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Using technological functions on a multi-touch table and their affordances to counteract biases and foster collaborative problem solving

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Abstract Nowadays touch technologies have become ubiquitous, motivating researchers to explore their potential - especially in collaborative scenarios. Studies on collaboration applying joint visual spaces like multi-touch tables (MTT) demonstrated positive effects on performance. Yet, factors like prior knowledge and preferences, resulting in cognitive biases, were neglected although they are likely to put additional demands on collaboration. Whether touch technology can support its users in mastering the resulting challenges remains an open issue. To address this issue, we employed a hidden-profile (HP) paradigm (e.g., Schulz-Hardt and Mojzisch 2012) to investigate whether the affordances of specific support functions realized in a collaboration support kit (CSK) on a MTT help to overcome established pitfalls of collaboration (prior preferences and discussion biases). The CSK comprised a joint space (JS) and private spaces (PS), it allowed participants to push information from the PS into the JS, to jointly sort information within the JS, and it provided automatic functions like merging information. To replicate traditional HP studies, triads in a standard HP condition ($n = 25$) exchanged information in a discussion; triads in the CSK condition ($n = 29$) were additionally provided with the CSK consisting of the aforementioned functions. Our results revealed that CSK groups showed greater discussion intensity, more balanced discussions, more indicators of mutual understanding, and better decision performance than standard HP groups. This is original evidence that affordances of a MTT with interactive support functions can be used to overcome biases from prior preferences and to enhance collaboration.

Keywords Collaboration · Collaborative problem solving · Computer support · Intuitive use · Prior preferences · Biases

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Introduction

In everyday life, collaboration is omnipresent (Hollenbeck et al. 1995; Lightle et al. 2009): We have meetings and brainstorming sessions at work, classes and learning groups at school, and we have research groups and conferences in academics. In sports, we have teams; in politics, we have parties, committees, and the parliament. We have advisory boards and expert panels for all kinds of tasks and problems, because we expect groups to deliver better results than individuals. As a result, important decisions are seldom made by one individual alone, but rather discussed and made within small groups (Schulz-Hardt and Mojzisch 2012). Therefore, the ability to collaborate is a ubiquitously required and increasingly important skill. Indeed, researchers agree that collaboration in small groups represents a valuable chance for activities and behaviors that are associated with intensive engagement, motivation and that can result in deep learning (Mercier and Higgins 2013; Ras et al. 2014). Hence, there has been growing interest in the topic of collaboration in research and comparative performance studies. This is reflected in various approaches attempting to define and assess collaboration skills as central 21^{st} century skills, e.g., by the Center for Research on Evaluation, Standard, and Student Testing (CRESST) and the Assessment and Teaching of 21^{st} century skills (ATC21S) project (Scoular et al. 2017).

It is important to note that in many situations, a single individual has neither all relevant knowledge nor every specific ability to meet the diverse challenges of complex tasks on his/her own. Hence, groups actually hold the potential to outperform individuals due to the inter-individual exchange and integration of diverse information, different viewpoints, and divergent expertise (Greitemeyer et al. 2003; Hinsz et al. 1997). Discussing, integrating and explaining content in collaborative scenarios has been linked to deep learning, critical thinking, shared understanding, and long-term retention, and has further been shown to improve social and communication skills (e.g., Garrison et al. 2001; Kirschner and Kreijns 2005). Also, high expectations for groups have been fueled by the assumption that they can create synergy effects, thus achieving outcomes that go beyond what any individual could achieve (e.g., McGrath 1984; Stasser & Birchmeier, 2003). Q1

However, insights from CSCL research show that collaboration does not automatically lead to beneficial processes for learning and task performance (Kharrufa et al. 2009). Despite the unequivocal potential of collaboration, it has repeatedly been shown that groups often experience major difficulties in pooling distributed information, in establishing and maintaining common ground, and in coordinating the collaborative process (Rummel and Spada 2005). To advance collaboration, the development and investigation of tools to technologically foster mutual understanding, appropriate actions, and team organization are important goals to pursue (OECD 2017). With regard to this agenda, an important insight coming from a broad range of CSCL research is that neither the use of media nor the possibility to collaborate per se improve outcomes (e.g., Dillenbourg and Fischer 2007). Rather, the crucial factor is to create an environment (e.g., through instructions and scripting) that fosters effective and productive interaction processes. Since reaching a mutual understanding of the task and the content is of utmost importance for successful collaborative learning (Barron 2003) one focus has been the potential of providing support for intersubjective meaning making/grounding processes (Mercier and Higgins 2013; Suthers 2006). Within the last years, various studies explored the advantages the large and shared display of a multi-touch table can provide to establish and maintain mutual understanding (Dillenbourg and Evans 2011; Mercier and Higgins 2014; Rick and Keynes 2009). Summing up this research, collaboration has often been supported using scripting procedures or specific software highlighting problems, difficulties, or to-be-discussed information (e.g., Deiglmayr and Spada 2010b). It is important to note that many of these applications and studies concentrate on school-aged children (Piper and Hollan 2009) and that it cannot be taken for granted that groups can use the provided support of a multi-touch table efficiently (Mercier and Higgins 2014).

The present study extends this research by examining how the affordances of an intuitively usable collaboration support kit (CSK) can spontaneously help university students to improve collaboration processes and thus to overcome pitfalls of collaboration. Our CSK comprised a joint space (JS; as in previous studies) and private spaces (PS), as well as interactive support functions: it allowed participants to move information on the multi-touch table (something students are supposedly familiar with due to the omnipresence of touchscreen devices in everyday life). In detail, participants were enabled to push information from the PS into the JS and to jointly sort information within the JS. Further, they were provided with automatic functions like the merging of redundant information in the JS. These functions were implemented without training. To investigate relevant collaborative problem solving (CPS) processes and to transfer insights from prior studies to a new setting, we used the hidden-profile (HP) paradigm (Stasser and Titus 1985) which represents an established paradigm in social psychology and which has previously been implemented to investigate CPS (OECD 2017). A major difficulty in this paradigm is to overcome an initially formed preference and the resulting biases in information exchange and processing (Schulz-Hardt and Mojzisch 2012).

While the use and the potential benefits of tabletops and touch technology for collaborative learning scenarios have been the subject of CSCL studies (e.g., Antle 2012; Harris et al. 2009; Higgins et al. 2012; Rick and Keynes 2009), the role of prior preferences and knowledge for the subsequent information exchange has not yet been addressed in detail. In educational and everyday scenarios outside of laboratories and carefully planned studies, biases resulting from prior preferences and knowledge are likely to influence the collaborative processes and should be taken into account. Aiming to reduce this gap, we combined insights from CSCL research on the use of tabletops with insights from HP research on detrimental processes and biases resulting from prior preferences. Our goal was to demonstrate that the affordances of our CSK can support groups in overcoming prior preferences by raising the quantity and the quality of the information exchange. Therefore, we assessed whether our CSK spontaneously elicits interactive processes which increase the likelihood of exchanging and integrating previously unshared information in a balanced manner (i.e., by reducing biases). We hypothesize the positive influence of the CSK to be reflected in increased discussion intensity and mutual understanding and in decreased discussion biases, which in turn are hypothesized to be associated with a higher probability of successful task solution.

Theoretical background

Collaboration is defined by Roschelle and Teasley (1995) as “a coordinated, synchronous activity that is the result of a continued attempt to construct and maintain a shared conception of a problem” (p. 70). Combining this understanding of collaboration with problem solving (see Mayer and Wittrock 2006), it follows that CPS comprises the process of jointly working towards the solution of a problem when the path to this solution is unclear. It has been shown that collaboration likely stimulates cross-fertilization and individual learning (Brodbeck et al. 2007). Indeed, learning effects in CPS have previously been the target of research, especially within the CSCL community. It is noteworthy that learning through collaboration can even occur in the absence of the intentional effort to learn, for example through insights coming up while working on a problem-solving task (Bronckart 1995; Dervin 2003).

Recently, CPS is receiving attention in educational contexts (Maquil et al. 2017).[1] Taking into account the complex nature of CPS, it can be said that several factors – task characteristics, medium, and team composition to name a few – are of relevance for successful CPS in a given situation and that their impact differs as a function of the specific setting (OECD 2017). However, one factor that drives successful CPS in *any* scenario is the means of communication between the collaborators (Dillenbourg and Traum 2006; Fiore and Schooler 2004). Proficiency in communication entails taking into account the perspectives and knowledge of others and establishing as well as maintaining a mutual understanding of the solution process (OECD 2017). Maintaining a mutual understanding in turn requires groups to engage in building and constantly updating a common ground, also necessitating efforts to coordinate the content and structure of the interaction (Clark and Brennan 1991). Hence, it is important to identify ways to support proficiency in communication as intuitively as possible – which we attempted to do by making use of a multi-touch table's technological characteristics and their affordances in the current study.

The role of technology

Since the establishment and maintenance of mutual understandings are central for successful collaboration (see PISA 2015), previous studies investigated how they can be fostered using modern technologies. Actually, many studies investigating the effects of communication technology compared face-to-face communication with computer-mediated communication; Wittenbaum et al. 2004). Overall, the results suggest that the "type" of communication does not substantially affect information pooling and decision quality in HP scenarios (Lu et al. 2012; Suthers et al. 2008a, 2008b; Wittenbaum et al. 2004). Nonetheless, numerous CSCL studies underline the important role technological support can play to ensure successful collaboration and thus the accomplishment of desirable consequences of collaboration (e.g., Deiglmayr and Spada 2010b).

Clearly, no specific technology can claim to be the sole means of salvation (Dillenbourg and Evans 2011). Still, modern technologies provide interesting possibilities to support groups and individuals in such a way to relieve them of straining factors (Suthers 2006). Therefore, it has to be kept in mind that technological tools may differ with regard to their affordances and thus with regard to the processes and results they spontaneously evoke. Affordances are

[1] The Organization for Economic Cooperation and Development (OECD) recognized the need to understand collaboration skills by including CPS in their latest Program for International Student Assessment (PISA) in 2015 (OECD 2017). In PISA 2015, CPS was assessed by implementing a standardized computer supported human-agent interaction, where a student was to solve the curriculum-independent tasks in collaboration with one or more computer-simulated agents using pre-defined messages (OECD 2017). In general, at each step, the student could choose the most adequate messages out of two to seven alternatives. When a message was sent, the computerized agent replied accordingly and a new set of messages to choose from was presented to the student. This circle repeated itself until the student came to the solution. It is important to note that students received guidance from one of the agents if their choice was not conducive to reach the solution. Therefore, every student ended up solving the task, only the paths to the solution differed. Summing up, in order to measure collaborative skills, PISA developed a scripted, highly standardized paradigm, yielding a reliable assessment approach. Still, this procedure comes with issues of reduced external validity, because this kind of collaboration with computer agents does not directly compare to collaboration with actual persons (Greiff, Holt, & Funke, 2013).

properties that impel an action, for example a handle has the affordance to grab it and a button has the affordance to press it (Norman, 1988, as cited in Kirschner and Kreijns 2005). Q5 According to Suthers and Hundhausen (2003), the affordances and possibilities technological functions offer hold the potential to lead interactions towards ideas that are associated with the afforded actions. If this holds true, then technological functions can be implemented precisely to make use of implied affordances in a goal-directed manner, namely to elicit desirable behavior without explicit instructions. Thus, an effective use of technology requires congruency of afforded and desired actions. To specifically foster collaboration, technological support should enable intellectual exploration and social interaction, and it should be specifically designed to mediate and augment the establishment of mutual understanding (Stahl et al. 2006; Suthers 2006).

Traditionally, research that investigated support functions targeted collaboration in *dispersed* teams. In line with current patterns of media use in everyday life (chat, videoconferences, etc.), mainly computer-mediated scenarios were explored (see Baltes et al. 2002; Wittenbaum et al. 2004). However, technological support can also improve communication between *co-present* collaborators (Suthers and Hundhausen 2003). An especially promising technology for group support in face-to-face situations is the multi-touch table which has been described as an “interpersonal computer” (Kaplan et al. 2009), because it has a large touchscreen surface, which allows a number of collaborators to simultaneously access a joint space and to interact with the represented content (Higgins et al. 2012; Shen et al. 2009). The simultaneously viewable screen (in comparison to individual screens or a small shared screen) and the possibility for joint control (no single input device like a mouse or a keyboard is needed) make up the special potential of a multi-touch table (Mercier and Higgins 2014). Thus, the employment of multi-touch tables may provide a technologically enriched setting especially suited to support face-to-face collaboration (Dillenbourg and Evans 2011; Higgins et al. 2011). In particular, multi-touch tables support co-location, multiple users, hands-on-activities, and multiple modes of communication (Dillenbourg and Evans 2011). This renders the multi-touch table a promising tool for learning settings at school or universities as well as professional settings whenever group work is applied. Within the shared and interactive visual environment, different functions can be implemented, such as the possibility to jointly move and structure pieces of information during discussion according to a commonly agreed “coding scheme”.

Previous studies conducted within the CSCL community provide evidence for the multi-touch table’s potential benefits on collaboration. Higgins et al. (2012) compared groups of students performing a task either in a paper-based manner or at a multi-touch table. Interestingly, students using a multi-touch table were faster in reaching a shared understanding of the task than students in the paper-based condition. More specifically, students using the multi-touch table built more strongly on each other’s ideas and showed higher rates of responding to and considering contributions of other group members during discussion. Thus, the multi-touch table environment facilitated a beneficial pattern of interaction. In a related study by Mercier and Higgins (2014), student groups used a multi-touch table to create external representations in a logical problem solving situation. Groups using the multi-touch table to externalize their reasoning processes reached higher levels of reasoning, indicating that the use of the multi-touch table can support joint reasoning and thereby facilitate problem solving. Basheri, Burd and Baghaei (as cited in Mercier and Higgins 2014) also report differences in the way people interact with multi-touch tables in comparison to PCs. For example, conversations in the multi-touch table condition were more task-focused and less process-focused, meaning groups in the multi-touch table condition talked more about task-related content than about how to proceed which was not the case in the PC condition (Harris et al. 2009). The potential benefits of multi-touch tables have been explored in a variety of case studies (Maquil et al. 2017). Researchers came to the conclusion that the decisive factor is not the multi-touch table itself but its use during collaboration, or rather, the affordances of the available functions and how they influence the manner of the interaction (Dillenbourg and Evans 2011; Higgins et al. 2011). To the best of our knowledge, the impact of affordances of multi-touch table support functions on *biased* communication processes has not been tested previously. The current study addressed this gap and complemented the existing research by investigating how affordances of intuitive interactive support functions implemented on a multi-touch table can support processes relevant for CPS, like a balanced exchange and integration of information as well as the establishment and maintenance of mutual understanding. To this end, we designed a CSK incorporating support functions to elicit the exchange and integration of information as well as actions related to building common ground in such a way that biases resulting from prior preferences can be overcome. For example, our CSK allowed users to push information pieces away from themselves into a shared area; we assume that this should help individuals to dissociate themselves from their own information pieces, thus potentially reducing the detrimental influence of ownership biases on discussion. Note that making use of these affordances can be viewed as an implicit scripting procedure. This should hence also help individuals to overcome prior preferences during discussion if new information contradicts previously-owned information pieces.

The challenge to counteract biases

When entering a collaborative situation, individuals usually hold some general beliefs; they have knowledge and convictions and are already persuaded by specific arguments (and reluctant to consider others). All of these are likely to influence the way in which an individual weighs upcoming arguments during information exchange and his/her interpretation of specific information pieces. Furthermore, they are likely to differ among the teamed-up individuals, who are thus likely to come up with different conclusions based on the information mentioned during a group discussion. Accordingly, there is evidence showing that existing knowledge and prior preferences can result in biased information exchange and processing (Greitemeyer and Schulz-Hardt 2003; Tversky and Kahneman 1974) which in turn can threaten the success of CPS. The role of prior preferences has often been investigated in the laboratory using the HP paradigm, which is well-established in the domain of small-group research in social psychology and has been employed in various contexts (e.g.; Deiglmayr and Spada 2010a; Greitemeyer and Schulz-Hardt 2003; Suthers et al. 2008a, 2008b). The defining characteristic of the HP paradigm is that prior preferences are experimentally manipulated by implementing an information distribution in which group members receive so-called *shared information pieces* (every member possesses this piece of information) as well as so-called *unshared information pieces* (only one member possesses this piece of information) prior to the group discussion. It is important to note that, within the HP terminology, the term "shared information" neither implicates a mutual understanding of the information nor awareness or common ground with regard to who else possesses this piece of information. It merely describes the fact that each group member has this information piece in his/her initial information set.

The HP paradigm consists of two phases, in which participants have to decide between several alternatives in a given setting such as a job candidate selection task in a professional setting. In the first phase, information about the alternatives is presented individually to each group member. Importantly, the set of information favors a suboptimal decision alternative for each participant. As a result, if he/she properly integrates the information pieces, each participant forms a "false" preference for a non-optimal candidate in this individual phase. Once all participants have formed a (false) preference, they enter the second phase of the HP paradigm, in which they meet the other group members for a discussion. The group's task is to exchange the pieces of information from the individual phase, to jointly integrate them, and to come up with the optimal decision collaboratively. The crucial point is that the optimal alternative is only revealed if the participants manage to exchange all pieces of information and integrate them in an unbiased manner. Surprisingly, groups often fail to solve the HP task (Brodbeck et al. 2007; Lu et al. 2012; Schulz-Hardt and Mojzisch 2012). They mostly concentrate on shared information and thus fail to overcome prior preferences and stick to a suboptimal alternative after the group discussion. Thus, even the exchange of all information does not guarantee successful task performance. The persistence of this group failure has sparked many attempts to identify the relevant processes (Brodbeck et al. 2007; Lu et al. 2012; Schulz-Hardt and Mojzisch 2012).

The skewed distribution of information among group members renders the HP the prototype of a situation in which a group has the chance to outperform an individual (Lu et al. 2012; Schulz-Hardt and Mojzisch 2012). In such a situation, collaboration can lead to synergetic effects, since it is the only way to solve the problem. This is because none of the individuals can find the best option based on his/her individual set of information. Therefore, group members have to overcome prior preferences through exchanging and integrating all pieces of information and constructing a shared understanding based on all information pieces in an unbiased manner. This makes the HP an ideal paradigm to study processes relevant for CPS and decision-making in a controlled experimental setting.

Note that the HP procedure is based on similar principles as "Jigsaw grouping" (e.g., Aronson et al. 1978), which represents an established cooperative learning technique within the CSCL community. In both scenarios, the exchange of information is necessary but not sufficient to reach the optimal solution. In Jigsaw grouping, each participant is part of one Jigsaw group as well as one expert group. In the first phase, each expert group studies one specific topic within the broad domain of interest. Later, each individual works together with his/her Jigsaw team, comprising one member of each expert group, to help one another learn about the domain as a whole (see also Slavin 2011). In both the HP task and Jigsaw grouping, exchanging and integrating information that had initially been known only by particular group members is crucial for successful learning and task performance. In both scenarios' second phases, participants are encouraged to integrate information from the first phase. In Jigsaw tasks, this information is unshared and the challenge is to combine it properly in order to draw the adequate inferences (i.e., knowledge from different expertise areas is combined). The crucial difference is that in HP tasks, there are shared and unshared information pieces, and thus incorrect preferences are experimentally triggered within participants prior to the exchange phase, so their specific influence on the group discussion can be investigated. Thus, the major difficulty within the HP paradigm is to establish an unbiased integration of information in spite of initially formed preferences and the resulting biases in information exchange and processing. Another difference between the paradigms is that Jigsaw focuses on information exchange with the goal to enhance each group member's *knowledge* based on the integration of all information, whereas the HP task requires participants to come to a joint decision. Yet, this difference mainly concerns the outcome measure of the collaboration. Though the HP task is completed only upon a decision about the optimal candidate, measures of information exchange and communication can and should be assessed as well, as both crucially determine successful HP performance. This is why we argue that the HP represents a fruitful approach to extend the knowledge on CPS processes in a situation where prior knowledge is apparent.

The HP paradigm has previously been implemented in a few CSCL studies to gain insights on collaborative processes. For example, Suthers et al. (2008a, 2008b) investigated collaborative knowledge construction and how it depends on different support functionalities. Dyads of asynchronously communicating partners were tested in a dispersed computer-mediated setting. Among others, the compared support approaches comprised conditions of threaded discussion or knowledge mapping. The result of this study neither revealed differences between the conditions with regard to solution quality, nor with regard to information exchange and memory measures. The observed differences rather concerned the usability (knowledge mapping received more negative comments), the timing of solution steps (earlier consideration of hypotheses in the mapping approach), and the discussion intensity (less discussion in the threaded discussion approach). This pattern of results might indicate that the different support approaches varied not so much in their effectiveness with regard to solution attainment but rather in their effect on the chosen *path* to the solution. Thus, not only outcomes like solution quality, but also the impact of a support approach on the solution process should be explored to increase our understanding of how technological support can be used to enhance processes relevant for CPS. That is, the HP task not only enables us to measure the decision outcome but also to assess indicators of the solution process, which forms an appropriate basis to generalize findings from the HP task to other collaboration scenarios.

In their studies employing the HP paradigm, Deiglmayr and Spada (2010a, 2010b, 2011) investigated the skill to draw inferences from interdependent information that had been unshared and distributed between collaboration partners ("collaborative inferences"). They showed that groups receiving training and guidance from a tutoring tool were better at drawing inferences from pooled information (a collaboration skill many people struggle with) in a subsequent task, compared to groups without tutoring tool or prior training (Deiglmayr and Spada 2010b). Participants with tutoring had to exchange information in a computer-mediated setting and received feedback, such as praise for every new information item they brought up and for drawing correct inferences. Furthermore, they received prompts as to who had corresponding information and hints when information pieces were still missing or an inference was not yet drawn. A human observer matched the feedback to the respective utterance. This specific feedback during the training phase is an example of a very effective and elaborate – while at the same time very close-knit and explicit – form of scripting, that holds the disadvantage of being quite resource demanding. Note that, though one cannot directly compare different types of inferences in this study's HP task to Deiglmayr and Spada (2010a, 2010b), our task is similar to the one used in their study in that participants need to integrate their collaborative knowledge resources in order to succeed. Furthermore, we employed no training or explicit scripting, choosing instead to focus on a less demanding and intuitively usable CSK. Employing this CSK and its affordances can be viewed as implicit scripting. For example, participants might perceive the availability of the different spaces (JS, PS) as a prompt where to place information pieces, and the structure of information pieces within the JS might highlight, whether an information piece has been discussed.

The current study

The current study aimed to investigate whether small groups in a relatively unrestricted setting can be supported in overcoming prior preferences and resulting biases in information exchange through the affordances of intuitively usable technological functions. We analyzed the discussion process of groups performing a HP paradigm through video data and additionally measured the joint task performance (i.e., final group decision). In accordance with the PISA framework, in which the establishment and maintenance of a shared understanding is postulated as one of the central competencies underlying successful human-to-human collaboration, our aim was to test how the affordances of interactive support functions elicit expedient behavior with regard to the aforementioned processes. To accomplish this goal, we observed CPS processes derived from the PISA framework in a computer-supported human-to-human interaction, focusing especially on processes related to establishing and maintaining a shared understanding and on processes relevant for the solution of HP tasks (OECD 2017; Schulz-Hardt and Mojzisch 2012).

According to Rick and Keynes (2009), the interface design elicits behavioral and emotional responses (in the sense of affordances) in users, thereby influencing the manner of the collaborative process. To determine what kind of interactive support functions would be most suitable to elicit desirable behavior in a HP scenario, we not only focused on the processes that are important for this type of task in general (e.g., establish and maintain mutual understanding), but also on processes that are specifically known as HP hindrances. To this end, we employed a recent model determining specific processes that can prevent groups from solving HP tasks (Brodbeck et al. 2007; Schulz-Hardt and Mojzisch 2012). The model postulates that two general processes are necessary for success: (1) the exchange of all relevant information within the group and (2) the processing of this information by each individual (Schulz-Hardt and Mojzisch 2012). In addition, Schulz-Hardt and Mojzisch (2012) state that these two processes have to be characterized by (A) a sufficient intensity and (B) a sufficient lack of bias. The combination of the two processes and the two characteristics results in four factors that are likely to impair the solution of HP tasks (see Fig. 1): a) insufficient discussion intensity (not all pieces of relevant information are exchanged), b) insufficient processing intensity (superficial processing, information is not encoded properly), c) discussion biases (shared and preference-consistent information is mentioned more often), and d) evaluation biases (shared and preference-consistent information is evaluated more favorably, perceived ownership of information leads to more favorable evaluations). With regard to biases, one influencing factor is that shared information is repeated more often during discussion, which may cause a shift in the processing and evaluation of this information (Lu et al. 2012). Furthermore, without sufficient motivation, the group members are likely to exchange information only superficially; the discussion intensity may thus stay low, impeding the solution of the HP task (Scholten et al. 2007).

	Intensity (A)	**Bias (B)**
Group level (1)	Discussion intensity ↑	Discussion biases ↓
Individual level (2)	Information processing intensity ↑	Evaluation biases ↓

Fig. 1 Factors possibly impairing the solution of hidden profile tasks according to Schulz-Hardt and Mojzisch (2012)

Note that a negative manifestation of only one of these factors is sufficient to prevent groups from finding the optimal alternative. Thus, to support groups in solving HP tasks, discussion biases should be minimized, discussion intensity should be increased, information processing should be facilitated, evaluation biases should be decreased, and group members should be sufficiently motivated. Without establishing and maintaining a mutual understanding of all information, solving the HP is unlikely.

Following Schulz-Hardt and Mojzisch (2012), we assume that the postulated processes are just as relevant in other collaboration scenarios and more natural settings. Therefore, we employed support functions that are also likely to elicit expedient behavior in other scenarios requiring the exchange and integration of information, as well as overcoming preferences (though this remains to be tested in future research). Using these functions to elicit certain behavior reflects an implicit form of scripting. In detail, we chose the functions comprising our CSK in a way to afford actions shown to raise discussion intensity (exchange of information), balance discussion biases (proportion of shared and unshared information), and foster mutual understanding. The functions aimed at eliciting a structured and balanced exchange of information and provided a setting in which a mutual understanding of the exchanged information can be established and maintained. Thereby, we planned to support participants in overcoming biases resulting from prior preferences. In detail, the CSK included the possibility to push individually owned information into a JS (promoting the exchange of all information and reducing the salience of ownership), the possibility to structure information together in this JS (promoting mutual understanding of the information), and a merging function (promoting a more balanced discussion with regard to shared and unshared information). Furthermore, we expected the use of the rich and interactive nature of the communication environment at the multi-touch table (as established by the employment of support functions in the CSK condition) to be linked to high engagement with the task, motivation, and involvement in the interaction. All these processes are expected to contribute to raising the chance to solve the HP. In sum, the effects of the CSK should be linked to a more intense and balanced discussion of information and to a better outcome.

To examine whether our technological support at the multi-touch table served its purpose to spontaneously elicit and enhance beneficial behaviors, we compared CPS processes and performance of groups with a CSK (CSK condition) to those of groups performing under traditional HP conditions without such support (standard HP condition). We designed the standard HP condition to replicate traditional HP setups while keeping the technological setting (i.e., individuals worked at the multi-touch table but each with a private space with no interactive features). This design allowed us to gauge our results in the context of other traditional HP studies and to investigate the potential of an intuitively usable CSK to foster processes relevant for CPS in situations where prior preferences are typical.

Summing up, we hypothesized that, compared to groups in the standard HP condition, groups with the CSK available should show:

1. a higher discussion intensity
2. a more balanced ratio of shared and unshared information during discussion (i.e., less biased discussions)
3. higher values on indicators for the establishment/maintenance of mutual understanding
4. a higher rate of correct solutions (i.e., less biased decisions)
5. higher engagement, motivation, and involvement

Methods

Participants

Participants were recruited via an online recruiting system (OrSEE) at the Leibniz Institut für Wissensmedien in Tübingen, Germany. Most participants were university students from different fields of study with a mean age of 22 years (SD = 4.55). In total, 219 participants (162 women) in 73 triad groups participated; they were randomly assigned to the experimental conditions. Nineteen groups were excluded from the analyses because videos were lost due to technical errors, leaving 29 groups in the support and 25 groups in the standard HP condition. Participants received an hourly rate of €8 as compensation.

Design

In our study, we manipulated whether the HP task was performed with the CSK at the multi-touch table vs. in a standard HP condition at the multi-touch table. Participants in the standard HP condition had access to their individual information sets within their PS during group discussion; participants in the CSK condition were enabled to move information pieces from their PS into the JS and to jointly sort them in any way to facilitate weighting of the arguments and decision making.

Dependent variables were several indicators of the discussion intensity and biases, indicators for the establishment and maintenance of mutual understanding, and the quality of the group decision. Following Schulz-Hardt et al. (2006), we interpreted the discussion intensity to be reflected by the duration of the group discussion. Coded discussion data was converted into frequencies of utterances within the categories described in Fig. 2. These frequencies were used to calculate further indicators of discussion intensity. One indicator was the proportion of information introduced into discussion (the number of items mentioned at least once divided by the number of existing items within the respective category). The average proportion was calculated as the unweighted mean of the percentage of shared and unshared information. We used the rate of information repetition as another indicator (the total number of repetitions per group divided by the number of items mentioned at least once within the respective category). The average rate of repetition was calculated as the unweighted mean of the repetition rate of shared and unshared information.

Regarding discussion biases, we first measured whether shared information was emphasized during the discussion (see Schulz-Hardt et al. 2006), reflecting both the introduction and repetition of shared vs. unshared information. This bias was thus assessed by comparing the overall proportion of introduced shared vs. unshared information or repeated shared vs. unshared information. Further bias measures regarding information introduction as well as information repetition were calculated based on Stasser et al. (2000).[2]

To assess the establishment and maintenance of mutual understanding, we analyzed indicators of the process of CPS and self-report measures as well as observer ratings. With regard to communicative processes, on-topic utterances and coordinative utterances were taken

[2] For the discussion bias measure according to Stasser, Vaughan, and Stewart (2000) the introduction/repetition rate for shared information was divided by the sum of the rate of introduced/repeated shared and unshared information. For this measure a value of .5 (range 0 to 1) indicates an unbiased discussion, larger values indicate a stronger bias towards shared information.

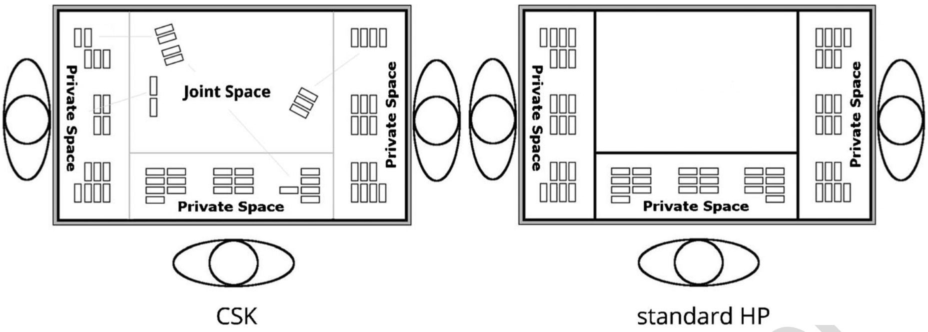

Fig. 2 Illustration of the experimental setup in both experimental conditions (left illustration: CSK; right illustration: standard HP)

as positive, whereas off-topic utterances were taken as negative indicators of mutual understanding. Further, mutual understanding of the information and the task at hand is reflected by whether integrated information (namely dimensions) or single characteristics form the base of the decision. Therefore, we analyzed self-report measures and observer ratings to reveal insights on the base of the group's decision.

The quality of a group decision was operationalized as the correctness of the choice the group agreed upon. The correct choice was Candidate C (in contrast to Candidates A or B).

Last, subjective user experience was measured using engagement, motivation, and interaction involvement scales. That is, participants rated their motivation (1 item, "Finding a good solution was important to me"), their involvement in the interaction (3 items, Cronbach's $\alpha = .52$, e.g., "I was intensely involved in the interaction"), and their engagement with task and technology (6 items, Cronbach's $\alpha = .76$; e.g., "The multi-touch table supported me in immersing myself in the task"); each of these items was measured on a scale from 1 to 7 (1 = do not agree, 7 = agree).

Apparatus

Multi-touch table The study was conducted on a multi-touch table by eyevis (EYE-LCD-8400-QHD-V2(-TIRP50AG)) with a 84" Ultra-HD LCD monitor and a resolution of 3840 × 2160 pixels at a frame rate of 660 Hz. The multi-touch table was equipped with a touch system from PQLabs and was capable of recognizing and recording over 50 touch points simultaneously. The task environment was programmed with ActionScript3.

Since we tested triads of participants, the multi-touch table interface consisted of three PSs (40 cm × 105 cm). In the CSK condition, we also had a JS (65 cm × 105 cm; see Fig. 2), so the information cards could be moved by each individual from his/her PS to the JS. This function was implemented to reduce the salience of ownership of information items (which has previously been shown to bias discussions; Brodbeck et al. 2007), to promote the pooling of all information items, and to enable visibility of own as well as of other group members' items. Once entered into the JS, cards could also be rotated and moved around freely. Thus, each individual could move and structure all items within the JS during the discussion. This function was implemented to promote the establishment and maintenance of mutual understanding. Some information cards were held by all three individuals; when one of those cards was pushed to the JS by one individual, then the matching cards were automatically pulled from the others' PSs and merged into one card within the JS (promoting balance of shared and unshared information during discussion). This function was implemented to counteract detrimental effects of repetition (e.g., Weaver et al. 2007) during HP task performance.

By providing the information within the JS to all group members, participants in the CSK condition were encouraged to not only verbally but also digitally exchange their individual information. All CSK functions were designed in a way to help the participants to integrate all information items and to overcome the preferences from the first phase.

Video and discussion analysis Group discussions were videotaped for in-depth analysis using a Panasonic camcorder with integrated microphone (HC-V707, 1080p). A professional company specialized in audio transcriptions (audioTranscribe GbR) produced transcripts as support for the analysis of discussions. We adapted existing coding schemes (see Kolbe 2007; Sassenberg et al. 2014) to our research, resulting in 17 categories covering five classes for utterances (see Fig. 3). Within the classes "item" and "candidate", the item number and candidate label were specified additionally to the category. Research assistants trained with the coding scheme coded the videos. An inter-rater reliability of Cohen's $\kappa = .69$ (Cohen 1960) for the most detailed level (accordance of class, category, and specification) was considered sufficient (Landis and Koch 1977).

Materials & procedure

At the beginning of the study, participants individually signed the informed consent and positioned themselves at the multi-touch table to receive information for the HP task. Three participants worked at the same multi-touch table. Following the established HP procedure based on Greitemeyer and Schulz-Hardt (2003), participants were instructed to imagine being part of a selection committee, receiving three applications for a position as a project team leader. Within their PS, participants were then individually presented with information about three candidates, named Candidates A, B, and C (9 items per candidate), with privacy shields separating their PSs to ensure that participants could not exchange (or spy) information during

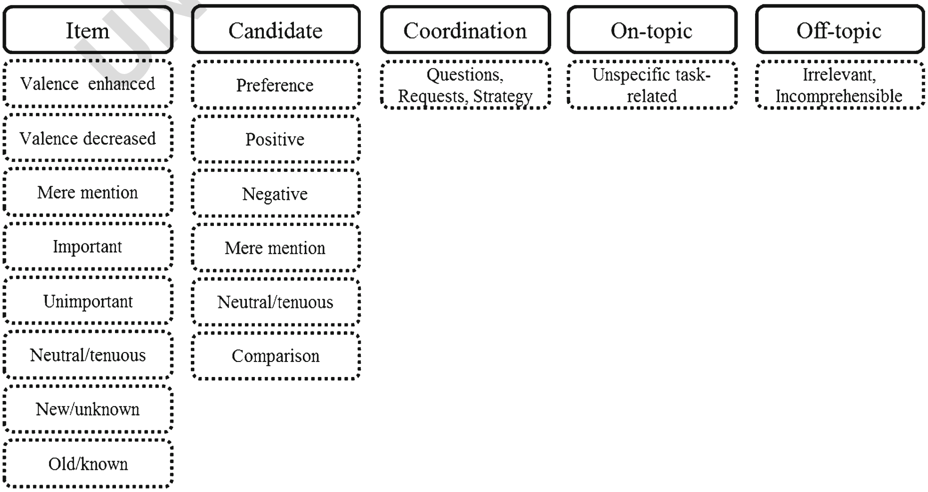

Fig. 3 Coding scheme used for the discussion analysis

the individual phase. Information were displayed on cards in black font on white background; the information cards additionally showed a blue square containing the letters A, B, or C as indicators of the described candidate. Each information item was either clearly positive (e.g., "Is happy to assume responsibility", "Speaks several foreign languages") or moderately negative (e.g., "Frequently changes his mind", "Is not very sociable"). All information items were chosen from a pool of 140 items tested in a pre-test ($N = 18$) in such a way that importance and valence ratings of the items were balanced across candidates. Each participant received 9 information items for each candidate; some of the information items were learned by all participants (i.e., "shared information"), other information items were only learned by one of the participants (i.e., "unshared information"). Taken together, there were 45 information items available to the group as a whole. These revealed Candidate C to be best option, B to be intermediate, and A to be least suitable. The overall information distribution was as follows: Candidate A had six positive (all shared) and nine negative (all unshared) attributes, Candidate B had seven positive (four shared, three unshared) and eight negative (two shared, six unshared) attributes, and Candidate C had nine positive (all unshared) and six negative (all shared) attributes. In a pretest, we presented participants with all three individual information sets at once (integrated information set; $N = 28$). Remarkably, 85.7% of participants in this pretest judged Candidate C to be the best candidate. In contrast, only 7.5% of the participants presented with any of the three individual information sets ($N = 40$) chose Candidate C, while 32.5% chose B, and 60% chose A to be the best candidate.

Each participant studied his/her initial information set for as long as desired and then chose a preferred candidate. All three participants indicated their individual preferences and rated each candidate with regard to his/her suitability (1–100). Next, instructions for the group discussion appeared within each participant's PS. Participants in both conditions read that, like committee members in real-life, they did not receive all relevant information in the course of the individual phase. Therefore, they would now collaborate with two other committee members to finally identify the optimal candidate based on a larger amount of information. Remarkably, in consideration of all information pieces available to the group as a whole, the preferences from the first phase were sub-optimal, so they had to be overcome during the second phase of group discussion. The discussions were limited to a maximum of 20 min and were videotaped. Instructions specifically pointed out that the group members had not received the exact same information about Candidates A-C beforehand, so they had to exchange all pieces of the individual information sets to determine the best candidate.

For groups in the CSK condition, the instructions additionally highlighted the available interactive support functions for the group discussion of the information pieces; they were asked to move all information items into the JS during discussion and were pointed to the possibility to sort information in any way to facilitate the decision for either candidate. Once all three PS were empty and triads indicated to have come to a joint decision, groups in the CSK condition were asked to enter their final decision and joint candidate ratings (on a scale from 1 to 100).

To prevent differential effects of forgetting in both experimental conditions, for the group discussion, the individual information sets were presented again within the PS in the standard HP condition; participants in this condition then had to verbally share the information pieces from the individual sets to find the best solution for the personnel selection task. After triads in the standard HP condition indicated to having exchanged all information and made their decision, the group decision was assessed. Then, the JS was activated and a merged version of all information items was therein presented (45 items, no repetition of shared information). The groups were then allowed to discuss the information and were again asked to indicate their (revised) decision and to jointly enter suitability ratings for each candidate within the JS.

Following the group decision, participants in both conditions again stated their individual decisions and candidate ratings (again protected by the privacy screen) and switched rooms to complete the paper-pencil questionnaire and the digital post questionnaires. At last, they received a debriefing and their payment.

Results

All analyses were conducted using the statistic software R (R Core Team, 2012); the α-Level was set to be .05 for all analyses. We first report the results from our analyses testing whether providing groups with the CSK during group discussion increased the discussion intensity (Hypothesis 1), decreased discussion bias (Hypothesis 2), and fostered grounding processes (Hypothesis 3), as compared to the standard HP condition. We then report the results regarding decision quality within the CSK condition vs. the standard HP condition (Hypotheses 4). Last, we report results from exploratory analysis and additional analyses concerning differences between the experimental conditions regarding self-report measures such as engagement with the task and motivation (Hypothesis 5), and satisfaction with the interaction.

Discussion intensity

We expected the discussion intensity (as indicated by the discussion time, the proportion of introduced information, and the rate of information repetition) to be higher in the CSK condition than in the standard HP condition. Differences regarding the discussion intensity as a function of technological support were analyzed by means of separate one-factorial analyses of variance (ANOVA) for each indicator.

Discussion time The overall discussion time differed between the CSK and standard HP condition, $F(1, 52) = 40.84$, $p < .001$, $\eta^2 = .44$. That is, participants in the CSK condition ($M = 15.65$ min, $SD = 3.99$ min) spent more time discussing before they indicated to having come to a joint decision than participants in the standard HP condition ($M = 8.08$ min, $SD = 4.71$ min).

Average proportion of information introduced The ANOVA revealed a significant difference between the CSK and standard HP condition, Welch's $F(1, 33.02) = 18.82$, $p < .001$, est. $\omega^2 = .25$. As expected, the proportion of introduced information items was larger in the CSK condition ($M = 93\%$, $SD = 11\%$) than in the standard HP condition ($M = 71\%$, $SD = 24\%$). This indicates that the collaborative process of information exchange was enhanced in groups provided with the CSK compared to standard HP groups.

Average rate of information repetition The average information repetition rate differed between conditions, $F(1, 52) = 5.55$, $p = .022$, $\eta^2 = .10$. Participants repeated information items introduced into discussion more often in the CSK condition ($M = 2.33$, $SD = 0.67$) than in the standard HP condition ($M = 1.89$, $SD = 0.68$), meaning that the discussion was more intense when the CSK was available. This higher repetition rate may have caused the longer discussion time in the CSK condition compared to the standard HP condition.

Summing up the results regarding the discussion intensity, the results regarding all three indicators deliver converging evidence that providing the CSK raised the discussion intensity compared to the standard HP condition, thereby supporting Hypothesis 1.

Discussion bias

To analyze the discussion intent, we compared the proportion of shared relatively to unshared information pieces as a function of the experimental condition. We expected discussions to be more "balanced" in the CSK condition than in the standard HP condition. In detail, we used (1) the proportion of shared and unshared information items introduced and (2) the repetition rate as dependent variables. We expected no difference between shared and unshared information items in the CSK condition, whereas we expected to replicate the established bias towards shared information in the standard HP condition. To test this assumption, we conducted two two-factorial ANOVAs with the between-participants factor experimental condition (CSK, standard HP) and the within-participants factor information sharedness (shared, unshared). With regard to the amount of shared and unshared information pieces introduced into discussion, main effects of condition, $F(1, 52) = 20.73$, $p < .001$, $\eta_G^2 = .26$, and information-sharedness, $F(1, 52) = 34.80$, $p < .001$, $\eta_G^2 = .08$, were observed. Importantly, these were qualified by an interaction effect, $F(1, 52) = 41.78$, $p < .001$, $\eta_G^2 = .10$., indicating that shared and unshared information items were introduced in nearly identical rates in the CSK condition, yet shared information was introduced notably more often than unshared information in the standard HP condition (see Fig. 4). Turning to information repetition rates, only main effects of condition, $F(1, 52) = 5.55$, $p = .022$, $\eta_G^2 = .08$, and information-sharedness, $F(1, 52) = 16.58$, $p < .001$, $\eta_G^2 = .05$, were obtained; no interaction effect was observed, $F(1, 52) = 2.17$, $p = .15$, $\eta_G^2 = .01$. That is, groups in both experimental conditions repeated shared ($M = 2.29$, $SD = 0.88$) information items more often than unshared information items ($M = 1.96$, $SD = 0.64$), and groups in the CSK condition

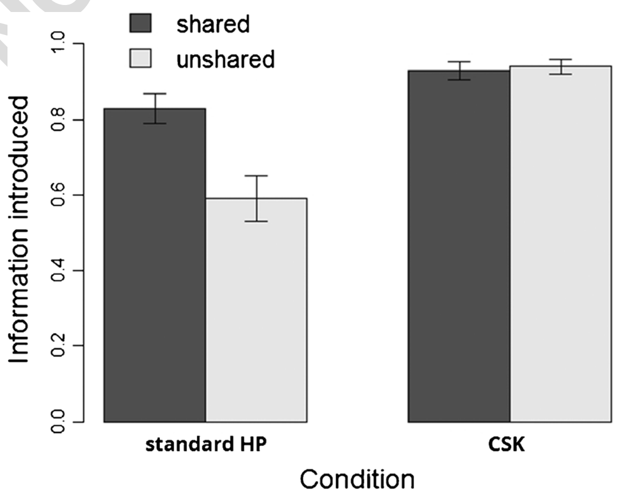

Fig. 4 Overall information introduction rate for shared and unshared information pieces in the standard HP and CSK conditions. Error bars represent the standard error of the means

($M = 2.33$, $SD = 0.72$) repeated more information than groups in the standard HP condition ($M = 1.89$, $SD = 0.80$).

Overall, these results indicate that the typical discussion bias in favor of shared information –as reflected in the proportion of information introduced into discussion– was balanced out in CSK groups, supporting Hypothesis 2.

Indicators of establishing and maintaining mutual understanding

In order to gain insights on how groups focused on establishing and maintaining mutual understanding, we analyzed objective measures gained by coding the discussion video data as well as subjective measures as assessed in our post-task questionnaire. For the objective-measures analysis, we compared the number of utterances that were on-topic, off-topic or focused on the coordination of the interaction between both experimental conditions using linear mixed effect modeling. The type of utterance (on-topic, off-topic, coordinative), $\chi^2(2) = 216.75$, $p < .001$, and the experimental condition (CSK, standard HP), $\chi^2(1) = 17.96$, $p < .001$, both influenced the number of utterances; more importantly, a significant interaction between both factors was obtained, $\chi^2(2) = 23.98$, $p < .001$. The increase of on-topic utterances in comparison to coordinative utterances, $b = 32.23$, $t(108) = 3.72$, $p < .001$, was higher in the CSK than in the standard HP condition (CSK condition: $M_{coordination} = 28.79$, $M_{on\text{-}topic} = 135.70$, $M_{off\text{-}topic} = 8.21$; standard HP condition: $M_{coordination} = 12.68$, $M_{on\text{-}topic} = 87.36$, $M_{off\text{-}topic} = 3.04$).

For the subjective-measure analysis, a one-factorial ANOVA was conducted to compare decision criteria between the experimental conditions (CSK, standard HP). Interestingly, a higher proportion of participants reported having used structured dimensions and integrated information (e.g., comparing candidate profiles) as decision criteria in the CSK condition ($M = 65\%$) than in the standard HP condition ($M = 31\%$), $F(1, 52) = 61.45$, $p < .001$, $\eta^2 = .54$. Further, unstructured specific characteristics of candidates were mentioned more often as decision criteria in self-reports from the standard HP condition (M = 73%) than in self-reports from the CSK condition ($M = 16\%$), $F(1, 52) = 65.90$, $p < .001$, $\eta^2 = .56$. In line with these subjective measures, the observer ratings also suggest that groups in the CSK condition discussed information with more focus on relevant dimensions like candidate, valence, and importance than groups in the standard HP condition ($M_{CSK} = 7.57$, $M_{standardHP} = 6.57$; $F(1, 52) = 9.45$, $p = .003$, $\eta^2 = .15$).

Taken together, the results obtained with regard to the objective as well as subjective indicators of the establishment and maintenance of mutual understanding converge in demonstrating that CSK groups reached a better mutual understanding than groups in the standard HP condition, thus yielding support for Hypothesis 3.

Decision quality

We assumed that beneficial effects of the interactive support functions on the collaborative process would carry over to the outcome quality. Hence, we expected the decision quality to be higher in the CSK condition than in the standard HP condition. We analyzed the decision quality as a dichotomous variable (right choice: Candidate C vs. wrong choice: Candidates A or B), so we fitted generalized linear effect models (glm model) of the logit-family to test our hypothesis, predicting the probability of the occurrence of a correct choice in the form of odds ratios (OR) with the *glm* function. Compared to a model containing only an intercept as predictor (intercept model, AIC: 76.56) the model with the condition predictor (CSK vs. standard HP, AIC: 69.56) showed a better goodness-of-fit, $\chi^2(1) = 9.06$, $p = .003$. This indicates that the conditions differed in decision quality. In detail, the chance to make the right decision was over five times higher (OR = 5.58) in the CSK condition than in the standard HP condition (see Table 1). While only 32% of the groups in the standard HP condition made the correct choice, 72% of the groups in the CSK condition succeeded to solve the HP task. Taken together, the decision data supports our Hypothesis 4: As expected, the CSK condition was substantially more likely to solve the collaborative task, compared to those groups performing the traditional HP task without the CSK.

With regard to the decision quality in the standard HP condition, an additional analysis revealed that the chance to make the right decision was over three times higher (OR = 3.78) after participants were presented with the merged set of information items than after pure discussion (see Table 2). That is, presenting participants with the whole set of information improved their decision performance. After the information had been presented within the JS, 64% of the groups in the standard HP condition decided for the best candidate C.[3] This analysis suggests that the pure presentation of the merged information pool might enable groups to reach better outcomes. However, it is important to note that our video data show that the path to this solution is characterized by little discussion, indicating a superficial integration process and no effort to build common ground. This indicates that activating the JS was less effective in enhancing the discussion than the usage of the whole CSK, comprising both the JS and automatic and adaptive support-functions.

User experience

We expected participants in the CSK condition to report higher engagement, motivation, and involvement in the interaction with their group members than participants in the standard HP condition. Separate one-factorial ANOVAs were conducted for these three self-report measures. These analyses revealed that participants in the CSK condition ($M = 5.76$, $SD = 0.96$) were more engaged with the task and technology than participants in the standard HP condition ($M = 5.18$, $SD = 0.94$), $F(1, 52) = 10.65$, $p = .002$, $\eta^2 = .17$. Similarly, participants in the CSK condition ($M = 5.84$, $SD = 0.85$) were more involved in the communication than those in the standard HP condition ($M = 5.4$, $SD = 0.90$), $F(1, 52) = 10.65$, $p = .002$, $\eta^2 = .13$. However, no differences between the conditions were observed with regard to motivation, $F(1, 52) = 1.06$, $p = .308$. Thus, the results do not support Hypothesis 5 unambiguously. It is notable, however, that motivation ratings of participants in both conditions were quite high ($M_{CSK} = 6.23$, $SD_{CSK} = 1.00$; $M_{standardHP} = 6.07$, $SD_{standardHP} = 0.95$ with "7" being the upper end of the rating scale), so possibly the lack of a difference between the conditions is attributable to a ceiling effect.

With regard to the manner of CSK utilization, no systematic analysis can be provided. However, a look into screenshots from the multi-touch table revealed that the way in which groups employed the CSK differed. For example, some groups structured the information

[3] When comparing the decision quality in the CSK condition to that of the standard HP condition after participants saw the merged information, adding the condition predictor (AIC: 70.83) to the intercept model (AIC: 69.27) did not improve goodness-of-fit, $\chi2(1) = 0.44$, p = .507. That is, having been presented with the merged information, the groups in the standard HP condition were as likely to decide for the best candidate as groups in the CSK condition. Specifically, the chance to make the right decision was nearly identical (OR = 1.48) in this analysis.

Table 1 Glm model parameters with the dependent variable correct choice (odds ratio, OR) and condition (standard HP / CSK) as predictor. *Z*-values were calculated with 52 degrees of freedom

	Estimate (OR)	SE	Z	p
Intercept	-0.75 (0.47)	0.43	-1.76	.079
Condition	1.72 (5.58)	0.60	2.88	.004**

pieces strictly in columns, others shoved information pieces into the JS without even aligning them, still others build piles of information, and yet others were more reluctant to employ available functions.

Discussion

In the current study, we investigated whether a support kit specifically designed to support collaboration by building on affordances of intuitively usable interactive functions on a multi-touch table can help to overcome the detrimental influence of prior preferences, beliefs and knowledge on group work. We provide original evidence that our CSK counteracted biasing effects of prior preferences, beliefs, and knowledge, and also elicited unbiased communication and collaboration processes (i.e., balanced information exchange and integration). Specifically, we demonstrated that the implemented support functions helped participants to adjust task-relevant interaction processes in an expedient manner.

We implemented a HP paradigm, requiring triads of participants to perform a personnel selection task. Importantly, triads had to overcome initial preferences during a group discussion at a multi-touch table to succeed in identifying the optimal job candidate (out of three candidates); they either had interactive support functions at the multi-touch table available (CSK condition) or performed the task in a traditional HP setting (standard HP condition) without joint control over the multi-touch table. During the first phase of the HP paradigm, which is performed individually, suboptimal preferences are evoked in the participants by confronting them with an experimentally controlled biased information set. This biased set comprises unshared information pieces (i.e., initially only one participant had this information) and shared information pieces (i.e., all participants had this information). In the HP task, the initial information sets are experimentally designed to lead to an initial preference for a candidate, which is not the optimal candidate in the light of the information presented to the triad as a whole. The second phase consists of a group discussion during which groups of participants have to realize that their initial preference is wrong, and they have to overcome it by exchanging the shared and especially the unshared information pieces from the first phase. Importantly, groups can only identify the optimal job candidate if the information pieces from all three individual sets are exchanged and integrated in an adequate manner. That is, groups

Table 2 Glm model parameters with the dependent variable correct choice (odds ratio, OR) and information display (standard HP - discussion/ standard HP - merged) as predictor. *Z*-values were calculated with 52 degrees of freedom

	Estimate (OR)	SE	Z	p
Intercept	-0.75 (0.47)	0.43	-1.76	.079
Information display	1.33 (3.78)	0.6	2.22	.026*

have to exchange sufficient information (discussion intensity) in a balanced way (discussion bias) and to build and maintain a mutual understanding of the task and the information at hand in order to manage to overcome the prior preferences and to choose the best candidate. In our study, we analyzed whether the CSK fostered desirable processes by comparing various indicators of discussion intensity and discussion content between the two experimental conditions. As expected, we observed higher discussion intensity in CSK groups compared to standard HP groups. Moreover, the discussion was more balanced with regard to shared and unshared information pieces, indicators of the establishment and maintenance of mutual understanding were more pronounced, and the overall decision quality was higher. In detail, the chance to make a correct decision based on the group discussion was over five times higher for CSK groups than standard HP groups. Furthermore, in both conditions, the multi-touch table environment led to high group motivation, high engagement with the task, and strong satisfaction with the group interaction.

Overall, the results support the hypothesis that affordances of intuitively usable interactive support functions can foster desirable behavior in HP scenarios. The discussion of groups in the standard HP condition resembled those typically observed in HP scenarios (see Lu et al. 2012), suggesting that we succeeded in creating a replication of a typical HP situation in our study. Remarkably, CSK groups achieved what groups in so many other studies (and also in our standard HP condition) struggled with: They identified the best solution for the HP (Brodbeck et al. 2007; Lu et al. 2012) even though participants held suboptimal preferences upon entering the group discussion. Importantly, our study also provides insights with regard to the mechanism presumably underlying the beneficial effects of the CSK: It seems that the affordances of the implemented interactive support functions positively influence the interaction quality in scenarios like HPs where CPS processes play an important role. In particular, this seems to be the case for functions like actively moving information items from a PS into a JS, structuring information within a JS, and the automatic merging of redundant information. Still, future studies are needed to single out more specific interactive support functions in order to gain a better understanding of the specific processes they support.

Our findings are in line with those from other studies reporting positive impacts of multi-touch table use on discussion quality and group performance (Higgins et al. 2011; Higgins et al. 2012; Mercier and Higgins 2014; Shen et al. 2009). Moreover, they complement existing research (e.g., Deiglmayr and Spada 2010a, 2010b, Deiglmayr and Spada 2011) showing that training and adaptive tutoring improves collaboration between dyads in a computer-mediated HP scenario. They provide evidence that such beneficial effects of technological support functions can also be obtained in a face-to-face setting, in triads of participants, without training or explicit scripting but rather by designing support functions that make use of the affordances of a technological tool – reflecting an implicit form of scripting.

The discussion intensity of groups in the CSK condition was significantly higher than the discussion intensity in the standard HP condition. It is important to note that high discussion intensity does not necessarily prevent potentially problematic discussion patterns such as the distortion of content. The analyses revealed that in the standard HP condition information mentioned during discussion was skewed in favor of shared information pieces, whereas CSK groups exchanged equal proportions of shared and unshared information pieces during discussion. This is an especially promising result, because in the HP literature, the discussion bias is agreed to be one of the main reasons for groups to fail to overcome prior preferences (Lu et al. 2012).

An additional analysis regarding our standard HP condition revealed that that the decision quality after a pure discussion was enhanced once groups were provided with the full set of information (i.e., merged version without indication of previously shared/unshared information) within a JS after the discussion. That is, after groups made their choice for a suboptimal candidate, they succeeded to correct this choice when a shared space was activated. This could either indicate that (1) activating a shared space (even without CSK) led groups to find the optimal solution or else that (2) having the merged information (visibly) accessible led groups to find the optimal solution. It is important to note, though, that the groups in the standard HP condition did not engage in intense communication upon the activation of the shared space. This indicates that the functions implemented in our CSK were indispensable to enhance the group discussion in a way to balance the discussion, to help participants to turn from own information or shared information to unshared information that else received too little attention (in the standard HP condition). Still, this finding shows that simply providing merged information might be a shortcut to a solution, but not to desirable group processes. Indeed, comparing the experimental conditions, groups with the CSK available were not only more likely to come to the right conclusion, they also engaged in more intense, structured and unbiased interaction and showed more indicators for mutual understanding, which is also essential for learning (Dillenbourg and Fischer 2007).

In order to gain a better understanding of how participants experience the collaborative situation with the CSK, we analyzed group motivation, involvement in the interaction, and engagement with the task. All participants reported to have been highly motivated, a finding possibly highlighting the potential of new technologies, such as the multi-touch table, to intrigue people. However, we cannot rule out that motivation ratings were influenced by social desirability, which is why these results have to be interpreted with caution. Participants who were provided with support reported higher engagement with the task and higher involvement and satisfaction with the interaction. Since subjective experiences can impact on the behavior of participants (Scholten et al. 2007), one should consider such beneficial effects of the rich communication environment created by setting when designing support systems to enhance CPS.

Although decision quality was high overall in the CSK condition, screenshots from the multi-touch table indicated that the way in which groups employed the CSK differed. This observation is in line with case studies showing that differences in group dynamics can lead to differences in the use and the effectiveness of the available support functions (Rick et al. 2011). Such differences between groups are underemphasized in empirical studies to enable the comparison between conditions. While a more detailed, case based analysis of our data might reveal valuable insights, we argue that the empirical comparison between conditions in a first step is important to gauge the generalizability of the effects of the CSK. On a similar note, Rick et al. (2011) suggest that the design of technological support should be adapted to prompt desirable collaborative behavior in a subtle way, thereby possibly balancing differences (Rick et al. 2011). The differences in the use of the CSK might also be caused by participants' unfamiliarity with the interactive support functions. While in our setting the intuitive and diverse employment of the CSK fostered processes beneficial for CPS without tutoring, more complex scenarios might (only) benefit if participants are trained to make use of the available functions. Mercier and Higgins (2014) point out the importance of preparing users to employ the available multi-touch table functions during collaborative scenarios. Therefore, in other contexts, providing warming up exercises might be important to familiarize participants before the actual task. Future research should thus address the boundary conditions of spontaneous effects of CSK on CPS as demonstrated in the current study. One can assume that in more complex scenarios implicit scripting does not suffice. Therefore, exploring the circumstances under which it might be more expedient to employ explicit forms of scripting is important.

As mentioned, task complexity might also modulate the use of available interactive support functions. That is, the implementation of the CSK might be especially promising when task difficulty is high and it is unlikely to solve a task without additional resources (Leat and Nichols 2000; Martin and Schwartz 2009). In such situations that require individuals to deal with huge amounts of information (which is e.g., challenging for working memory), individuals may be more likely to use the CSK to create external representations. In conclusion, positive effects of interactive support functions might be even larger than suggested within the current research, when more difficult or burdensome tasks are implemented.

Due to the relatively unrestricted setting used (i.e., free discussion, no explicit scripting), the current study adds insights to highly standardized studies assessing CPS skills like PISA 2015 (OECD 2017). Generally, investigating CPS processes in real groups might be valuable to determine possible differences between human-to-human and human-to-agent interaction. A major advantage of the latter account is that it offers a high degree of standardization in CPS assessment, permitting use in a large-scale assessment like PISA 2015. While the high standardization of communication in the form of predefined messages is an asset in large-scale assessments, it also introduces a level of artificiality, that could induce unrealistic expectations for the interaction patterns CPS in the real world requires (Rosen 2015). So far, direct comparisons of human-to-human and human-to-agent CPS scenarios often used predefined messages even in the interaction with another human (see Rosen 2015), implying that the external validity of this approach in capturing an interaction between two or more humans is questionable. It is therefore important to study and compare CPS in situations in which interaction is unrestricted and follows natural communication patterns. Collaborative situations like those that we created in the present research elicit more realistic expectations and might therefore be well suited if CPS skills are to be trained. Additional value of studying ways to support and influence technology-assisted natural interactions stems from its transferability to a multitude of real world scenarios, like a political committee discussing possibilities to counteract climate change or university students discussing different scientific publications critically. As such, our findings are likely to generalize to CPS in school and professional contexts; there, considering prior knowledge, beliefs, and preferences and designing technological functions to emphasize and thus counteract them during group discussion might also further increase the beneficial potential of group work. Future research should thus adapt the current attempt and procedure to other settings. The current study also complements existing CSCL/CPS studies that focus on creating conditions that lead to maximal learning outcomes, as well as HP studies that have not yet focused on possibilities to technologically enrich face-to-face collaboration. Accordingly, future studies should employ more sophisticated and direct measures of grounding processes and mutual understanding, for example by coding non- and para-verbal cues (which are often used to establish common ground and to signal understanding) to get a clearer picture of how these processes can be supported (Clark and Brennan 1991). One example for such a measure would be to analyze the extent of idea co-construction (ICC) within groups (Gweon and Rosé 2011). Gweon and Rosé (2011) define ICC as the process of "of taking up, transforming, or otherwise building on an idea expressed earlier in a conversation" (p. 1) and point out its relation to constructs like transactivity (Teasley 1997), social modes of co-construction (Weinberger and Fischer 2006) and inter-subjective meaning making (Suthers 2006). A higher extent of such communication patterns has been related to knowledge acquisition and is considered to be crucial in group work settings (Fischer et al. 2002; Gweon and Rosé 2011; Teasley 1997). With regard to knowledge acquisition, it is important to note that we did not attempt to specifically target learning gains in the current study. Thus, it remains an open issue whether the use of the CSK may also improve CPS skills in the long run. Although one might assume that our paradigm should also set conditions for successful learning of relevant CPS skills.

Future studies should concentrate on the achievement of procedural knowledge during collaboration, for example by observing effects of training and experience with interactive support functions on the use of the available resources and the task performance. With new technological developments, the presence of touch technologies such as the multi-touch table and the familiarity with often-implemented functions are likely to increase. It is possible that effects of such designed functions change with increasing experience, as it has been observed for computer-mediated communication (with more experience, communication can be adapted and disadvantages of computer-mediated communication like reduced social presence etc. are experienced less negatively; DeLuca et al. 2006; Nowak et al. 2006). Therefore, observing how the use of interactive support functions changes with experience and how they can be adapted to elicit desirable behavior in different settings is an important task for future research.

Due to the continuous increased occurrence of dispersed teams and working groups and the upswing of technological developments like e-mail, chat, video-chat, research has concentrated on computer-mediated communication in dispersed settings for a long time (Baltes et al. 2002; Swaab et al. 2012). However, collaboration in face-to-face scenarios remains indispensable in many situations. Hence, it is vital to understand how these everyday-life scenarios can be supported technologically to shed light on prior knowledge and preference in order to enhance and de-bias collaborative processes in the context of work, education, and learning. In our study, we employed a HP scenario at a multi-touch table, investigating the interaction of groups in an actual face-to-face scenario. Results indicate that groups can be supported technologically during face-to-face discussions, fostering desirable communication processes and rendering the CPS process more expedient. Using a technological kit of multi-touch table functions, we succeeded in eliciting interactive processes increasing the likelihood that groups exchanged and integrated previously unshared information, overcame prior preferences, and established and maintained mutual understanding. We demonstrate that the affordances of our CSK can increase discussion intensity and mutual understanding and balance discussion biases. Furthermore, the task focus can also be increased (i.e., stronger amount of on-topic utterances), and the discussion content can be balanced (i.e., decreased discussion bias). In addition, it is promising for other contexts in which prior preferences and knowledge play a role, such as collaboration in the classroom or in decision-making scenarios with multiple stakeholders. For example, it could support a multidisciplinary team of medical specialists deciding on the optimum treatment for a patient. The current results show that the availability of interactive support functions can elicit processes to enhance the intensity and favorability of collaborative processes, increasing outcome quality.

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