6-14-2021

Designing Multimodal BI&A Systems for Co-Located Team Interactions

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Research Paper

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Abstract

Teams are crucial for organizations in making data-driven decisions. However, current business intelligence & analytics (BI&A) systems are primarily designed to support individuals and, therefore, cannot be used effectively in co-located team interactions. To address this challenge, we conduct a design science research (DSR) project to design a multimodal BI&A system providing touch and speech interactions that can be used effectively by teams. Drawing on the theory of effective use and existing guidelines for multimodal user interfaces, we propose three design principles and instantiate them in a software artifact. The results of a focus group evaluation indicate that enhancing the BI&A system with multimodal capabilities increases transparent interaction and facilitates effective use of the system in co-located team interactions. Our DSR project contributes novel design knowledge for multimodal BI&A systems with touch and speech modalities that facilitate effective use in co-located team interactions.

Keywords: Multimodal Interaction, Business Intelligence and Analytics, Theory of Effective Use, Design Science Research, Co-Located Team Interaction.

1 Introduction

The increasing importance of data-driven decision making in organizations reshapes work practices of employees at any level (Chen et al., 2012). To support employees' data understanding and decision making, most organizations have implemented business intelligence & analytics (BI&A) systems. These systems process and present data to a broad spectrum of users, for example, in the form of reports or dashboards. Given their widespread availability, BI&A systems are now used in all areas of business to facilitate decision making. However, the success of BI&A systems will be determined by how effectively they are used (Burton-Jones & Grange, 2013).

Today, decisions based on BI&A systems are not only made by individuals alone but increasingly also by teams. Due to this trend, teams are crucial for organizations in making data-driven decisions (Majchrzak et al., 2012). For example, before deciding on a new customer retention strategy, employees from sales, controlling, and management departments meet and analyze churn data from the past. These insights and informed actions are derived in co-located team interactions (Dennis, 1996; Isenberg et al., 2012; Schmidt et al., 2001). Yet, surprisingly few BI&A systems support co-located team interactions (Berthold et al., 2010; Isenberg et al., 2012) and many teams struggle with working together equitable and flexible using current BI&A systems (Dayal et al., 2008; Kaufmann & Chamoni, 2014). For example, with current BI&A systems, only one person in a team meeting would interact with the system and carry out the analysis, while the other meeting participants can only observe the activities or comment on the results. Consequently, achieving effective use of BI&A systems in co-located team interactions remains a challenge.

According to Burton-Jones and Grange (2013), effective use of information systems (IS) involves three core elements: transparent interaction, representational fidelity, and informed action. Teams need to unimpededly interact with a BI&A system in order to obtain faithful representations (e.g., data analyses), which ultimately enables them to take informed actions (e.g., make business decisions). Therefore, at the most fundamental level, BI&A systems need to be designed in a way that facilitates transparent interaction because otherwise achieving effective use is likely not possible. One approach to facilitate transparent interaction with BI&A systems in co-located team interactions could be to supplement the established interaction modalities of BI&A systems (i.e., mouse, keyboard, and touch) with speech interaction. In recent years, the capabilities of conversational user interfaces (CUI) have greatly improved and they are increasingly used to enable users to access information and interact with a system in a more natural and intuitive way (McTear, 2017). Hence, combining existing interaction modalities with speech interaction provided through a CUI may compensate for the disadvantages of each modality and, therefore, facilitating effective use of BI&A systems. Consequently, BI&A systems that support multiple modalities (hereafter referred to as multimodal BI&A systems) could enable teams to interact with a BI&A system in a flexible and effective manner and more actively support involving all team members in the decision making process (Deng et al., 2004; Oviatt, 1999).

However, while there is a large body of design knowledge on BI&A systems for individual use contexts, research on the effective use of BI&A systems for team interaction is scarce. Furthermore, multimodal BI&A systems have been predominantly studied from a technology-centric perspective (Turk, 2014). Thus, there is a lack of prescriptive knowledge on how to design multimodal BI&A systems for co-located team interactions. Moreover, it is not well understood whether and how multimodal BI&A systems can facilitate effective use and support decision making in co-located team interactions. Hence, we address the following research question:

How to design multimodal BI&A systems for co-located team interactions in order to facilitate the systems' effective use?

To address this question, we conduct a Design Science Research (DSR) project (Kuechler & Vaishnavi, 2008). Drawing on the theory of effective use (Burton-Jones & Grange, 2013) and existing design knowledge for multimodal user interfaces (MUI) (Deng et al., 2004; Reeves et al., 2004), we designed, implemented, and evaluated a multimodal BI&A system that combines touch and speech interaction. We developed and evaluated our software artifact using a confirmatory focus group in cooperation with the finance & accounting department of a large European energy provider.

This paper presents the results of our first design cycle. Overall, our DSR project contributes to the body of design knowledge for BI&A systems by demonstrating how the combination of touch and speech increases transparent interaction and representational fidelity in order to achieve effective use in co-located team interactions. Furthermore, our proposed design principles advance existing guidelines for MUIs and ground them in the theory of effective use. In particular, we contribute with three design principles for multimodal BI&A systems for teams. Overall, our work represents an improvement in the DSR knowledge contribution framework (Gregor & Hevner, 2013), as it represents a more efficient and effective solution for a known problem. For practitioners, we provide applicable guidelines for the implementation of multimodal BI&A systems (Gregor & Jones, 2007).

2 Related Work and Theoretical Foundations

2.1 Business Intelligence & Analytics Systems for Teams

Business intelligence & analytics (BI&A) is often described as "techniques, technologies, systems, practices, methodologies, and applications that analyze critical business data to help an enterprise better understand its business and market and make timely business decisions" (Chen et al. 2012, p.

1166). BI&A reinforces human cognition as well as capitalize on human perceptual capabilities by integrating data analysis systems with decision support systems (Yigitbasioglu & Velcu, 2012). In order to accomplish this, tools, applications, and technologies focussing on decision making are required (Larson & Chang, 2016).

In the process of deriving knowledge from the data using BI&A systems and making decisions, additionally, tools are required that support teams in collaborating (Abbasi et al., 2016). Different approaches have been used to support teams during decision making and data understanding. Group decision support systems (GDSS), for example, have been researched for a long time in order to increase team effectiveness, efficiency, and satisfaction in decision making (Burstein et al., 2008; Nunamaker & Deokar, 2008). Key insights from these research streams are, that cross-functional teams can lead to an increase in effectiveness due to synergies. However, they can also lead to incomplete access to and use of information needed for successful decision making (Nunamaker & Deokar, 2008). These insights are crucial to data-driven decision making in organizations and, therefore, the collaborative aspect of decision making receives increasing relevance in BI&S system research (Abelló et al., 2013; Berthold et al., 2010). Suggesting that during the transfer from individual to team level, especially, the functional and technical aspects need to be mapped to the requirements teams pose to BI&A systems (Kaufmann & Chamoni, 2014). However, research on BI&A systems for co-located team interaction and their requirements is crucial but scarce (Berthold et al., 2010; Ruoff et al., 2020).

2.2 Multimodal User Interfaces

Multimodal user interfaces (MUI) enable processing two or more input modalities from users, such as speech, touch, or gaze (Oviatt, 2003). Their fundamental idea is to remove existing constraints on human-computer interaction by leveraging the full communication and interaction capabilities of humans in order to provide a natural interaction between the user and the system (Turk, 2014). The first MUI was Bolt's "Put-that-there" system (1980) integrating speech and gesture to increase the ease of use of the system. Since then, many MUIs have been developed (e.g., Turk, 2014). Particularly, speech input has been often used in combination with other modalities, since speech has powerful complementary capabilities, such as providing complex interactions in contrast to the simple interactions of touch (Deng et al., 2004; Saktheeswaran et al., 2020). Several guidelines have been published by research describing the general requirements for MUIs (Reeves et al., 2004) and by practice describing requirements for the combination of specific modalities (Deng et al., 2004). Integrating insights from different research streams, such as research on CUI (Gnewuch et al., 2018; McTear, 2017) as well as interaction preferences (Pitt et al., 2011). Today, MUIs are attributed a high degree of relevance for BI&A systems as they can provide fluid interactions during decision making (Dayal et al., 2008; Roberts et al., 2014; Saktheeswaran et al., 2020). However, there is still a lack of research on multimodal BI&A systems, even though this could enhance the interaction between users and BI&A systems and could lead to improved effectiveness and efficiency (Dayal et al., 2008).

2.3 Theory of Effective Use

IS should be used effectively since the shallow use of them alone is not sufficient to ensure that the organization’s objectives are met (Seddon, 1997). According to Burton-Jones and Grange (2013), effective use can be defined as “using a system in a way that helps attain the goals for using the system” (p. 4). Based on their conceptualization, effective use is an aggregated construct comprising three hierarchical dimensions: (1) transparent interaction, (2) representational fidelity, and the outcome dimension (3) informed action (Burton-Jones and Grange 2013). As illustrated in Figure 1, the three dimensions of effective use are influencing each other. Initially, the unimpeded access to the system’s representations (transparent interaction) improves the ability to obtaining representations that faithfully reflect the domain (representational fidelity). The representational fidelity in turn aims to improve informed action, which is the extent to which a user acts on faithful representations.

Therefore, a user's overall level of effective use is determined by the aggregated levels of the three dimensions (Burton-Jones & Grange, 2013). For example, users of a BI&A system need to access accurate business information (transparent interaction), such as which products had lower revenue than expected based on the purchase history (representational fidelity), to be able to make decisions for future business endeavors (informed action).

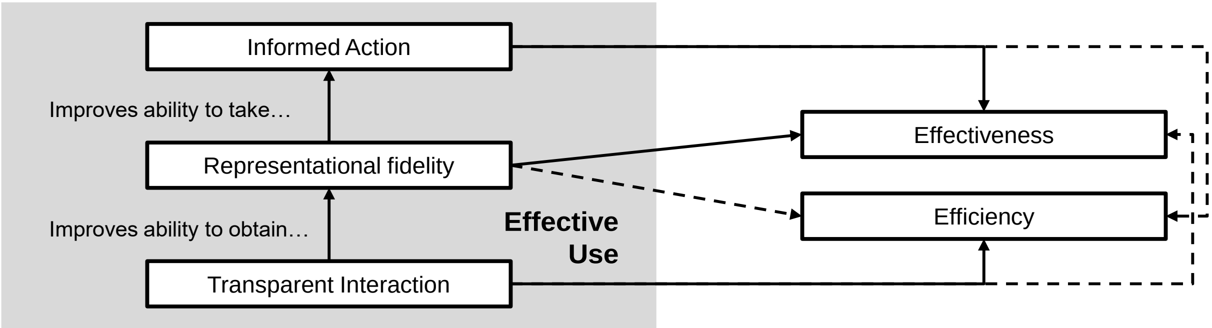

Figure 1. Theory of Effective Use (adapted from Burton-Jones & Grange (2013))

In order to positively influence effective use during the interaction between users and IS, Burton-Jones and Grange (2013) identified two major drivers: adaptation actions and learning actions. In our paper, we focus on adaptation actions, which are defined as any action a user takes to improve (1) a system's representation of the domain of interest; or (2) his or her access to them, through a system's surface or physical structure. Therefore, researchers in the context of BI&A systems need to expand their focus from organizational aspects and data quality (Surbakti et al., 2020) to include also the interaction between users and the system. Especially, when designing multimodal BI&A systems, researchers should consider how users are able to adapt their interaction with multimodal BI&A systems according to the task and context.

3 Design Science Research Project

To design a multimodal BI&A system that can be effectively used in co-located team interactions, we follow the DSR approach as described by Kuechler and Vaishnavi (2008). We argue that this research approach is particularly suited to address our research question because it allows us to integrate existing design knowledge (Deng et al., 2004; Reeves et al., 2004), descriptive knowledge from the theory of effective use (Burton-Jones & Grange, 2013), and empirical results from our evaluation phases to incrementally improve our artifact. These foundations provide a rigorous grounding and allow us to contribute to the existing knowledge base. To further provide relevance to our rigorous approach (Hevner, 2007) in understanding multimodal BI&A systems, we collaborate with an industry partner serving as our research case. Our industry partner is the finance & accounting department of a large European energy provider. The joint research project is conducted because the company is aware of the need to establish new forms of interaction with data. The access to practitioners enables us to sharpen our awareness of the problem as well as to perform evaluations with practitioners.

General Design Science Cycle	Cycle 1 Understanding	Cycle 2 Lab Experiment Evaluation	Cycle 3 Application to practice
Awareness of Problem	Literature review Interaction-elicitation study	Reflection of focus group analysis	Reflection of experiment analysis
Suggestion	Synthesis of design principles based on empirical findings and theory	Adapt design principles based on evaluation results and insights from focus groups	Adapt design principles based on evaluation results and insights from lab experiment
Development	Instantiation of design principles as a software artifact	Modification of software artifact	Modification of software artifact
Evaluation	Qualitative evaluation of software artifact (confirmatory focus group)	Quantitative evaluation of software artifact (lab experiment)	Quantitative evaluation of software artifact (field experiment)
Conclusion			Deliver nascent design theory

Figure 2. Design Science Research Project (adopted from Kuechler & Vaishnavi (2008))

In our first design cycle, we focus on the fundamental dimension of the theory of effective use, the transparent interaction with multimodal BI&A systems, and the impact of the systems' design on their effective use.

Awareness of Problem: In order to better understand issues of data-driven decisions in co-located teams and potential issues in the design of multimodal BI&A systems, we started our research by conducting a literature review on multimodal BI&A systems for co-located team interactions. This literature review provided us with potential issues in the design of multimodal BI&A systems for co-located team interactions and allowed us to extract approaches on how to tackle these issues from various disciplines, such as the discipline of computer-supported cooperative work and information visualization.

Subsequently, we conducted an interaction-elicitation study following the approach by Morris (2012) to derive data on how people would want to interact with a multimodal BI&A system to compare the proposed guidelines to feedback from potential users. Overall, 30 participants with an average age of 22.8 years (SD = 1.9) took part in the study. There were 8 female and 22 male participants, mostly students with a background in economics and engineering. In accordance with Badam and Elmqvist (2019), we motivate the choice of using students as the representative population as the focus of this study was to extract interactions with multimodal BI&A systems, and therefore, no specific expertise except the experience of using touch and speech interfaces was needed.

The interaction-elicitation study consisted of two parts (Ruoff & Maedche, 2020). First, the participants were shown 14 randomized core functionalities of BI&A systems, such as filtering, selecting, and obtaining details, which we extracted based on the framework of Yi et al. (2007). After each demonstration of a functionality, the participant was asked to propose an interaction on how s/he would invoke the functionality using speech, touch, and the combination of these modalities. For each modality, the participant stated in which context s/he would use this interaction. Furthermore, the participant rated for each functionality which modality s/he would prefer and stated why s/he rated the modalities in this order. Finally, after proposing interactions for each functionality, a semi-structured post-study interview was conducted with a focus on the use of multimodal BI&A systems as well as on how they provide assistance to users in order to interact properly. With the consent of the participants, audio and video were recorded for the whole interaction-elicitation study.

In order to analyze our results, we coded the post-study interviews to derive common issues from the users' perspective and the user-defined interactions for the core functionalities. To calculate the agreement for the interaction of each modality and core functionality, we derived the percentage of participants proposing the most popular interaction (Morris, 2012). For example, 17 participants proposed the interaction “Filter for <Entity>” as a speech interaction for the functionality “filtering”. Therefore, the interaction for filtering using the modality speech has an agreement of 57%. Furthermore, based on the ranking of the modalities for each functionality, we were able to derive the modalities preferred for the functionalities.

Suggestion: To address the issues identified in the problem awareness phase, we proposed three design principles for multimodal BI&A systems. These design principles were derived based on our literature review, the results of our interaction-elicitation study, and the theory of effective use as our kernel theory.

Development: To demonstrate how these design principles can be implemented, we instantiated them in a software artifact using state-of-the-art technologies for the recognition of speech and touch input.

Evaluation: In the evaluation phase, we opted for confirmatory focus groups as they provide a collective view on a topic of interest from a group of experienced participants and to establish the utility of the software artifact in field use (Tremblay et al., 2010). We invited thirteen employees from the finance & accounting department with a focus on controlling, customer processes, data science, as well as general management in the context of finance (9 males, M_{age} = 34.6 years, $M_{WorkExp}$ = 10.1 years). Therefore, all practitioners have experience using BI&A systems in co-located team interactions and can provide insights into the topic of interest. The guiding thought of these confirmatory focus groups were issues related to the use of multimodal BI&A systems of practitioners in co-located team interactions and possible strengths, weaknesses, opportunities, and threads of facilitating the interactions of the multimodal BI&A system through touch and speech.

After a short introduction into the goal and procedure of the confirmatory focus group, we separated them into two groups of six and seven practitioners. The confirmatory focus group with both groups followed the same procedure. First, the use case of leveraging the multimodal BI&A system in co-located team interactions was presented to the practitioners. The moderating researcher guided the practitioners through questions that are of interest in a typical decision making task (e.g., whether the price for an energy product should be increased in the future). During the demonstration of the use case, the moderating researcher was supported by our multimodal BI&A system and used various possible interactions with the multimodal BI&A system, such as speech for filtering or touch to select data of interest. The practitioners were included in the interaction with the system and could also use the multimodal BI&A system during the demonstration. After the demonstration, questions regarding the use case and the multimodal BI&A system were discussed. Following a 20 minute discussion, we explained the Strength-Weakness-Opportunity-Threat (SWOT) analysis method to the practitioners which was used to structure the confirmatory focus group. Subsequently, the practitioners were given time to write down their perceived strengths, weaknesses, opportunities, and threats of multimodal BI&A systems in co-located team interactions on index cards. Finally, the index cards were read out loud and explained by the respective practitioner, providing the researchers with the possibility to ask follow-up questions on recurring points. Both sessions were recorded with the consent of the practitioners and transcribed after the workshop.

Following the confirmatory focus groups, all audio recordings were transcribed using MAXQDA 2018. Similar to previous evaluation studies that used recorded verbalization, our “coding scheme consisted of a series of categories about the behavior to be studied” (Vitalari, 1985, p. 226). More specifically, our coding scheme included the concepts of effective use (e.g., transparent interaction and representation fidelity) and the relationships between them. In the first step, we combined similar index cards with overlapping explanations by the respective practitioner based on the results of the initial coding. In a second step, we derived first-order concepts from these groups (Zhang, 2017). For example, *“no tool knowledge needed”* and *“makes it easier to find options that can otherwise only be reached with many clicks”* were combined with other similar statements to a group and the first-order concept *“Limited knowledge about the functionality of the system necessary”* was derived and mapped to the corresponding design principle.

As depicted in Figure 2, we plan to conduct two additional cycles to further refine our design and evaluate it in a lab and field experiment. In the second design cycle, we plan to refine the design principles based on the evaluation results of the first cycle. Furthermore, we will focus on how to adapt the multimodal BI&A system to team characteristics and context. We plan to experimentally evaluate how the adaptation of the transparent interaction and representation fidelity affects the effective use of the BI&A system. The final and third design cycle aims to fine-tune our design principles using the results of the previous evaluations. This will provide us the opportunity to introduce the multimodal BI&A system to various teams in the finance & accounting department and to better understand the impact of the design principles on effective use. Our ultimate goal is to deliver a nascent design theory for multimodal BI&A systems as described by Gregor and Jones (2007).

4 Results

4.1 Awareness of the Problem

In the following, we present the results of the problem awareness phase along the two main dimensions of effective use as a lens: (1) transparent interaction and (2) representational fidelity. Specifically, we raise three major issues (I) with regards to current BI&A systems.

Transparent Interaction: Researchers aim to facilitate effective use by providing unimpeded access to current BI&A systems through additional input modalities. Multiple studies have explored how the combination of different modalities in multimodal BI&A systems can assist teams during co-located team interactions (Badam et al., 2016; Langner et al., 2018; Lee et al., 2015; Nguyen et al., 2017). The combination of modalities used in these studies varies between touch and speech, mid-air hand gestures and touch, mid-air hand gestures and speech as well as touch and pen. Therefore, it is difficult to generalize the results of these studies. However, the general conclusion of these studies is that only providing additional modalities to users does not automatically increase effective use (Nguyen et al., 2017). Therefore, it is unclear which and how multiple modalities in BI&A systems should be combined in order to facilitate transparent interaction **(I1).**

A common modality used for multimodal BI&A systems is touch since it conveys the team member's "intention quickly and unambiguous to the system" (Badam et al., 2016) and is in line with the affordance of displays to be touched (Norman, 2016). However, teams are still unable to convey complex information to the multimodal BI&A systems without help from menus. To tackle the limitations of touch and to fulfill the requirements of the adaptivity of MUIs (Reeves et al., 2004), researchers combine touch with additional modalities. To augment touch as a modality, guidelines for MUIs and the results of our interaction-elicitation study indicate that speech could be beneficial to convey complex information (Deng et al., 2004; Saktheeswaran et al., 2020). Especially since the team can "easily manipulate the visualized data in a natural and intuitive approach" (Nguyen et al. 2017, p. 7) through speech. However, in most multimodal BI&A systems, speech is still a hidden affordance as the microphone is subtly integrated into the display and the interaction provides no physical feedback. Therefore, individuals and teams struggle to use modalities, such as speech, because they are less "visible" **(I2)**.

Representational Fidelity: In many studies, achieving representational fidelity is supported by providing either a dashboard (Badam et al., 2016; Langner et al., 2019; Lee et al., 2015) or a single information visualization (Nguyen et al., 2017). In order to maintain representational fidelity during decision making, teams need to be able to adapt the visual representations using transparent interaction (Srinivasan et al., 2020), by altering queries to the data (Jetter et al., 2011), or by enhancing or changing the underlying data (Chung et al., 2014). These adaptation actions can be performed using different modalities. For example, users could click on a filter (touch) or ask the system to select a specific year (speech). However, in the context of MUIs, researchers currently design the mapping between interaction techniques, which users can utilize to maintain the representational fidelity, and the system functionality bottom-up based on their specific system. As a result, a guiding paradigm or design principle is missing to guide this process. Therefore, it is unclear how to map fundamental dashboard interaction techniques to multimodal system functionalities (**I3)**.

In summary, there are several issues in the design of multimodal BI&A systems for co-located team interactions. Based on the results of our literature review and interaction-elicitation study, we determined that existing research is missing an understanding how to facilitate effective use of BI&A systems in co-located team interactions. Therefore, we subsequently focus on the gap in how multimodal BI&A systems need to be designed to facilitate effective use and how teams can be assisted during their interaction.

4.2 Suggestion

To address the identified issues of multimodal BI&A systems, we suggest designing a system that facilitates effective use by providing a MUI. Building on the theory of effective use, we argue that a multimodal BI&A system that provides unimpeded access to the system's representation (transparent interaction) and enables users to obtain faithful representations (representational fidelity) will positively influence informed actions and, therefore, facilitate effective use. Consequently, we formulate two meta-requirements (MR) based on the dimensions of effective use: Multimodal BI&A systems should provide a high level of transparent interaction (MR1) and representational fidelity (MR2).

To increase transparent interaction (MR1) and to tackle I1 & I2, the theory of effective use suggests adapting the physical structure and the surface structure. It further indicates, that "the sole purpose of these structures is to support access to representations" (Burton-Jones & Grange 2013, p. 646). In the context of the physical structure, the core strength of providing multiple input modalities is that multimodal systems decrease the distance between intent and interaction (Lee et al., 2012) and, therefore, support the access to the representations of the system, which is based upon the use of different modalities complementing each other (Sundar et al., 2015). By providing the possibility to choose between modalities, the multimodal BI&A system is robust to varying contexts, such as noise, and team member preferences. This addresses the guidelines for error prevention and adaptivity in the "Guidelines for multimodal user interface design" by Reeves et al. (2004). Furthermore, unimpeded access to the system's representation in the context of co-located team interaction is only possible if the whole team can view the multimodal BI&A system. Particularly during decision-making, perspectives of all team members need to be considered in the analysis and thus systems are required to support all team members in their transparent interaction (Dennis, 1996; Dennis et al., 2001). Therefore, we articulate the first DP:

DP1: *To improve team members' transparent interaction with a BI&A system in co-located team interactions, integrate multimodal interaction capabilities on large interactive displays.*

In the context of adapting the surface structure, the most critical mechanisms are the affordances and the feedback the system provides. In order to address the issues of hidden affordances (I2), we propose to implement signifiers for the affordances of multimodal BI&A systems, in accordance with the theory of affordances (Norman, 2016). The crucial affordances of multimodal BI&A systems providing touch and speech as modalities are touching the system and speaking to the system. However, even though most of the displays used in co-located team interactions integrate microphones, in conformance with I2, the affordance to speak to the system is not visible to the team members and lacks signifiers. Therefore, an approach to make speech perceptible is to provide signifiers to the team members. These signifiers create awareness for team members on what modalities are available for interacting with the multimodal BI&A system. Furthermore, teams need to understand how to properly interact with the multimodal BI&A system in order to increase transparent interaction. Therefore, the multimodal BI&A system should provide perceptual information on the basis of which teams can reinforce and, if necessary, modify their behavior. Deng et al. (2004) proposed to implement reactive feedback in CUI in order to assist users during the interaction. Using reactive feedback, the system's interpretation of the team members' speech interaction can be visualized for confirmation and missing information can be requested by the multimodal BI&A system. For example, after a complex speech interaction, team members should be able to understand whether the system invoked the correct functionalities or if the team members need to undo the last step and try again in a different way. Therefore, we articulate the second DP:

DP2: *To improve team members' transparent interaction with a BI&A system in co-located team interactions, employ feedback and signaling affordances that clarify its interaction capabilities.*

To increase the representational fidelity (MR2) and to tackle Issue 3, the theory of effective use suggests adapting the representations of the system. In this cycle, we focus on the visual representations of the system and not on adapting the mapping of the database or the functionalities of the system, which is also part of representational fidelity. In order to achieve higher representational fidelity by adapting the visual representations using transparent interaction, direct manipulation of the visual representations is crucial. Direct manipulation has been shown to simplify the mapping between goals and actions by reducing the semantic and articulatory distance (Frohlich, 1993). Furthermore, Yi et al. (2007) proposed a set of interaction techniques for visual representations, which are independent of the modality used for facilitation. Combining these two concepts enables the user to utilize transparent interaction to adapt the representation of the system in order to maintain representational fidelity during decision making. Even when the problem statement or the information need shifts. Therefore, we articulate the third DP:

DP3: *To support team members in obtaining faithful representations while using a multimodal BI&A system in co-located team interactions, enable direct manipulation of visual representations using common interaction techniques (e.g., selecting, filtering).*

4.3 Development

For our first design principle, we chose a Microsoft Surface Hub 2S to provide the touch and speech modality as well as the visualization of the system (Figure 3), as it provides a large interactive display to the team. Our multimodal BI&A system should be independent of specific BI&A systems used in teams. Therefore, we used a two-layer architecture. The first layer is responsible for the integration of the BI&A system and its corresponding data into the system. We used the SDK of Microsoft Power BI, which is the platform for BI&A mainly used in the case organization. However, the focus of our system is on the second layer, which is responsible for the interaction between teams and the BI&A system. To provide a CUI and to implement speech interaction into our BI&A system we used Microsoft's Cognitive Services. This provides us the capability to perform speech-to-text analysis and the identification of intentions. The touch interactions were facilitated by JavaScript.

Figure 3. Multimodal BI&A System in co-located team interactions at industry partner

To instantiate the second design principle, we provide a signifier for the affordance of speaking to the system. Signifiers in the digital context can consist of but are not limited to buttons, labels, and sounds coming out of a speaker, or haptic vibration. We provide a signifier, which is constantly available to the team. Furthermore, in the post-study interviews from our interaction-elicitation study, participants stated that they would prefer a visual representation, indicating the availability of speech to the team. Therefore, we opted for a visual representation of the affordance that provides a visible signifier to the team at all times during the interaction. A microphone symbol on the large interactive display indicates the ability to speak to the system and tapping the symbol initiates speech interaction.

Additionally, to provide reactive feedback to the team members (DP2), the system displays the interpretation of the speech input and explains the changes that were made based on that interpretation in the CUI. Figure 4 shows the feedback that the team receives after filtering the dashboard via speech. It includes the functionality invoked ("filter") and what parameters were changed (i.e., "Planning Status"). This provides team members the ability to check whether the system understood them correctly or if they need to undo the last step and try again in a different way.

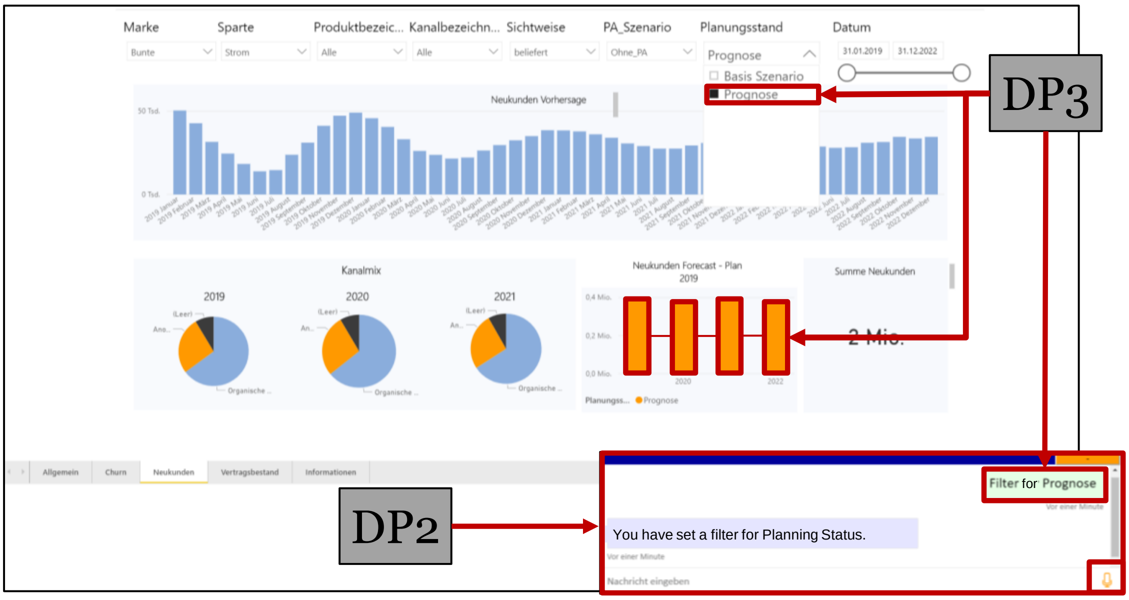

Figure 4. Instantiation of the second and third design principle

Finally, to instantiate the third design principle, we used the results of the interaction-elicitation study to understand how users would like to perform the interaction techniques provided by Yi et al. (2007) with BI&A systems using touch and speech. To demonstrate the capabilities of a multimodal BI&A system and the implementation of our third design principle, we opted for filtering, selecting, reconfiguring visualizations, interacting with bookmarks, asking questions to the data (ex. What is the Product with the highest return in 2019?) as well as switching tabs as core functionalities provided by multimodal BI&A systems.

We selected for each modality and functionality the interaction that was proposed by most participants of the interaction-elicitation study. However, if multiple interactions had a high agreement for a modality and functionality and did not have a conflict, we integrated all. For example, for filtering and touch the integration of a drop-down menu has an agreement rate of 53%, and tapping on the depiction of a variable in a visualization has an agreement rate of 40%. By providing both possibilities, we are able to provide interactions independent of team member preferences. Furthermore, we provide the possibility to choose between speech and touch at any step of the interaction. To continue the example of filter, as depicted in Figure 4, the team members are able to use speech ("Filter for Prognose") or touch (Drop-Down Menu OR Tap on Variable in a Visualization) based on their current context and preferences.

4.4 Evaluation

In order to evaluate our multimodal BI&A system for co-located team interactions, we conducted confirmatory focus groups (Tremblay et al., 2010) with thirteen employees of our industry partner. The recorded focus group discussions were analyzed using a SWOT analysis. The results of the SWOT analysis in the context of each design principle are explained in more detail below.

DP	Strengths	DP	Weaknesses
1	S1. Modality can be selected based on context, team member characteristics, and task S2. Increased interactivity of co-located team interactions and involvement of all team members	1	W1. Missing trust in the reliability of speech and its adaptivity to the context and team member characteristics W2. Speech is seen to reduce the privacy of its users
2	S3. The team can concentrate on the communication and the task at hand		
3	S4. Limited knowledge about the functionality of the system necessary S5. Increased effectiveness of co-located team interactions due to ad-hoc analysis	3	W3. Onboarding needed to provide teams the ability to interact properly with the system
DP	**Opportunities**	**DP**	**Threats**
2	O1. Shifting the role of the BI&A system from an information provision platform towards becoming a key tool for teamwork	1	T1. Every team member can interact with the system which limits the control of a presenter and may lead to inefficient teamwork
3	O2. Increased effectiveness of co-located team interactions as additional information can be acquired based on more complex interactions with and drill-down into the data	3	T2. Simplification and automation of the functionality through more intuitive modalities can lead to unnoticed mistakes

Table 1. Summary of the SWOT Analysis

First, participants stated that integrating multimodal interaction capabilities on large interactive displays (DP1) would help them in more effectively using the BI&A system. Particularly the interactivity and involvement of all team members in co-located team interactions was regarded as a major benefit. One participant stated: *„When working with people who are experts in their field, everyone can interact from their standpoint and provide insights to the discussion"* and that *"the modalities in the system assist the interactivity of the meeting"*. Furthermore, the first design principle was regarded as a key strength of the multimodal BI&A system, *"as it offers more possibilities in contrast to current systems and, therefore, enables us to choose the fitting modality. For example, if the noise in the room is too loud, the team members can switch to touch."* Moreover, the participants confirmed the insights from existing literature that *"the combination of touch and speech is beneficial, as they are able to use speech for complex interactions and touch for simple and fast interactions."* However, one major weakness of the multimodal BI&A system, hindering effective use, is the missing trust in the reliability of speech processing and its adaptivity to the context and team member characteristics. The participants fear, that *"the system would require an unnatural syntax for speech interaction"* and that it cannot be adapted to the respective team members. Finally, participants mentioned that speech *"decreases privacy, as everyone hears what you are working on."*

In general, the participants also liked the fact that the multimodal BI&A system employs feedback and signaling affordances that clarify its multimodal interaction capabilities (DP2). Especially, since in the context of decision making using BI&A systems, they fear that *"through the ability to invoke complex functionalities with simple interactions, multimodal BI&A systems may misinterpret the intentions and provide the wrong information for the following discussion."*. Therefore, the reactive feedback would help them spot mistakes in the system's interpretation of the interaction. However, during the discussion, team members may still miss the feedback provided by the system and use the information provided by an unfaithful representation to derive wrong insights.

The participants additionally mentioned that enabling direct manipulation of visual representations using common multimodal interaction techniques helps them to *"derive insights and configurations that else would be hard to find"* and enables *"ad-hoc analysis to answer questions arising in the discussion"*, which supports the third design principle. They further stated that this would help them to improve their informed actions and would, therefore, facilitate the effective use of the multimodal BI&A system. As the system already provides transparent interaction (DP1 & DP2), in order to easily invoke complex functionalities of the system, the participants imagine the third design principle could provide *"additional insights that would be overlooked in current meetings and would currently require the team to reschedule the meeting."* Moreover, *"meetings and analysis, in general, could get faster."* However, according to the participants, providing the direct manipulation of the visual representations using speech might require *"the user to learn the syntax beforehand."*

5 Discussion

While important decisions based on data are often made by cross-functional teams, current BI&A systems are primarily designed to support individual decision makers. To address this problem, we conduct a DSR project to design multimodal BI&A systems for co-located team interactions. Drawing on the theory of effective use, we examined how the combination of touch and speech modalities can facilitate the effective use of multimodal BI&A systems. In the first cycle of our DSR project, we proposed three design principles and instantiated them in our artifact. Subsequently, we conducted a confirmatory focus group evaluation with our industry partner. The results of our evaluation suggest that the combination of touch and speech for multimodal BI&A systems provides teams with additional possibilities to interact properly based on the team characteristics and context. However, the results also illustrate that the adaptivity of the speech interaction and an onboarding phase might further increase transparent interaction. Therefore, our DSR project provides valuable theoretical contributions and practical implications that we discuss in the following.

First, our research contributes to the body of design knowledge for multimodal BI&A systems in particular, and MUIs in general. The results of our evaluation suggest that the effective use of multimodal BI&A systems in co-located team interactions can be increased by offering touch and speech modalities on a large interactive display (DP1). This design principle enables team members to select modalities depending on their preferences and their current tasks, but they also have the ability to choose another modality if the context changes. Furthermore, the system creates awareness of possible modalities and provides reactive feedback (DP2), which allows team members to understand how to properly interact with the system and to spot mistakes in the system's interpretation (e.g., of their speech input). This reduces team member's worry to overlook possible mistakes of the system and using the wrong information to make decisions. Moreover, all design principles are key to provide the possibility to conduct ad-hoc analysis during co-located team interactions and to derive insights that would otherwise be overlooked. Therefore, these design principles can facilitate effective use of multimodal BI&A systems in co-located team interactions. Taken together, our research shows how the theory of effective use can be applied to improve the interaction of users with BI&A systems and advances our understanding of how users interact with MUIs.

Our evaluation also sheds light on additional design issues, which offer valuable starting points for a further improvement of multimodal BI&A systems. First, one weakness of multimodal BI&A systems derived in our evaluation indicates that the users need to be able to perform adaptation actions on the speech interaction itself. If the speech interaction feels unnatural to team members or the system repeatedly fails to understand their speech input, teams are unlikely to use multimodal BI&A systems. To provide the system with the capabilities of adapting its speech interaction and to facilitate transparent interaction, Li et al. (2017) propose to make multimodal systems "instructable". This would imply that, if the multimodal BI&A system fails to understand the teams' intention or input, team members are able to provide feedback back to the system. More specifically, teams could not only mark their input as interpreted incorrectly but also demonstrate the correct intention to the system using touch which the multimodal BI&A system provides due to its multimodal nature. For example, if a user wants to "Filter for the critical customers", the system would not know what critical customers are. Therefore, the user can demonstrate for future cases using touch that critical customers have an order volume of higher than 1 million and a remaining contract term of 1 year. Therefore, providing MUIs with the ability to improve their recognition of intentions for a certain modality using input from another modality could facilitate the effective use of MUIs in general.

Furthermore, our results suggest that an initial onboarding could further facilitate effective use as it helps teams to learn how to interact properly with the system. Using multimodal BI&A systems during co-located team interactions allows everyone to interact with the system and contribute equally to the discussion and derivation of insights. However, this brings new challenges to the moderator of the discussion and the proper interaction with the system. Therefore, teams should be guided through the system in an onboarding phase to help them adapt their behavior to the system (e.g., how to formulate their questions in natural language) and show them how to get information using which modalities. Furthermore, during the use of the multimodal BI&A system, feedback should be provided based on the current interactions to help teams understand which information is further needed by the system, where the boundaries of the system are, and what modalities are available. Our reactive feedback (DP2) already provides feedback to teams on their current interactions. However, it does not provide explicit suggestions on how to interact with the system and how teams may adapt the multimodal BI&A systems in accordance with their team characteristics. This reactive feedback could be enhanced with further inquiries, suggestions, and insights in order to make the interaction between the team and the multimodal BI&A system not a one-way, but a two-way conversation.

Finally, there are also some limitations of work that should be considered. First, our multimodal BI&A system only implemented two modalities: touch and speech. Although they are generally considered to be important modalities in HCI, future research could evaluate how other modalities (e.g., gaze and speech) complement each other and can be integrated into multimodal BI&A systems to facilitate effective use. Second, we instantiated our design principles on a large interactive display. However, the size, as well as the appearance of the interactive surface, may influence how people interact with our artifact. Consequently, future research could evaluate the influence of the type of device used for the provision of the artifact. Finally, we used a confirmatory focus group to perform a qualitative evaluation of the impact of the software artifact on the facilitation of effective use. Although we argue that this approach is appropriate given the innovative nature of multimodal BI&A systems, further research using quantitative evaluation methods is needed. Therefore, a quantitative field-based study could provide additional insights into the impact of multimodal BI&A systems on their effective use in co-located team interaction.

6 Conclusion

This paper reports the results of the first cycle of a DSR project focusing on the design of multimodal BI&A systems for co-located team interactions. Overall, our DSR project contributes with design knowledge that can be applied to facilitate the effective use of multimodal BI&A systems in co-located team interactions. In particular, we contribute with three design principles in order to provide a multimodal BI&A system to teams consisting of user-defined multimodal interactions as well as feedback and signaling affordances for speech interaction. The design principles were derived based on the theory of effective use, guidelines for the design of MUIs, and empirical insights of an interaction-elicitation study. We instantiated our design principles and developed a running software artifact based on state-of-the-art technology. Finally, our evaluation of the software artifact in the form of a confirmatory focus group with an industry partner demonstrates the potential of our proposed software artifact.

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