), computer-based media and media that utilizes virtual reality. The computer-based media is divided into the three mentioned levels (communication, coordination and collaboration oriented) and also into the sub-categories synchronous and asynchronous. While phone calls and video-conference meetings are synchronous communication tools, e-mail and newsgroups are asynchronous tools for communicating. Regarding examples for asynchronous collaboration tools, Grieb states file sharing systems, whereas he refers joint editing systems as synchronous. For the coordination of a team, there is no differentiation concerning the time aspect (Grieb, 2008). The third group is media based on virtual reality (VR). The intention of VR is the representation of product properties, e.g. using a CAVE (Cave Automatic Virtual Environment), in a preferably realistic manner. The representation addresses senses, mostly haptic, visual and acoustic or a combination of these. One of the challenges of VR is the modelling of real-time presentation and interaction (Grieb, 2008). Concerning the communication, Gaul (2001) developed the House of Communication to correlate characteristics of communication technologies to (1) the information to communicate and (2) communication technologies. This so-called House of Communication is a tool to support a collaborative team when exchanging information. The importance of informal communication within the design process is evident (Törlind & Larsson, 2002), so there are several approaches to support it. Törlind & Larsson present a Contact Portal that assists informal communication and information sharing via an online-based tool. This Contact Portal includes awareness cameras, instant messaging (IM), diaries and short message service (SMS) to enable a casual communication between the involved partners. Moreover, Neubauer et al. (2012) propose a framework for informal communication. This framework consists of eight fields like development of culture, set-up of confidence, support of coordination and collaboration. In addition, there are various works dealing with the exchange of knowledge in collaborative teams, e.g. (Pol et al., 2008; Yesilbas et al., 2006).

4 Potentials and Challenges of digitalisation

This section highlights the potentials and challenges of digitalisation of working life with regard to collaborative design. One of the mayor potentials of an increasing digitalisation is the possibility to work in a more digital environment, and thus in a geographically distributed collaboration. As a result of this trend, the amount of communication engineers have to perform increased from about 10 % in 2000 to more than 15 % in 2006. In the same time, the amount of professional tasks decreased form nearly 50 % to about 25 % (Schleidt & Eigner, 2010). From personal views, this leads to new possibilities to broaden one's mind when working in distributed virtual teams. This trend demands new competencies required to cope with the upcoming challenges like missing direct contact, different cultures and, thus, potentially different understandings. New orginization models are established to face the challenges like a more and more flexible working time at flexible places. Subsequently, the employees have to accept and live those new structures. To do so, besides modern communication, coordination and collaboration technologies, they need competencies such as confidence competence, work-life-competence or coopetition competence when working together with competing enterprises (Auffermann et al., 2007). Auffermann et al. (2007) determined 14 fields of competencies which are required in virtual teams formed by various members from different companies or freelancers. Some of them can be transfered to engineering design tasks, like Schleidt (2009) does to achieve the House of Engineering Competencies (see section 3.1). Further research deals with new competencies in a digitalised working environment like (Getha-Taylor, 2008; Hertel et al., 2005; Shin, 2004). Aditionally, Gaul (2001) states that the mood of the team members should be constantly observed to identify problems at an early stage. Since digitalisation is driven by the technological progress, the technological-methodical view provides various potentials. New technologies allow to share and use knowledge from all over the world. The results of a survey among engineers from industry whose work is partly negatively influenced due to distributed work display a moderate to high potential to enhance the design process by improving the technologies. Within this survey, the most requested additional media the engineers wanted are Shared Applications and VR-media (Grieb & Lindemann, 2005). Concerning especially the sharing of data, one of the mayor challenges is the security of this knowledge and these data.

5 Towards a holistic support of collaborative design

To face the challenges mentioned above, we propose a concept for a collaborative design that includes the three views: personal, technological-methodical and process. We base our concept on the work of Gaul (2001) as well as of Schleidt (2009) and combine both approaches into a holistic support. The concept proposed is depicted in general and has to be adapted to the conditions of the considered enterprise or enterprise networks.

The single elements that form the concept are described in detail in the following. In section 5.2, we will demonstrate the interaction and the steps to use the concept in two different ways.

5.1 A concept for a collaborative design

The concept to support collaborative design consists of three matrices (see Figure 1). The structure is based on the method Quality Function Deployment (QFD). This structure is also used by Gaul for the House of Communications and by Schleidt for the House of Engineering Competencies.

The first matrix reflects the relation between the competencies required and the special collaborative working conditions called collaboration characteristics. These characteristics are adopted from Gaul and Schleidt. In a first approach, we chose the competencies fields proposed by Schleidt (2009) for collaborative engineering teams considering the four groups: business management competence, communication competence, self-management competence and work-life-balance-competence. Besides a determination of the existing competencies of individual persons within a team, the diagnostic tool of Kauffeld and Henschel (2010) can be used to receive competencies in the fields of social, methodical, professional and self-competence. These two options on the one hand allow us to make general statements about the exigence of competencies for certain collaborative situations (Schleidt, 2009). On the other hand, it is possible to obtain competence profiles of whole teams by averaging the single results. The second matrix indicates the suitability of various communication technologies (e.g. mail, phone, special software) depending on the collaboration characteristics. In the third matrix, a set of methods or tools used in an enterprise or network of enterprises is related to the collaboration characteristics. Similar to the QFD method, there are correlations between the single matrices. The communication technologies and methods and tools are correlated to each other in the "roof" of the house. In a second correlation matrix, competencies and communication technologies are related to each other.

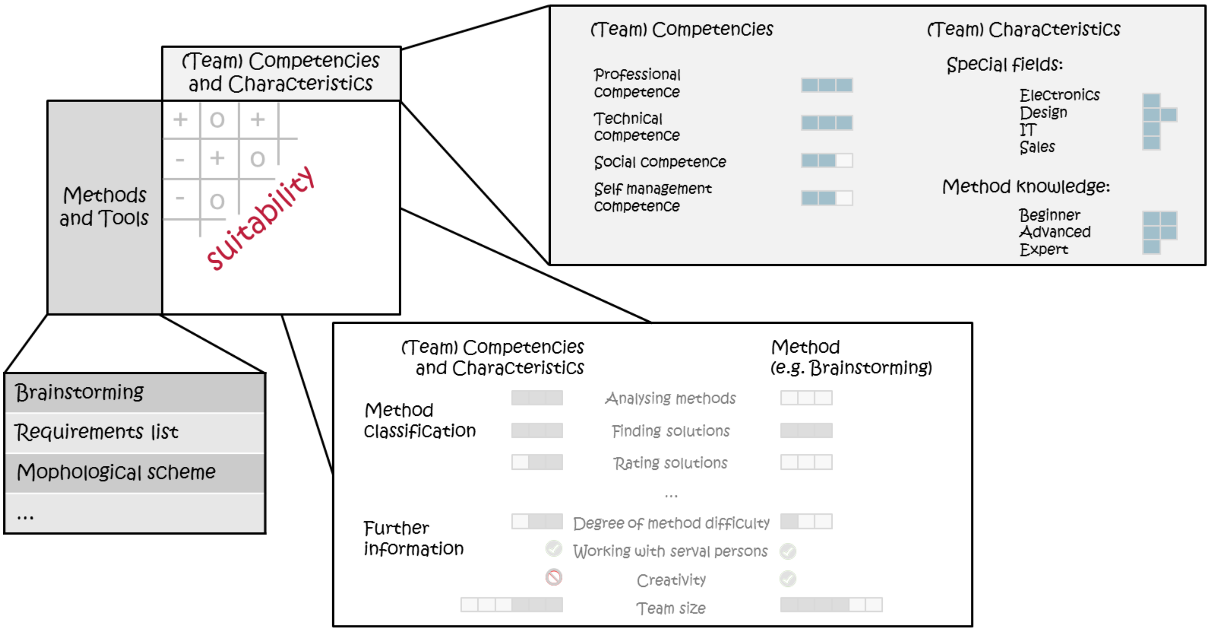

Figure 1. Competencies-Methods-Matrix to correlate the competencies of a design team to possible methods to use.

Another element of the holistic concept is the Competencies-Method-Matrix (CMM) which represents the missing correlation of the house described above. The rows of this matrix contain the methods and tools considered. The columns are filled with the competencies as well as the certain characteristics of the collaborative team (see Figure 2). The correlation is based on a three-point scale concerning (1) the competencies (average of team), (2) the characteristics of the method or tool. The team characteristics are counted by the number of persons who correspond to the characteristic. The team size is also counted by the number of persons. The suitability of a team to conduct creativity methods or techniques is indicated by "yes" or "no". The same is applied for the information whether working as a team (at the same time) is desired. These data are used to calculate the suitability within the CMM.

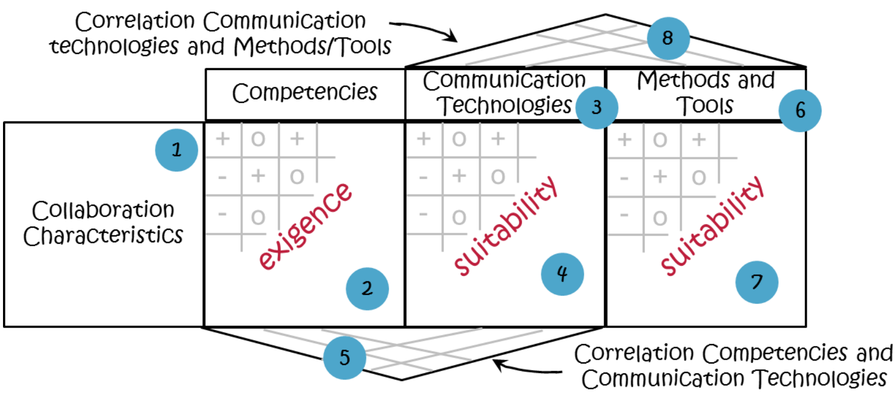

Figure 2. Concept for a holistic support of collaborative design using the Matrix of Distribution Characteristics of Gaul (2001), the Working Conditions of Schleidt (2009) and the Competencies of Kauffeld (2010).

As explained before, the concept to support collaborative design has to be adapted to the enterprise or enterprise networks in which the collaboration is taking place. The following steps have to be undertaken for adaptation (see also Figure 2):

1. Reviewing the collaboration characteristics of the enterprise by using the proposed lists of Gaul for Distribution Characteristics and Schleidt for Working Conditions.
2. Evaluating the required competencies for each characteristic by using the competence scheme of Kauffeld.
3. Identifying the communication, coordination and collaboration technologies available within the considered enterprise.
4. Evaluating the suitability of the technologies concerning collaboration characteristics.
5. Correlating the competencies and the communication technologies.
6. Identifying the methods and tools known and implemented or useful methods that can be implemented easily within the enterprise.
7. Evaluating the suitability of the methods / tools concerning collaboration characteristics.
8. Correlating the communication technologies and methods / tools.

5.2 Example for the application

Thanks to the various parts of the concept proposed for collaborative design, one can choose the required matrix or element to deal with different collaborative situations. Figure 3 demonstrates two different ways to apply the concept.

In case A, a task within the development process, e. g. the evaluation of different design solutions, is given. Using the House of Communications (Gaul, 2001), a suitable communication technology can be chosen. The second matrix of the concept helps the user to identify the possible collaboration characteristics to handle the task. Based on this information, the user can determine the required competencies as well as suitable methods or tools to solve the task. Applying the CMM, the user notices possible gaps between actual and target competencies and can induce special measures like training.

Case B starts with given collaboration characteristics, e.g. geographical distribution of the partners. The adapted concept of an enterprise reflects the competencies that are available within the collaboration. Via CMM, suitable methods or tools can be chosen considering the characteristics and competencies of the engineers involved. In the next step, the concept provides the correlation to communication technologies. Finally, possible tasks that can be handled by the team within the collaboration can be determined applying the House of Communications.

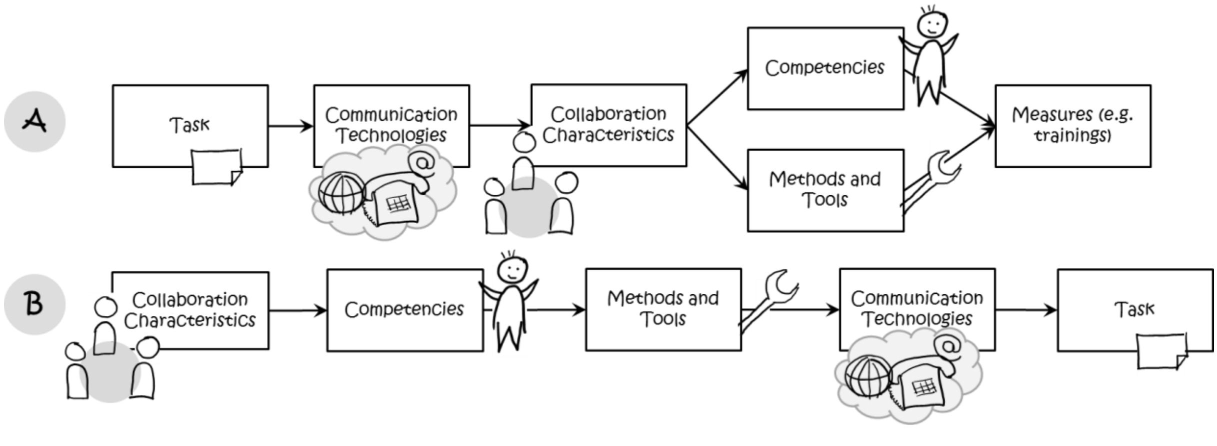

Figure 3. Two different possibilities to apply the concept: A – from a given task to required measures to face the task and B – from the existing collaborative characteristics to possible tasks that can be solved.

6 Discussion, future work and conclusion

Even though the approach presented has not been evaluated yet, it consists of a matrix based concept to support collaborative design considering the personal, technical-methodical and process view. In this way, we try to achieve a holistic approach towards collaboration. As the concept is composed of different aspects derived from other work, the single parts have to be validated, for instance concerning the correlation between methods – competencies or communication technologies – methods. In addition to that, the whole concept has to be proven concerning the usability and utility. A first evaluation within a collaborative student project (design students from Magdeburg, Saxony-Anhalt (Germany) and engineering students from Braunschweig, Lower Saxony (Germany)) is planned as well as a first application in industry. The results will be used to improve the concept and to subsequently derive a digital tool supporting the application. Following, the developed tool should be applied in a collaborative industry project to learn its weaknesses and strengths.

Actually, there is a method database called Methodos (Bavendiek et al., expected 2016) that is, inter alia, able to match methods and collaboration characteristics. This single element has only been evaluated in a student context as it is supposed to support students. First results mirror a medium interest of students considering collaboration information. Additionally, the work of Bavendiek et al. (2015) reflects a correlation between method use and team meeting characteristics like meeting satisfaction and task performance. Based on this collaboration with the colleagues from the Institute of Psychology (TU Braunschweig), we plan to do further research on the correlation methods-competencies considering collaborative circumstances.

Concluding, we gave an overview of the potentials and challenges of collaborative design and focused on tools for its support. The approach proposed is a first step towards a holistic support, but it still has to be applied and evaluated in industry to proof its benefits.

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