Exploring How Workspace Awareness Cues Affect Distributed Meeting Outcome

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ABSTRACT
Nowadays, using the online whiteboard to share knowledge in distributed meetings has become a common practice. Existing studies and practices have attempted to visualize attendees' interactive activities in whiteboard tools to support the virtual team's workspace awareness (WA). However, the impact of such visual cues on meeting success remains unclear. For this purpose, we primarily explore whether and to what extent WA cues are conducive to meeting outcome. This study applies activity theory to guide our prototype design and research analysis. A customized web-based whiteboard interface is implemented under two conditions. We conduct a study with 42 subjects in a distributed meeting scenario via a controlled experiment. Also, we analyze the system affordance via user experience. The results demonstrate that the benefits of WA cues to meeting outcome are especially embodied in goal attainment and quality of contributions, but not effectively supported in productivity and user satisfaction. Moreover, subjects report that they do not feel distracted by the system's visual cues because they do not notice those cues most of the time and use them only when needed. Drawing upon findings from our trial work, we provide several implications for designing a collaborative knowledge-sharing environment to assist the visual support of WA in distributed meetings.

KEYWORDS
knowledge sharing, distributed meeting, workspace awareness, meeting outcome, activity theory

1. Introduction

Globalization, telecommuting, and crisis cases (e.g., the COVID-19 outbreak) have made it essential for geographically dispersed teams to share and exchange knowledge using online whiteboards or similar digital tools (Gumienny, et al., 2013; Zillner, et al., 2014). Compared with traditional tools, the online whiteboard supports more interactive functions, meanwhile maintaining the flexibility and fluidity of physical whiteboards (Cherubini et al., 2007). It allows virtual teams to share knowledge, exchange information, or depict ideas simultaneously, which overcomes such shortcomings as "production blocking" in oral conversations (Ivanov, & Zelchenko, 2019). In practice, the online whiteboard has been proved its value in informal collaboration, team decision, and awareness (Mangano, et al., 2014).

However, in comparison to face-to-face environments, distributed teams struggle to maintain awareness of others in their workspace (Gutwin & Greenberg, 2002; Jang,

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Steinfield, & Pfaff, 2002; Zillner, et al., 2014). For example, they often have difficulty or uncertainty about who else is in their shared workspace, where they are working, what they are doing, and how activities are occurring (Gutwin & Greenberg, 2002). In online whiteboards, it is arduous for users to perceive the source identity of content via direct observation, if there exists no explicit visual cues about the authorship (Mangano, et al., 2014). Moreover, users often lack intuitive awareness about what collaborators are doing and where they are working in the whiteboard workspace. If user actions are minor or the workspace is messy, visual information about the activity may be difficult to see, and it becomes increasingly difficult for users to notice changes in the workspace as tasks get demanding (Gutwin et al., 2011). Although largely focusing on the tools' collaborative usage (Mangano, et al., 2014; Gumienny, et al., 2013), the potential of enhanced functions (Zhao et al., 2014; Nilsson, & Svensson, 2014), and simulating physical experience (Zillner, et al., 2014; Higuchi, et al, 2015), whiteboard studies for distributed meetings have begun to concern the visual support of workspace awareness (WA) in such interfaces. In the commercial domain, there are already abundant web-based whiteboard tools, such as MURAL [2], Lucidspark [3], and Conceptboard [4], some of which have the ability to identify collaborators by color-coded lists, track all attendees' editing position via cursors, or recall history collaborative activities in form of timeline lists or video playbacks.

While existing tools or works have taken specific steps or suggestions to support WA by visualizing such information as users' interactive activities on the whiteboard, the benefits of these visual cues to distributed meetings, however, have not been clearly verified. On one hand, this content transparency renders co-workers informed about who is performing what action at when. This practice perhaps inspires an impetus for individual participation, hence increasing team production and the accuracy of information shared by teams (Stuart et al., 2012). On the other hand, these visual cues make everyone's behavior visible real-timely, which would boost the pressure on participants to collaborate, such as "evaluation apprehension" of their work (Thompson, Sebastianelli, & Murray, 2009). Also, it might interfere with ongoing tasks continuously and thus affect production (McFarlane, & Latorella, 2002). Therefore, it remains an open question whether and to what extent such visual cues are beneficial to the success of distributed meetings.

Exploring the effects of WA cues on meeting outcome is vital in designing a better collaborative environment for virtual teams. However, this issue may pose several challenges. Firstly, existing works lack a feasible theoretical framework for understanding the virtual team's interactive activities in distributed meeting scenarios. To thoroughly examine the core elements and their relationships in this context, a reference framework grounded in existing theories is needed to gain a deeper insight into the potential impacts of WA cues. Secondly, while qualitative and/or quantitative methods are available to measure a meeting's success from diverse perspectives, there is currently no clear consensus on what components contribute to a successful meeting due to the absence of assessing reference (Romney, Smith, & Okhuysen, 2019).

To tackle these problems, we start our work by clarifying the concept of WA in virtual teams. Adhered to (Gutwin & Greenberg, 2002), we signify workspace awareness as the up-to-moment understanding of all attendees' interaction with a shared whiteboard workspace, which clarifies five questions: who, what, where, when, and how. That is, attendees can be aware of others' actions on certain artifacts in the shared

[2]https://www.mural.co
[3]https://lucidspark.com
[4]https://conceptboard.com

whiteboard, including ongoing activities, dynamic changes, and interactive histories. In this paper, WA is adopted as the proxy of meeting ownership. The ownership of a meeting indicates the extent to which all attendees perceive responsibility for the meeting outcome, such as a decision, a solution, or a set of suggestions, including influential elements of participation in the meeting process and factors that exert a beneficial role (Davison, 1997). Based on this, we emphatically concern the following question: "Does and to what extent the visual cues based on workspace awareness can elicit a better meeting outcome?"

For this research question, we attempt to understand collaborative activities of team's sharing contents in distributed meetings from the lens of activity theory (AT) framework (Engestrom, 1987). The reason why we choose AT is that it fits our scenario well. As a comprehensive framework that has been extensively used in HCI domains for decades, AT's elements can be used to explain the components and their relationships involved in team activity. Also, its principles, such as development, can depict possible contradictions among those elements in a distributed meeting context. Moreover, AT can analyze how the awareness-related element affects others, such as meeting outcome. For this purpose, we analyze how elements such as attendees, teams, tools, rules, tasks, and division of labor interact and coordinate in this context. We focus on intuitive WA visual support of existing tools to perceive others' knowledge-sharing behaviors on the shared whiteboard. Grounded in AT, a customized web-based whiteboard prototype called ActVis (Action Visualization) is proposed. We primarily encode five data elements: users, actions, entities, time, and status (inspired by (Gutwin & Greenberg, 2002; Shi et al., 2018)) as contextual information in ActVis's visual area. With a linear timeline mechanism, our prototype provides awareness cues that enable participants to intuitively perceive all attendees' event stories (i.e., who has done what at when and how) during a meeting. On this basis, to evaluate our visual cues in facilitating meeting success, we mainly consider three dimensions by synthesizing existing literature: effectiveness (Haynes, 1998), productivity (Romney, Smith, & Okhuysen, 2019), and satisfaction (Prenner, Klünder, & Schneider, 2018). To implement our research, we conduct an exploratory experiment with 42 subjects to solve a meeting problem, comparing two different configurations: with the visual support versus a non-visual aid baseline.

The user study results show that the advantages of WA cues on meeting outcome are significantly reflected in goal attainment and contribution quality. However, we discover no compelling evidence in productivity and user satisfaction. These findings shed insights on maximizing the role of visual cues as auxiliary means through concise, optional, and analogous ways for future virtual small-team meetings.

The main contributions of our work include: (1) we construct an AT-based framework to illustrate team content-sharing activities in distributed meeting scenarios, as a guideline of our prototype design and research analysis. (2) we simulate a web-based whiteboard system, ActVis, to enable virtual teams to collaboratively create and share contents, and the visual support of WA regarding users' interactive behaviors on the shared whiteboard is underscored. (3) we conduct an exploratory study to explore the effects of WA cues afforded by ActVis on meeting's effectiveness, productivity, and satisfaction, as well as user experience on system affordance.

The rest of this paper is structured as follows. In Section 2, we provide a review of related work. An AT-based model is introduced in Section 3. Grounded in AT framework, we outline the whiteboard interface ActVis in Section 4, and present our research questions and methodology in Section 5. Section 6 presents the results of our findings. Section 7 and 8 elaborate discussion, implications, and limitations of our study, respectively. The conclusion is given in Section 9.

2. Related Work

In this section, we present previous studies closely related to our work, including (1) the theoretical framework; (2) evaluation of meeting outcome; (3) visual cues related to workspace awareness.

2.1. Theoretical Framework: Activity Theory

AT has been widely employed as a conceptual framework by HCI researchers to describe, analyze, and understand human activities (Kuutti, 1995). Several studies used AT to guide the design of various systems or tools. For example, grounded in AT, Houben et al. (Houben et al., 2013) built a co-Activity Manager to support knowledge workers' personal and collaborative practices under three principles: configuration, articulation, and coordination. Doweling et al. devised an AT-based conceptual model for the design of interactive system that combines social, physical, and technical contexts of activities (Dweling, Schmidt, & Gob, 2012). Other works used AT to support activity analysis. For instance, Bardram adopted the "Activity Analysis" approach based on AT concepts to conduct an empirical analysis of collaborative work between wards and operating rooms in a hospital (Bardram, & Doryab, 2011). Through wearable sensing and visualization devices, Clegg et al. studied how elements within AT framework affect learners' scientific exploration and life-relevant experience in the classroom environment (Clegg et al., 2017). Kou and Gui used the forum community for understanding the role of explanation mediated in the interaction between game players and AI, and further analyzed explainable AI (XAI) by a case study from AT's lens (Kou, & Gui, 2020).

In this paper, with the guideline of AT's core concepts, we will analyze essential elements, subsystems, and principles in distributed meetings, emphasizing the potential impacts of WA cue on meeting outcome. Accordingly, the system prototype's design criteria are extracted from the AT model.

2.2. Evaluation of Meeting Outcome

While there is no clear consensus on the dimensions of meeting success in existing literature, several scholars have sought to evaluate meeting outcome from disparate aspects. For instance, Prenner et al. quantified meeting success gathered from user feedback, categorizing three themes: effectiveness (perceived degree of meeting goal achievement), efficiency (perceived relationship between involved time and meeting effectiveness), and satisfaction (positive attitudes toward the meeting, without complaints and discomfort) (Prenner, Klünder, & Schneider, 2018). Kauffeld et al. believed that a meeting would be effective if teams could accomplish their common goals in the lowest time (Kauffeld, & Lehmann, 2012). Tropman depicted an effective meeting with good decision-making results and time-taking worthwhile felt by attendees (Tropman, 1996). There was also work that measured meeting effectiveness using two criteria: goal attainment and decision satisfaction (Nixon, & Littlepage, 1992). By collecting data from subjects about their recent experiences, Romney et al. categorized three themes regarding meeting success: participant learning and development, coordination of performance, and shared understanding among attendees (Romney, Smith, & Okhuysen, 2019).

In this paper, we will classify the success of a meeting into three dimensions combing recurrent characteristics of prior research results: effectiveness, productivity, and satisfaction. Effectiveness refers to attendees achieving their shared goals in the shortest time possible. Productivity means that the meeting has deliverable or tangible results. Satisfaction reveals that users have positive attitudes toward the meeting. Of note, although we have fully consulted available literature on three dimensions of the meeting success, attributes for each dimension are not guaranteed to be exhaustive.

2.3. Visual Cues Related to Workspace Awareness

Workspace awareness is a critical aspect of collaboration in distributed scenarios. By providing up-to-date knowledge of what action collaborators are doing and how they perform it, WA often relies on visual display techniques (Gutwin et al., 2011).

To support such awareness cues — understanding of who is in the workspace, where they are working, what they are doing, and how and when activities are changed (Gutwin & Greenberg, 2002), scholars have proposed various visualization approaches. Participant lists (Blichmann, & Meißner, 2017), multi-user scrollbars (Gutwin, Roseman, & Greenberg, 1996), and radar views (Gutwin & Greenberg, 2002) are examples of widely adopted in existing works, which mostly display WA cues in a specific area of the shared workspace. The participant list comprises all elements concerning who, such as online status and identity information. It indicates that user lists belong to the platform level, whose information about attendees' presence and identity are generally available at the time of initializing the platform (Blichmann et al., 2015). The radar view is provided with detailed visibility to interactive actions of the shared workspace, which displays telepointers and rectangles representing users' viewports (Gutwin & Greenberg, 2002). Although the concept of workspace awareness was rarely mentioned in distributed meeting scenarios, current scholars have unfolded a series of visualization methods to enhance such awareness. For example, Aseniero et al. (Aseniero et al., 2020) developed MeetCues, an online interactive platform to increase awareness of a meeting's atmosphere through visualizing participants' contributions and salient moments. Certain commercial tools also develop similar functionality to support user awareness in online meetings. For instance, Miro [5] identifies collaborators by color-coded lists, tracks all attendees' editing positions via cursors, and records all attendees' history collaborative activities in the "Board History" module.

In this paper, combining existing literature practices and commercial tools' features, we externalize workspace awareness in node chain forms by visualizing collaborative sharing behaviors of all participants on the shared whiteboard with the visual module, i.e., who is doing what action at when and how it changed.

3. AT-oriented Model in Distributed Meeting Contexts

AT is a conceptual framework for describing, analyzing, and understanding human collaborative activities (Bardram, & Doryab, 2011), which has been applied as the design guideline or design methodology (Houben et al., 2013). In this section, we elaborate AT's elements, subsystems, and principles, mapped in distributed meeting

[5]https://miro.com

scenarios. We attempt to understand how the WA element affects meeting outcome in such a context, thus deriving requirements for the prototype design from our AT model.

- ***Elements***

In the distributed meeting context, an activity launched by attendees is to share various contents collaboratively. Drawing from Engestrom's concept of "activity system" (Engestrom, 1987), our theoretical framework is modeled, as illustrated in Figure 1. According to this model, we expound elements in distributed meeting activities and why they are so designed.

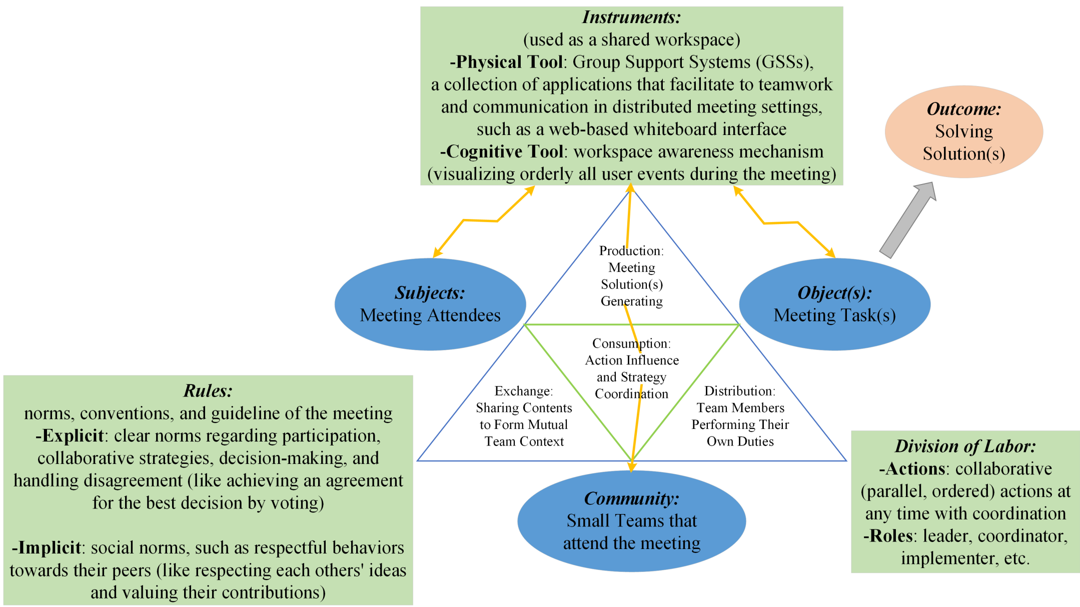

Figure 1. The Activity System Model in Distributed Team Meeting Environment.

Subjects: attendees, who are controllers and creators of team meeting activities.

Object(s): meeting task(s), which are the meeting goals aimed to be achieved. Objects are transformed towards desired outcomes by subjects.

Instruments: media that subjects act on objects, including two types: one of which is the physical tool. This category covers a series of application components (group support systems, GSSs) to sustain and facilitate collaboration and communication for a virtual team, such as the simulated whiteboard interface. The other is a workspace awareness mechanism in cognitive aspects, whose elements (who, what, where, when, how) are shown in Table 1. Its practice is to externally visualize all attendees' behavioral events in temporal sequence forms (e.g., who are sharing what contents and how at any time), thus enabling participants to real-timely perceive their interactive activities on the shared GSSs such as whiteboard workspace.

Community: the small team that subjects belong to, which shares the same object or common motivation with subjects.

Rules: norms, conventions, and guidelines of meeting activities, both explicit and implicit. Concretely, explicit rules are those about participating in the meeting, coordinating strategies, making decisions, and so on. For example, the consensus of team decisions is reached by voting. Implicit rules cover such social norms as esteeming others' ideas, valuing collaborators' contributions, etc.

Division of Labor: assignment of task, power, or status within the community, which involves how team members perform certain roles and organize their actions in interactive activities. During the meeting, an attendee acts such as the leader, coordinator, and implementer, whose role does not emphasize to be assumed beforehand. A subject interacts with his/her team via collaborative behaviors like parallel or ordered actions.

Outcome: meeting solution(s), are results of objects being transformed by subjects through the team activity process.

- ***Subsystems***

As shown in Figure 1, AT's elements are assemble to form four small triangles, namely, production, exchange, distribution, and consumption subsystems.

Production: the process of a meeting solution is generated. That is, participants exploit tools such as GSSs to accomplish meeting task goals, with a result of generating their solutions.

Exchange: the process of forming a mutual "team context" through sharing contents, knowledge, and ideas related to meeting tasks. Following common rules, all attendees in the community conduct interactive communication, such as sharing and discussing task materials. Throughout this process, involved teams gradually establish a mutual interrelated partnership or "community context".

Distribution: the process of team members performing their duties. Specifically, due to the diversity of team members in professional experience, knowledge level, and work skills, the community adopts a flexible division strategy. For example, diverse attendees are assigned different task-related materials and undertake varying divisions of (sub)tasks, enabling disparate members to exert distinct roles, such as leader, coordinator, and implementer, and execute various interactive (parallel, ordered) behaviors. What the aim of these strategies within the community is to accomplish the meeting tasks together.

Consumption: the process of behavior interplay and tactic coordination among members within the team. As the subjects of a meeting activity, attendees are constantly influenced by the community (i.e., team) during fulfilling the objects (i.e., meeting tasks). For example, they assimilate and even integrate contents shared by others, and thus correspondingly adjust their tactics that affect and transform objects, such as altering sharing/discussion strategy. This process needs to consume both physical (e.g., meeting materials) and mental (e.g., comprehension capacity) resources for the community and its subjects. For instance, the community enables subjects to launch activities to generate the task solution (i.e., outcome). Meanwhile, it also influences or coordinates subjects' strategies of achieving their objectives.

- ***Extensible Principles***

Standing on previous works, we illustrate how the following principles guide our prototype design from the ideas of AT.

Object-Orientedness: team activities are targeted towards accomplishing the meeting task that needs to be pre-planned, clearly stated, and possibly adjusted during specific activity.

Hierarchical Structure: In distributed meetings, an activity covers three levels of hierarchy. On the first layer, participants complete the meeting task collaboratively, which is a collective *Activity* driven by the subjects' motives. On the second layer, participants share materials, discuss together, etc., which are individual *Actions* oriented by goals. On the last layer, participants create, modify, delete texts and graphics, which are *Operations* supported by conditions. The workspace awareness that surrounds attendees' interactive activity with the whiteboard is decomposed to the operation level in our settings. A top-down relationship exists between these hierarchies: the user motive is decomposed into multiple goals, and each goal owns its actions completed by unconscious and automatic operations in virtue of capture technique conditions.

Internalization and Externalization: the activity is categorized as internal (mental) and external (practical) ones. Internalization is the process by which people abstract and conceptualize external activities and transform them into internal wisdom. On the contrary, externalization is the process of guiding external activities with human wisdom. In our meeting scenario, visualization of user events allows participants to perceive others' interactive behaviors on their shared workspace. Conversely, workspace awareness brought by such visual cues possibly affects users' actual behaviors, such as engagement and contribution.

Artifact-Mediation: the tool plays an essential mediating role in the interaction between subjects and objects. In the meeting context, attendees undertake their task-related activities using various media, such as GSSs. As a cognitive mechanism, workspace awareness is designed to assist subjects in performing these tasks.

Development: as the core of AT, contradiction is a driving force of development in activity systems (Engestrom, 2001). When elements of the system are combined to conduct a collective activity, various contradictions within and between those elements inevitably arise, accompanied by an ever-changing characteristic. For instance, during a meeting, it is required to be dynamically coordinated, revised, or re-planned when tools, rules, or objects change, become unstable, or even break down. The new system repaired may further trigger or impact the interaction between elements. In practice, we can draw from the contradiction analysis method (Engestrom, 1987) and dynamic transformation concept (Bardram, 1998) to deeply decompose, transform, and develop meeting activities.

According to AT's development principle, with continuous changes in human, community and technology elements, contradictions probably emerge within an activity system (Kou, & Gui, 2020). Thereby, it is requisite to readjust equilibrium among elements so as to make the system stable again. It has been stated that the teams, especially virtual ones, suffer from lacking visual awareness of collaborators' activities and their collaborative process intuitively (Jang, Steinfield, & Pfaff, 2002). Analogously, in a distributed environment, there are two similar contradictions, as shown by yellow arrows in Figure 1. Firstly, the contradiction occurs between subjects, community and instruments. Concretely, attendees and their virtual team are likely to lack contextual awareness of others' interactive behaviors in their shared whiteboard workspace, so the tool needs to furnish users with visual support to perceive remote participants' real-time behaviors. Secondly, the contradiction exists between objects and instruments. Compared with face-to-face communication, the virtual team's dynamic collaborative process of achieving task goals, such as meeting progresses, is often not intuitively perceived. Thus, the tool has to provide intuitive affordance for presenting how team activities evolve. Summarily, as an interactive medium, the supported tool needs to possess two major requirements for satisfying the distributed meeting scenario. That is, it should supply the direct visual support for both interactive behaviors and collaborative process of participants so that all team members can jointly perceive these awareness cues. As shown in Table 1, these cues can be attributed to all elements of workspace awareness, i.e., who has done what at when and how. What information we provide enables participants to be aware of the following at a glance: (1) others' ongoing actions; (2) dynamic changes of user events; (3) an overview of the team collaborative process.

Anticipation: motive of the activity, which is a predictive function (Pena, Sossa, & Mendez, 2014). Here, we exploit this principle to evaluate the impact of workspace awareness cues on meeting outcome, which is the focus of our work.

Table 1. Essential Elements of workspace awareness (Gutwin & Greenberg, 2002; Shi et al., 2018).

Category	Element	Description
Who	Authorship	Who is doing that (attendee)?
What	Action Artifact	What are they doing (e.g., sharing, discussing)? What are their current activities (e.g., solving certain task)? What objects are they working on (e.g., texts, graphics)?
Where	Location	Where are they working (certain zone of whiteboard workspace)?
When	Event History	When did that event happen?
How	Changes Action History Artifact History	What changes are they making? What are changes being made? How did that operation happen? How did this artifact come to be in this state?

4. Web-based Whiteboard Interface: ActVis

Grounded in AT framework that frames necessary elements involved in our scenario, we simulate a web-based shared interface called ActVis. Its whiteboard area supports virtual teams collaboratively share contents to solve a common problem during a distributed meeting. In the visual area of ActVis, the workspace awareness mechanism visualized in a linear timeline explicitly enables participants to perceive others' interactive behaviors on the shared whiteboard. The visual zone is used to examine how such awareness cues will affect meeting outcome.

In terms of visual representation, we consult several concepts from existing literature, such as "narrative structure" (covering who, what, when, where, how of an event) (Shi et al., 2018) and "file biography" (displaying milestone actions of an activity horizontally) (Lindley et al., 2018), as well as common forms from popular commercial tools, such as the "Board History" (chronologically recording historical actions) of Miro. Together, these combinations constitute our practice of visualizing the workspace awareness information in the event-sequence timeline form.

It is worth noting that in collaborative works, tools that allow rapid prototyping of interaction concepts and experimental scenarios are critical to evaluate the effectiveness of interactive approaches (Sigitov, 2016). In this paper, our goal is to implement a prototype for simulating the off-the-shelf web-based whiteboard system, rather than designing a brand-new one, whose awareness cue is emphatically used to evaluate its impact on the meeting outcome. To be specific, we exploit the AT framework to frame minimal constituent elements necessary for the prototype to function in a distributed meeting scenario, emphasizing the visual support of workspace awareness. The core principles of AT guide our prototype's design criteria. Based on these guidelines, we further refine and identify the feature components of this prototype.

4.1. Design Rationale

Drawn from "keep the user learning curve short; use simple interfaces" (Chandrasegaran et al., 2019), we take "keeping the interface as simple as possible" and "revealing information in a non-intrusive manner" as our design guidelines. Established on these two principles, we emphatically identify five design criteria under the AT framework.

G1: Support Collaboration and Sharing

Following AT's mediation principle, the prototype is designed to simulate an online whiteboard environment, facilitating distributed users to collaboratively share and exchange knowledge in the shared workspace.

G2: Support Workspace Awareness

Based on the AT's internal and external principle, subjects (i.e., attendees) within the community (i.e., team) should be able to real-timely perceive the interactive content-sharing behaviors of others in the shared interface. Abided by AT's hierarchy principle, the prototype should track the community activity via recording all subjects' interactive actions related to content sharing and discussing. These actions comprise milestone operations, such as create, move, modify, and delete.

G3: Support Rich Media

Following AT's hierarchy principle as well, the artifacts operated by subjects should cover various media types, such as rich text, drawing, photograph, audio, and video.

G4: Convergent Work

Based on AT's object-oriented principle, our simulated scenario is to complete the same task target by sharing contents among distributed attendees (i.e., subjects). For that, users need to digest, integrate, and summarize those contents as such to make an consistent choice together, which would be a continuous convergent process towards meeting task goals (i.e., objects).

4.2. Supportive Functions

Following the guidelines above, we elaborate how to refine these guidelines into functional attributes supported by our prototype.

F1: Displaying Participant Information

Several information such as nickname, discipline, and status (preparation, presence, and departure) are exhibited to keep users aware of all other members' identity and presence (Guideline G2). As mentioned earlier, although these information (about "who") belong to workspace awareness, they are generally available as essential elements of a meeting once the online platform is initiated. Thus, the participant information is not within the scope of workspace awareness mentioned in this paper.

F2: Collaboration and Content Sharing

In the shared workspace, attendees are supported to create, share, and exchange various contents real-timely (Guideline G1). For simplicity, we mainly focus on textual and figures (Guideline G3). In order to achieve a common goal, participants can create, move, modify, copy-paste, delete, undo/redo what they share (Guideline G2), as well as make the common choice collaboratively (Guideline G4).

F3: Process Visualization

Process Recording. We call users' ordered events a sampled record of what has happened to the corresponding entities via users over time, inspired by the existing practices of literature (Shi et al., 2018; Lindley et al., 2018) and whiteboard tools. In order to track participants' interactive process, we emphatically record contextual information about those events, including user, entity, operation, time, and status (Guideline G2). Almost supported actions are recorded, excluding the move operation due to storage overhead consideration.

Interactive Visualization. Participants' sharing process is viewed in "overview + detail" mode (Guideline G2), inspired by (Zhao et al., 2017). In the overview mode, users can observe temporal sequences of all attendees' actions through shuttling those nodes, whose information includes executing users, acted entities, operation types, occurred time, and workspace status. Also, the dynamics of an emerging action highlighted in the latest node can be witnessed real-timely by all participants during the meeting. In the detail mode, participants can watch the corresponding whiteboard snapshot detailedly to check the shared content's status if clicking a certain action node. By interacting with these visual cues in this way, attendees can perceive interactive behaviors of all meeting members, including team collaborative process, emerging actions, and action dynamics.

4.3. User Interface

To meet the aforementioned functional requirements, the main interface of our prototype contains four coordinated panels as indicated below (Figure 2). The element mapping between ActVis and AT is shown in Table 2.

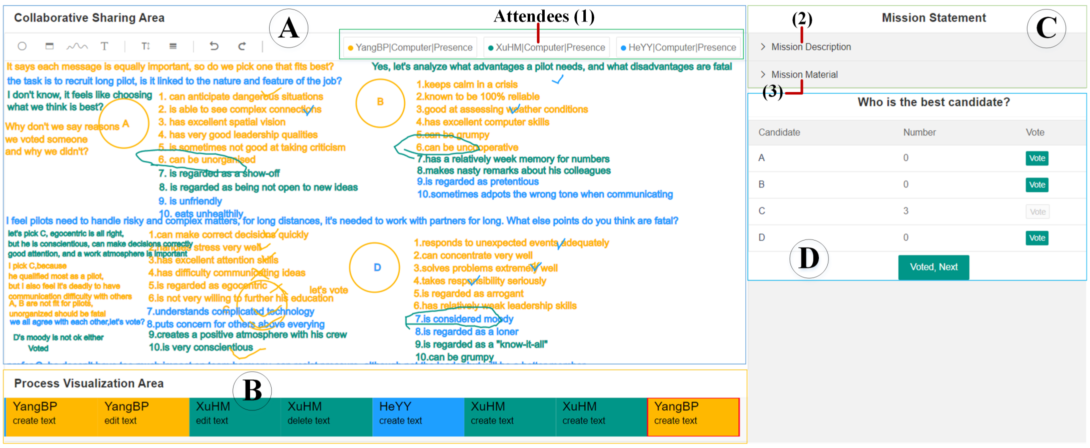

Figure 2. The ActVis interface is composed of (A) the collaborative content-sharing area, (B) the process visualization area, (C) the mission statement area, and (D) the voting area.

Table 2. Element mapping between our prototype and AT-oriented model.

AT	Symbol	System
Subjects	A(1)	**Attendees**, located in top-right corner of the collaborative sharing area
Object	C(2)	**Mission Description**, which clarifies what the meeting goal is
Community	A(1)	not explicitly reflected, attendees together as a **Small Team**
Instruments	-, B	Physical: GSSs, mapped to the **Overall Interface**, including virtual whiteboard, mission statement, and voting area Cognitive: workspace awareness mechanism, externalized in **Process Visualization Area**, which enables attendees to perceive other's interactive actions
Rules	C(2), D	Explicit: **Mission Description and Voting Area**, which identify such strategies as making the team decision by voting Implicit: not explicitly reflected, **Social Norms** in meeting settings, such as respecting other's ideas, valuing peer's contributions, etc.
Division of Labor	C(3), A	**Mission Material**, which allocates diverse materials to different attendees who play certain roles parallel and ordered actions for participants are supported in the **Collaborative Sharing Area**

Collaborative Sharing Contents. In this panel (also called virtual whiteboard), attendees are supported to collaboratively create, move, modify, copy-paste, delete, and undo/redo any circles, rectangles, strokes, and text contents (Function F2). We attempt to simulate that attendees share contents on the whiteboard in realistic meetings with mouse-and-keyboard inputs. Additionally, except for user backgrounds such as username, discipline, and distinct colors designed to recognize participants, we also display attendees' status about their preparation, presence, and departure in current meeting scenario (Function F1). Participants can see this information in the top right area, thus constituting a meeting team atmosphere. Upon logging into the prototype platform, this information is accessible to all attendees, which is generally an essential element of any small team meeting.

Process Visualization. This panel, grounded in the workspace awareness mechanism mentioned earlier, allows users to perceive collaborators' interactive behaviors by visualizing ordered events of all participants (Function F3). Specifically, attendees can notice any emerging action attached on the latest node (highlighted with a red box) dynamically in this area. Also, attendees are supported to drag left and right to overview historical information of their actions, such as performed users, operation types, and targeted objects. For details, users can click a certain node to comprehend how an action change to its current state by viewing the corresponding whiteboard snapshot.

Mission Statement. In this panel, the task's description and material are assigned to clearly inform attendees of the meeting goal, content sharing strategies, and so on.

Voting. This panel explicitly explain the rules of team decision-making by allowing members to vote or alter their decisions at any time, but with only one vote per person (Function F2).

5. User Study

In this research, supported by the prototype above, we used AT as an analysis framework to conduct a between-subject user study with two experimental conditions (With and Without visualization). Our work aimed to quantitatively examine how WA cues (i.e., instrument) might influence meeting outcome in distributed settings, including the productivity of attendees (i.e., subjects), the community's goal (i.e., object) completion, etc. We also explored participants' experience with the system itself in qualitative questionnaires and interviews. This study was conducted in two phases: the first phase was to identify the system interface iteratively from preliminary user feedback. In response to user feedback, we aligned the colors of the user's handwriting and visual cue with those in the user list. That is, the operations of diverse users were intuitively identified by the colors that uniquely represent them. Also, for all visual information, we decided not to visualize attendee's operation time, because it was deemed unnecessary by participants to externalize the time during the meeting and its order could be indirectly identified through the timeline. Moreover, we displayed the task description in the whiteboard interface too, except in the task instruction interface, so that subjects could clarify it at any time. The second was to initiate formal research to answer our questions.

5.1. Research Questions

Drawing from the review of evaluating meeting outcome presented earlier, we divided it into three dimensions: effectiveness, productivity, and satisfaction, each with several attributes respectively (as shown in Table 3). These dimensions constituted core characteristics of meeting success by extracting overlapped indicators in existing literature, although not guaranteed to be exhaustive. Based on this, we explored the following research questions:

RQ1: Does the workspace awareness cues elicit teams to accomplish meeting task goals in a shorter time effectively?

Prior works suggested that a meeting is effective if attendees achieve their targets in a minimum time (Prenner, Klünder, & Schneider, 2018; Haynes, 1998). Also, effectiveness involves whether teams successfully reach a meeting goal (Lehmann, Allen, & Belyeu, 2016; Nixon, & Littlepage, 1992). Moreover, existing studies uncovered that participants' perception of achieving meeting goals was also crucial in effectiveness aspects (Prenner, Klünder, & Schneider, 2018; Haynes, 1998).

Thus, to measure meeting effectiveness, we primarily quantified three indicators: task efficiency, goal attainment, and perception of achieving the meeting goal. Task efficiency denoted the time teams spent to complete meeting tasks (Verma et al., 2013). The second aspect was objectively measured as the degree to which users accomplish specific goals (Prenner, Klünder, & Schneider, 2018). Specifically, we evaluated the proportion of participants who made the right decision (Huang, & Tausczik, 2018). Regarding attendees' perception, we measured their subjective feelings about the meeting goal (Nixon, & Littlepage, 1992), such as task difficulty, mutual learning willing, coordinated consistency, and divergence negotiation (Prenner, Klünder, & Schneider, 2018).

RQ2: Whether attendees produce higher productivity in ActVis?

Tropman described a productive meeting as one with good decision-making results (Tropman, 1996), in which actual performance of teams, such as numbers or quality of generated contents, could be covered (Nunamaker, et al, 1991). Therefore, we defined meetings productive as those with deliverable and tangible results.

In this paper, we evaluated meeting productivity in two aspects. Meeting solution denoted whether a meeting produces clear outcomes, and the number of contributions was to measure concrete contents that participants produced in quantity aspects (Verma et al., 2013).

RQ3: Are attendees using the visual cues more satisfied with the meeting?

According to affective events theory, the meeting is an affect-generating event that significantly influences participants' overall mood, job satisfaction, and individual weebeing (Lehmann, Allen, & Belyeu, 2016; Rogelberg et al., 2010). Satisfaction is one of the most frequently measured variables on meeting success in existing research, which includes both process and outcome factors (Prenner, Klünder, & Schneider, 2018; Davison, 1997; Rogelberg et al., 2010). In this paper, satisfaction suggests that participants possess positive attitudes towards the meeting.

To evaluate meeting satisfaction, we asked participants to rate their meetings. We employed four indicators, respectively: team performance, team efficiency, team results, and self-contribution, from participant's viewpoints (Kauffeld, & Lehmann, 2012; Hunter, et al, 2011). These items included such questions as "I was satisfied with the performance of our team". Each item was rated on a 5-point Likert Scale, ranging from "strongly disagree" to "strongly agree".

Table 3. Three factors on the meeting outcome.

Dimension	Attributes	References
Effectiveness	time efficiency, goal attainment, perception of achieving the meeting goal	(Prenner, Klünder, & Schneider, 2018; Haynes, 1998; Lehmann, Allen, & Belyeu, 2016)
Productivity	deliverable and tangible result(s)	(Verma et al., 2013; Romney, Smith, & Okhuysen, 2019; Tropman, 1996)
Satisfaction	satisfied with the process and outcome of the meeting, from participant perspective	(Kauffeld, & Lehmann, 2012; Prenner, Klünder, & Schneider, 2018; Rogelberg et al., 2010)

5.2. *Research Methodology*

5.2.1. *Setting*

Two display modes, i.e., With and Without visualization, were employed as varying experimental conditions (seen as Figure 3). Specifically, we did not afford visual cues of user sharing behaviors under the baseline. The aforementioned visual aids were furnished in the experimental condition. Participants were assigned to a group of size 3, a typical size for traditional small teams in prior studies (Lu, Yuan, & McLeod, 2012). To compare diverse conditions, quantitative analysis, questionnaires, and interviews were performed at the end of our study.

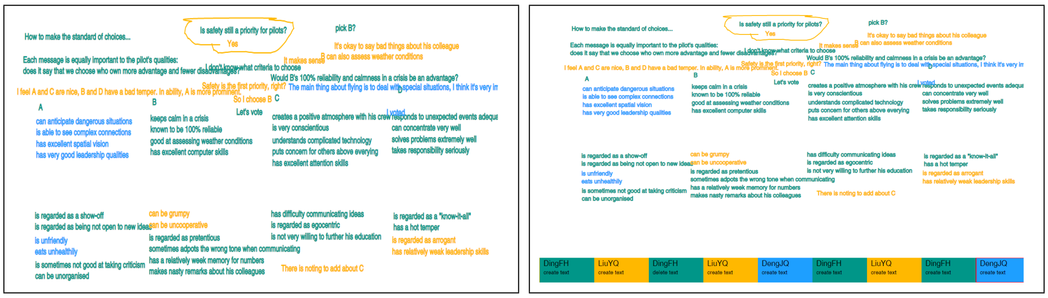

Figure 3. Examples of two experimental conditions: the baseline (left), the experiment condition (right).

5.2.2. *Task*

During the task session, each group was asked to complete a job candidate selection task (Stefan et al., 2006). Specifically, in the simulated distributed meeting, all team members were required to create, share, and discuss four hypothetical candidates A, B, C, and D's soft skills (e.g., communication skills, personal character, teamwork) and decide the best alternative for the job. At the beginning of the meeting, a necessary notification was clarified to each attendee. Not all materials were shared among group members, and each skill was seen as equally important. Only one of the candidates qualified for the job. It was considered successful only if most team members chose the correct answer ultimately.

In this study, with a total of 40 facts of four candidates (See Appendix A), some skills were owned to only one individual (called unique facts), while others were known to everyone (called common facts). Specifically, each member in one group was obtained 8 unique information (including A, B, D's two weaknesses, and C's two strengths), and 16 common facts (containing A, B, D's four strengths, C's three weaknesses and one strength). Before group discussion, they would favor A, B, or D as the best candidate, of which C was the weakest. Thus, participants had to share and pool unique materials to identify the ideal choice C, who had the most strengths, as the optimal solution.

We selected this task for three reasons. One was that it is a classical hidden profile task used in past small-group studies (Verma et al., 2013; Huang, & Tausczik, 2018; Stasser, & Stewart, 1992), characterized by certain information being unshared to the majority or even all group members. However, the unshared information might be crucial to the final solution, which impels the need for mutually sharing contents, unique ones in particular, within the group. The second was that it resembles a common problem-solving scenario in collaborative meetings. During this meeting, knowledge, especially unique information, from diverse attendees would be possibly shared, collected, and debated to achieve the mutual decision. Finally, different from a traditional recruitment of job candidates that requires interviewers to possess professional knowledge, it enables participants with various domain-knowledge levels to participate, as the team simply integrates all the information possible to get the right answer.

5.2.3. Participants

A total of 54 volunteers were recruited in this research, in 18 groups of 3 participants. We received all participants' informed consent before the experiment. Amongst them, we exploited 3 groups for the preliminary pilot to optimize the prototype, which was therefore not within the scope of our statistics. Additionally, 1 group failed to comprehend the task and did not share any content, thus eliminating their results. As a result, 42 subjects (8 females, 34 males), aged 19-35 years (average age of 26), were included in the final experimental analysis. There were 4 Undergraduates, 25 Postgraduates, and 10 Ph.D. as students or workers, predominantly (approximately 90%) with a background in Computer Science. Participants were randomly assigned to either baseline or visual conditions. Of these participants, 6 groups were mixed-gender, and 8 were all-men. 62% of them had participated in at least one meeting in the previous week, and nearly 36% had experience using whiteboard media to share contents.

5.2.4. Procedure

Although without time-bound, we set 90 minutes default as the upper duration.

Firstly, we released guideline booklets to all group members, asked them to spend 5-10 minutes comprehending the whole task procedure, and familiarized themselves with the system freely.

Then, participants were asked to complete a pre-experiment questionnaire to collect their background data.

Next, participants were required to thoroughly read the task instruction stating that "An airline company was recruiting a new long-distance pilot ... We were asking you to attend a three-person meeting via sharing available materials of four candidates with others and identify whom you think to be most suitable for the job ...", before entering their meeting environment.

After that, all group members created, shared, and discussed contents in the virtual whiteboard area, conveyed decisions together by the voting buttons, and filled out a post-experiment questionnaire immediately concluding the meeting to log their perceived experience.

Finally, an interview was conducted to pursue the experience details of participants.

5.2.5. Data Collection

Video recordings were not allowed in both conditions to avoid the potential intrusion.

Each participant was asked to complete two questionnaires: pre-meeting and post-meeting. The pre-meeting questionnaire collected subjects' backgrounds such as gender, age, academic level, and meeting-related experience. Participants' collaborative experiences, including task perception, meeting satisfaction, and system affordance, were primarily recorded in the post-meeting questionnaire (See Appendix B). We also devised an interview to closely capture participants' experience details.

Moreover, relevant data such as participants' contribution quantity, contribution category, completion time, and task outcome (success/failure) were also automatically recorded.

6. Results

In this section, we mainly analyzed a series of questions that we desired to explore.

6.1. RQ1: Does the workspace awareness cue elicit teams to accomplish meeting task goals in a shorter time effectively?

Task Efficiency. Execution time could reflect the quality of teamwork on the efficiency level in certain extents (Verma et al., 2013). Here, we evaluated per-team completion time as an indicator of task efficiency. An independent t-test analysis indicated no significant difference in the time taken to complete the task between two conditions (With: Mean = 21.89 min (SD = 6.24), Without: Mean = 15.50 min (SD = 8.14); $F(1, 40) = 1.89$, $p = 0.13 > 0.05$).

Goal Attainment. Answer accuracy, i.e., the proportion of participants who choose the correct candidate (Huang, & Tausczik, 2018), was measured to indicate the degree of goal attainment in both conditions (Prenner, Klünder, & Schneider, 2018). We observed an obvious correlation between the visual cues and participants identifying the correct candidate ($\chi^2 = 5.46$, $\mathbf{p = 0.02^* < 0.05}$). Comparison of the Chi-Square Test revealed that more participants voted for the ideal person in With condition, which signified that attendees with visual cues had a higher probability of completing the task successfully. Specifically, 10 subjects (47.6%) under the experiment condition reported the right candidate, while only 3 participants (14.3%) voted correctly in the baseline (Figure 4).

Perception of Achieving the Meeting Goal. Here, we categorized 4-dimensional questions, including task difficulty, mutual learning willing, coordinated consistency, and divergence negotiation, as an indicator of participant perception about achieving the task (Prenner, Klünder, & Schneider, 2018; Hunter, et al, 2011). A Wilcoxon Rank-Sum test indicated that attendees in With condition (Mean = 3.05, SD = 1.02) thought the task significantly harder than those of the baseline (Mean = 2.38, SD = 0.97), with Z = -2.16, $\mathbf{p = 0.03^* < 0.05}$ as a result. Significant effects across two conditions were not found in the other three dimensions, as shown in Table 4.

In short, participants with the support of WA cues had a higher probability to successfully complete the meeting task, which was perceived more difficult. Perhaps, the reason for it was that compared with the baseline, subjects under With condition discussed more contents and showed less task-unrelated behaviors (as reflected in subsequent results). Under With condition, teams probably conducted in-depth digestion, discussion, and analysis on their shared materials from diverse perspectives. Over time, some members were likely to unearth the truth, thus rendering them a higher probability of making correct decisions. Sometimes, there might exist divergence amongst group members in decision-making, especially when users tried to persuade each other.

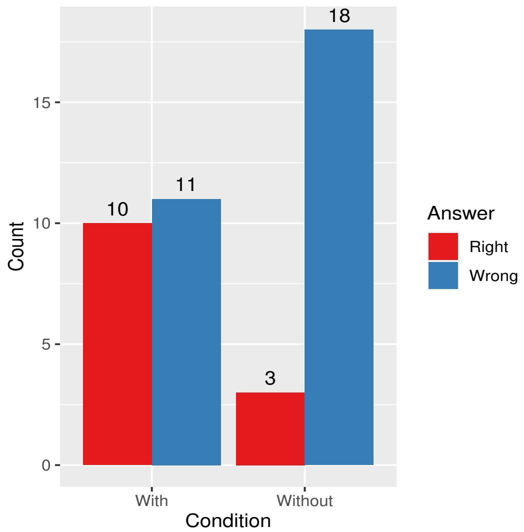

Figure 4. Counts of participants choosing the correct candidate in With and Without conditions.

Table 4. Results of participant perception on achieving the task goal across two conditions (5-point Likert Scale).

Questions	**With**		**Without**		**Wilcoxon Rank-Sum**	
	Mean	**SD**	**Mean**	**SD**	***Z***	***p***
1. task completion difficulty	3.05	1.02	2.38	0.97	-2.16	***0.03****
2. willing to learn from each other	4.43	0.60	4.76	0.44	1.95	*0.052*
3. group efforts were coordinated and consistent	4.48	0.68	4.62	0.59	0.69	*0.49*
4. negotiate divergence in friendly and effective ways	4.19	0.51	4.48	0.51	1.72	*0.09*

*: $p < 0.05$

Still, they asserted their own views, rendering it difficult for the team to reach a consensus. Thus, at that moment, attendees felt the group being involved in a "stalemate" doubtlessly, resulting in the feeling that they had been dilatory in deliberating their decisions. Those experiences might make subjects think they had to pay certain efforts, overcome divergence obstacles, and keep in track with the goal, for the sake of completing the task. Contrarily, attendees in Without condition did not expend more efforts to share and discuss contents about candidates adequately. Thus, they felt fewer obstacles, tardiness, or difficulties in coming to an agreement, due to a lower probability of trapping in dissension.

6.2. RQ2: Whether attendees produce higher productivity in ActVis?

Meeting Solution. We employed per-group's meeting outcome (success/failure) to evaluate the quality of a clear solution produced by the meeting across two conditions (Verma et al., 2013). The result showed that more teams successfully accomplished the task (i.e., most group members chose the right candidate) under With condition. Wherein, 4 teams (57.1%) obtained success (i.e., most group members chose the right candidate) in visual condition, while only one team (14.3%) succeed in the baseline.

However, the relationship between visual cues and team outcome was not statistically significant ($\chi^2 = 1.24$, $p = 0.27 > 0.05$).

Amounts of Contributions by Attendees. Number of participants' contribution could be also a symbol of team productivity (Verma et al., 2013). **(1) Total Contributions**. An analysis of Wilcoxon Rank-Sum test indicated that there was no significant difference in total amount of contents contributed across two conditions (With: Mean = 23.00 (SD = 12.05), Without: Mean = 21.10 (SD = 17.87); Z = -1.06, $p = 0.29 > 0.05$), as shown in Figure 5. **(2) Textual and Graphical Elements**. We explored the number of contents in each condition by the operated object type: texts and graphics (stroke, circle, and rectangle). Results showed that subjects in With condition did not create more textual contents significantly than those in Without condition (With: Mean = 16.43 (SD = 8.13), Without: Mean = 15.38 (SD = 13.49); Z = -0.98, $p = 0.33 > 0.05$). Likewise, no significant difference was found in graphical contents across two conditions (With: Mean = 6.57 (SD = 5.46), Without: Mean = 5.71 (SD = 8.42); Z = -1.37, $p = 0.17 > 0.05$). **(3) Sharing, Discussion, and Irrelevant Contents**. Contents contributed by participants could be classified into three categories by the task goal: sharing-related (e.g., sharing strategies, sharing candidates' materials, auxiliary annotations of sharing), discussion-related (e.g., clarifying task objective; analyzing, negotiating, and deciding who is the ideal candidate; auxiliary annotations of discussion), and irrelevant contributions (e.g., confirmation or testing of system functions at the beginning, doodle irrelevant to the task). Results (Figure 5) revealed that participants in With condition significantly discussed more contents (With: Mean = 11.38 (SD = 5.90), Without: Mean = 6.38 (SD = 4.99); Z = -2.90, $\mathbf{p = 0.004^{**} < 0.01}$), and doodled less (With: Mean = 4.05 (SD = 5.78), Without: Mean = 9.90 (SD = 10.84); Z = 2.01, $\mathbf{p = 0.045^{*} < 0.05}$), as compared to the baseline. However, the analysis for effects of sharing-related aspects was found no significant difference between two conditions (Z = -1.77, $p = 0.08 > 0.05$), although attendees with visual cues shared more contents (With: Mean = 7.57 (SD = 7.95), Without: Mean = 4.81 (SD = 6.82)). Two raters were randomly assigned to code two condition's contribution calculation for assessing the inter-rater reliability. The Cohen's kappa score was substantial: 0.66, 0.67, and 0.62, respectively.

Additionally, existing studies have uncovered that unbalance contributions may cause insufficient motivation for individuals to participate, due to their suffering from the free-rider and sucker effect. As a result, it potentially poses productivity loss in groups (Salomon, & Globerson, 1989). Here, we used the Gini coefficient of inequality, ranging from 0 (no inequality) to 1 (total inequality), to indicate the balance degree in the number of contributions between group members (Andolina et al., 2018). The analysis of independent t-test indicated that the contribution of participants was more balanced in visual condition with Mean = 0.19 (SD = 0.13) than that in the baseline with Mean = 0.26 (SD = 0.14). However, the difference was not statistically significant ($F(1, 12) = 0.18$, $p = 0.35 > 0.05$).

Summarily, there was no significant difference in total contents contributed by users between two conditions, with the same results of textual and graphical elements. More success solution, content sharing, and balanced participation were observed in experimental conditions than those in the baseline, but those differences were not statistically significant. However, there yielded an obvious effect with discussion-related and irrelevant contributions. That is, participants discussed more contents and behaved fewer doodles significantly in visual condition. In our subsequent questionnaire and interview, although the user feedback testified that subjects did not feel distracted by the ActVis and did not pay additional attention to its visual area, the WA cue made it

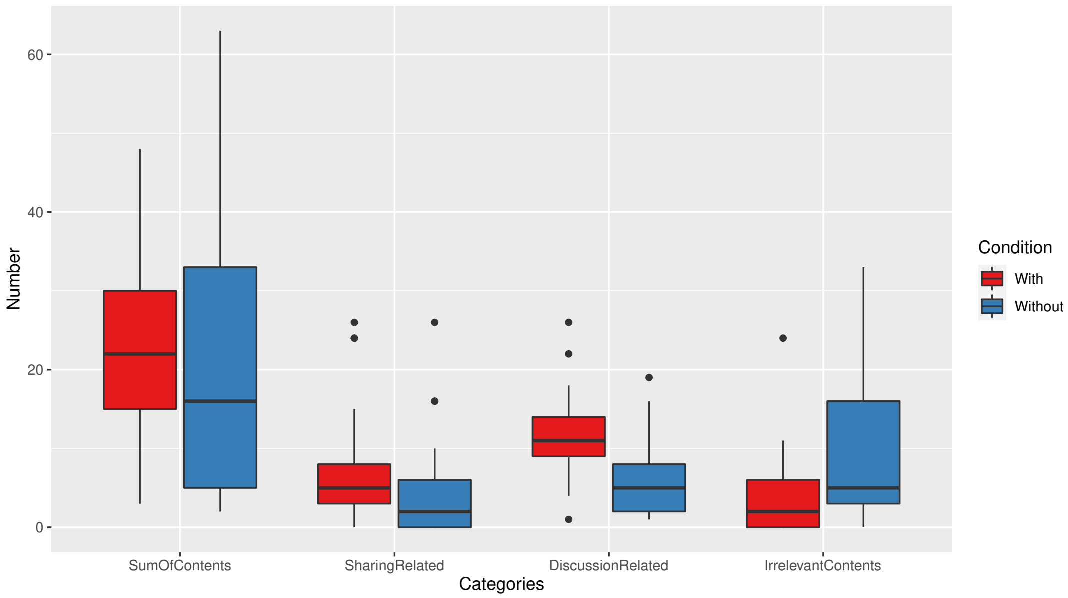

Figure 5. Amount of contents created by participants across two conditions from diverse categories.

clearer for them to visualize who contributed what contents at when and how under With condition. This might incur users more self-consciousness about the quality of their contributions from the beginning, at the same time, however, stimulated their more potential participation motivation. Therefore, the total number of contributions did not increase significantly, meanwhile, participants' tendency was involved more equally. Also, attendees became more cautious during the team collaboration course. For instance, they embodied fewer doodle behaviors unrelated to the task goal and spent more effort discussing the ideal candidate in-depth while making their decisions.

6.3. RQ3: Are attendees using the visual cues more satisfied with the meeting?

Satisfied with Meeting Process and Outcome. We evaluated participant's satisfaction with the meeting in process and outcome aspects (Siemon et al., 2017; Rogelberg et al., 2010; Hunter, et al, 2011), primarily including 4 dimensions: team performance, team efficiency, team results, and self-contribution. We observed no obvious difference in overall satisfaction between two conditions ($Z = 1.09$, $p = 0.28 > 0.05$). But surprisingly, subjects with the visual cues were less satisfied with team efficiency evidently than those in Without condition (With: Mean = 3.90 (SD = 0.54), Without: Mean = 4.43 (SD = 0.60); $Z = 2.78$, $\mathbf{p = 0.005^{**} < 0.01}$). No obvious differences were found in the other three dimensions under two conditions, as shown in Table 5.

As previously mentioned, compared with the baseline, users with the visual cues obviously discussed more contents (With: Mean = 11.38, Without: Mean = 6.38) and contributed less irrelevant ones (With: Mean = 4.05, Without: Mean = 9.90). During the task, teams were likely to assimilate, discuss, and analyze their shared information from various angles. When it occurred that the minority or even majority of members' thinking angles were not correlated with the task, participants would likely feel that the team was breaking away from the task goal or "completely running in opposite

Table 5. Results of satisfaction with the meeting process and outcome across two conditions (5-point Likert Scale).

Questions	With		Without		Wilcoxon Rank-Sum	
	Mean	SD	Mean	SD	*Z*	*p*
1. satisfied with team performance	4.05	0.50	4.24	0.63	1.15	*0.25*
2. satisfied with team efficiency	3.90	0.54	4.43	0.60	2.78	***0.005*****
3. satisfied with team results	4.33	0.58	4.33	0.66	0.10	*0.92*
4. satisfied with self-contribution	4.19	0.60	4.10	0.83	-0.18	*0.86*

**: $p < 0.01$

directions". Thus, it evoked their perception that the team efficiency was not high enough.

6.4. System Affordance

Here, we emphatically explored participant's experience with the system affordance across two conditions, by analyzing the post-meeting questionnaire and interview data.

As in Figure 6, we covered 9-dimensional questions, inspired by (Chandrasegaran et al., 2019; Shi et al., 2018). Specifically, via the supported system under each condition, convenience examined whether users could conveniently share contents or communicate ideas with other members. Readability referred to the subject's easiness of seeing who shared what contents at when. Helpfulness studied whether subjects were aided to see the historical actions of their own and others. New details explored whether users were reminded of certain meeting details they had not previously thought of. Whether the system offered a good representation of the collaborative meeting process was evaluated in visual encoding. Informativeness stated whether the system showed some important or key points of the meeting. Valence probed whether the impact of the system on meeting retrieval was positive, and distraction checked whether respondents were distracted by the system. Through an independent t-test analysis, we did not discover a significant difference in attendee's overall evaluation across two conditions ($F(1, 40) = 0.65$, $p= 0.13 > 0.05$). Each of all dimensions yielded no significant effects either.

In follow-up interviews, for all groups (G1-G14), we shed some discoveries on topics in content readability, new details, and distraction.

The results revealed that users mostly used colored marks on the whiteboard to distinguish what contents were being shared and discussed by which person, together with their real-time changes. Meanwhile, they relied on the visual area that changes dynamically to perceive the newest contents added on the whiteboard. They determined the orders of user actions via the whiteboard layout and logical connection between contents, and the minority identified content sequences by toggling between visual nodes.

Almost all participants stated that they did not feel distracted by the visual aids because they seldom viewed the system's visual area. Users were concerned about it only when they felt the need to know exactly who created what content, how it was generated in current contexts, whether they had missed key points (e.g., individual

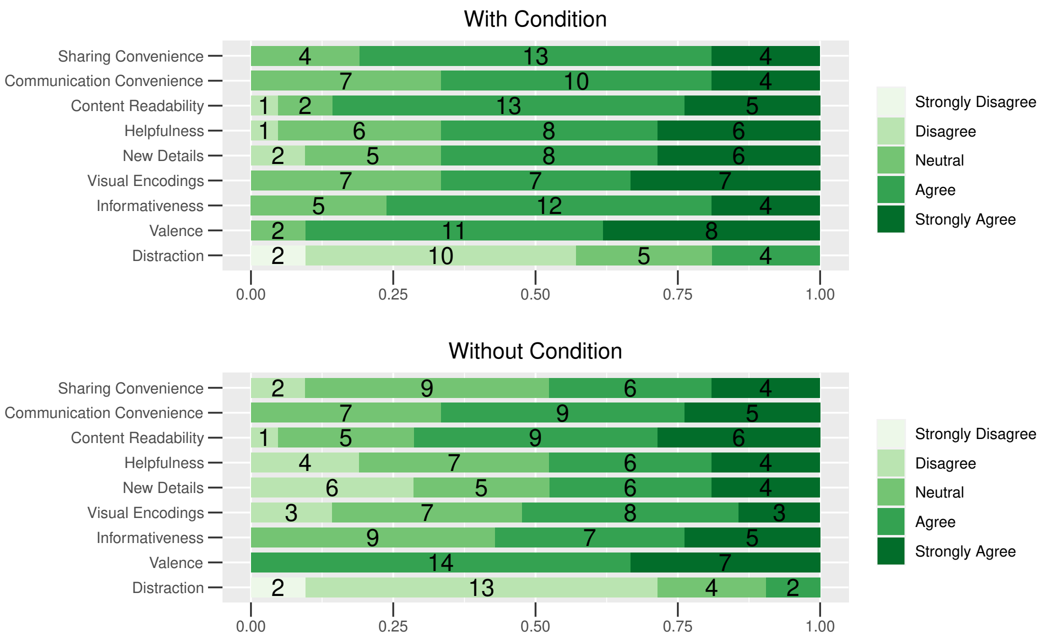

Figure 6. Participant feedback on system affordance for each condition using a 5-point Likert Scale.

viewpoint, decision making), and the latest news. For example, *"It didn't occupy too much of my efforts, and I clicked it when I wanted to see the [content] order. Sometimes, I wanted to confirm which member said firstly and then what he/she said, so I verified the sequence [of contents] by switching between the visual nodes when I wasn't sure ... Our decision has been changed. Maybe we chose A or B from the start, [and changed our decision later]. When we had to determine a [unified] plan finally, I turned to the [visual] nodes to view them (these decisions) chronologically. The fresher time was, the closer our solution was. The previous decision must has been denied due to certain factors"* (G8P22). *"I didn't pay special attention [to the visual area]. Maybe there existed a message that I didn't notice at that time. When [I noticed the node] suddenly changes, I might [steer to the visual node to] check who has edited this content recently"* (G6P17). *"It didn't disturb me at all, because we were editing [contents] on the whiteboard for the most time ... I nearly have spent only 30% of my whole time to see the visual area. When I didn't know who had said what contents specifically, I clicked the specific node to look back at the information on the whiteboard snapshot ... I mainly wanted to see why others and myself said this at that time. I clicked the nodes back and forth and watched [detailed] contents to know what the context or motivation was"* (G8P23).

7. Discussions and Implications

In this section, we analyze our findings and discuss design implications to aid the WA cues in future virtual teams' content-sharing meeting environments.

7.1. Answers to Research Questions

By examining the results of the visual effect on meeting outcome, we summarize that:

RQ1: Does the workspace awareness cue elicit teams to accomplish meeting task goals in a shorter time effectively? We mainly evaluated three metrics: task efficiency, goal attainment, and perception of the meeting goal. Findings revealed that participants with the visual cues owned a higher chance of succeeding in the task (Figure 4), and did not spend more time costs. However, they thought it was tougher to accomplish the task. This was because attendees, aided by the WA cues, spent more efforts discussing facts deeply. Thus, they had a higher probability of unearthing the truth. Meanwhile, this in-depth discussion increased the likelihood of trapping in a decision divergence for teams. Therefore, meeting members felt more obstacles, tardiness, and difficulties had to be overcome to achieve group consensus.

RQ2: Whether attendees produce higher productivity in ActVis? Two dimensions of meeting solution and participant contributions were considered in this question. We found no significant correlation between visual conditions and meeting outcome (success or failure). However, only 5 (35.7%) of total teams solved the solution successfully. We gained a low team success rate due to the low demonstrability of the task itself, which would be analyzed subsequently. Figure 5 showed contribution amounts of attendees across two conditions, which revealed that participants with visual aids did not contribute in total more than those of the control condition. No significant differences across two conditions were found in textual and graphic elements either. Nevertheless, compared with the baseline, participants in visual condition obviously discussed more and doodled less, as well as inclined to share more contents. This indicated that the visual cues of clarifying user actions stimulated attendees to self-consciously concern their quality of contributions throughout the meeting course. Thus, it rendered them not make more contributions, remained cautious about their behaviors such as less doodling, and spent more energy on in-depth discussion for group decisions.

RQ3: Are attendees using the visual cues more satisfied with the meeting? From the user perspective, we primarily captured participant's feedback on team performance, team efficiency, team results, and self-contribution. There was no obvious difference between two conditions in overall satisfaction. However, compared with the baseline, subjects in visual condition were less satisfied with their team efficiency (Table 5). It might be because they spent more effort on discussion, and hence had higher chances of facing a dilemma in divergence before trying hard to reach an agreement to complete the task.

We found no significant difference in participants' overall scores on system affordance across two conditions through questionnaire and interview questions. Attendees under ActVis did not feel distracted by the visual cue. They utilized it only when needed to identify who created what contents, the context of content being created, missing critical points, and the newest information.

Moreover, we have concerned two factor composition of participants and checked whether they would influence our results across two conditions: sex and familiarity (Verma et al., 2013). The Chi-Square Test revealed that there existed no significant difference in sex distribution across two conditions ($\chi^2 = 0.15$, $p = 0.69 > 0.05$), but the prior familiarity among participants under two conditions was evidently different ($\chi^2 = 9.15$, $\mathbf{p = 0.02\ ^* < 0.05}$). However, the analysis with mixed-effect ANOVA indicated that subject's contributions were not affected by their familiarity, with a result of total ($F(1, 40) = 0.50$, $p = 0.61 > 0.05$), sharing-related ($F(1, 40) = 0.01$, p

= 0.97 > 0.05), discussion-related (F(1, 40) = 0.54, p = 0.59 > 0.05), and irrelevant (F(1, 40) = 0.70, p = 0.50 > 0.05) contributions, across diverse familiarity. Also, the Chi-Square Test of answer accuracy among familiarity (χ^2 = 2.50, p = 0.52 > 0.05) testified its minor role played in goal attainment.

7.2. Further Analysis of Results

Visual encoding of meeting elements. In our study, the visual system was designed to describe attendees' collaborative interactions by capturing and visualizing user events, which encoded contextual meeting elements that chiefly involved users, entities, actions, status, and time. We selected those elements mapping with the narrative structure of a story (e.g., who, what, when, how) (Gutwin & Greenberg, 2002; Shi et al., 2018), intended to record who did what and how at when as a meeting summary.

Additionally, our study could be viewed as a practice of activity theory (Bardram, & Doryab, 2011), aiming to portray, analyze, and understand human collaborative activities in a distributed meeting scenario. In this paper, we adopted the CMC (Computer-mediated Communication) technology to collect meeting data, such as activity (actions, participants, artifacts), subject (participant), actions (e.g., creating operations), artifact (e.g., a meeting record of whiteboard snapshot), and context (e.g., time).

Regarding data capturing, we emphatically captured milestone events to aid attendees in perceiving, digesting, and retrieving the meeting with their minimum efforts. However, we adopted the system to automatically record those "critical moments" that we presumed, instead of from the user's perspective. Perhaps, it might be more reasonable to authorize the initiative to participants to choose which actions could be recorded, by note-taking, annotation, and analogous methods (Whittaker, Kalnikaité, & Ehlen, 2012). Also, corresponding with actions, captured content details were snapshotted in canvas forms, resembling the behaviors that participants take whiteboard photos during a meeting. However, over-capturing the content for almost every user event would render search struggle and thus lower visual cues' utility value for participants. Some solutions should be considered to alleviate the dilemma. For instance, we can merge records for continuous actions of the same type from the same user.

Possible explanation of task failure. As mentioned earlier, although WA cues enhanced attendees' chances of successfully achieving the task goal, there was a low success rate of the task outcome generally, with only 57.1% of teams successfully solving the solution even in visual condition. For this phenomenon, previous studies have demonstrated that success in such hidden profile tasks could be influenced by other factors, such as effective sharing of information, the motivation of team members, and information's importance perceived by participants (Stasser, & Stewart, 1992). Our study emphatically examined the last facet starting from the user's understanding of the task by a qualitative interview.

On the whole, participants had unambiguous perceptions about the task target and distribution bias of materials. In our interview, most subjects mentioned that despite being informed from the start that each statement for the candidate carried equal weight, they still intuitively believed some advantages were more important and certain disadvantages appeared more serious when discussing the pilot's qualification. In the subsequent discussion, they did not maintain continuous attention to this message, or just considered the task an open-ended question whose answer was more than one. For instance, *"I paid little attention to this message, [and] I ignored it directly. I felt it* *didn't affect my judgment whether with this message or not ... We tried to determine which strengths were more important and which shortcomings were more serious. [For example], we did not consider it as a big problem of 'sometimes not good at taking criticism' "* (G4P11). *"I thought it was an open problem, and there was not necessarily only one answer"* (G8P22 & G8P24). *"It was vague for me, and I didn't understand its meaning well ... Some shortcomings were thought to be intolerant ... Someone might notice this message, [but] we decided to concern who had the most shortcomings and chose the one with the least ..."* (G6P17). *"It was understood that each trait had the same weight, but I forgot it in later discussion. We thought some [traits] were more important ... I didn't maintain [continuous] attention to this [message] in our subsequent discussion"* (G8P23).

The above phenomena were caused by the characteristic of the task itself essentially, i.e., low demonstrability, whose answers might be affected by individual judgments about the information's importance for each decision alternative (Lu, Yuan, & McLeod, 2012). Specifically, even if all attributes of each candidate were known to every participant, they might still have discrepant subjective judgments on the importance of particular pieces of information. Thus, it caused the task outcome likely to have diverse tendencies accordingly. Moreover, the proportion of team silent lulls (i.e., nobody contributed for at least one minute) (Shi et al., 2017) in cumulative time were relatively low (approximately 25% of total time) in both conditions (With: Mean = 24.75% (SD = 18.18%), Without: Mean = 25.95% (SD = 17.45%); $F(1, 12) = 0.01$, $p = 0.90 > 0.05$). It might indirectly indicate that teams spent most of their efforts creating and discussing contents, but did not pour too much time to assimilate their shared contents. Thus, many teams generated a poor decision quality or task failure. A similar finding was also embodied in (Verma et al., 2013).

Potential application of AT in distributed meeting scenarios. In this paper, we tried to use AT as the guideline framework for both design and analysis, aiming to shed some insights into the design of a system that supports workspace awareness in a distributed meeting environment. We also utilized such a theoretical framework to deepen users' understanding of the supported tool's impact on the meeting outcome.

On the one hand, collaborative meeting activities can be mapped to AT elements, including subjects (attendees), instruments (e.g., virtual whiteboard interface, workspace awareness mechanism), community (virtual teams), rules (e.g., decision strategies, social norms), division of labor (e.g., leader, coordinator, implementer), and outcome (solution). This helps designers understand the context of meeting activities and analyze possible contradictions between or within elements. For instance, contradictions among subjects/community/objects and instruments are concerned in our work. It raises how to solve intuitive perception problems using a visual tool (i.e., workspace awareness mechanism) for subjects and their community, thus enlightening the workspace awareness support in distributed environments.

On the other hand, using AT as the analytical framework, we can categorize quantitative and qualitative data as activities into basic analysis units. This helps researchers to analyze potential impacts between elements in the activity system. This paper focuses on the effects of a certain element (a workspace awareness-based tool) on the other such as meeting outcome, which covers subjects' contribution productivity, community's task fulfilling, and so on. This work will likely inspire the system design in future distributed meeting scenarios.

Moreover, we can also use AT lens to analyze distributed meeting activities from organizational, collaborative, and technological perspectives, which can be fully applied in real-world practice. At the management level, it emphasizes the coordinated mechanism among attendees to facilitate their knowledge sharing and all hierarchical activities' goal achievement, such as rule constraints like sharing and decision-making strategies, workspace awareness mechanism that visualizes attendees' interactive behaviors. At the collaboration level, it concerns the interaction between meeting subjects and the community, including communication, cooperation, and collaboration. For example, certain meeting decisions require teams to collaborate together to generate acceptable solutions, during which team members need to exchange knowledge and weigh arguments mutually. Wherein, team interaction characteristics can be represented by social rules. Team members' roles can be conveyed with static (e.g., functional roles of human resources), dynamic (e.g., specific roles in actual interaction), or both dimensions (Pena, Sossa, & Mendez, 2014). At the technology level, it is dedicated to providing a series of technical tools for meeting activities, which involves hardware (e.g., desktop, notebook), and software (e.g., the shared web-based whiteboard system ActVis).

7.3. Opportunities for Visual Design

From the results of our study, the visualization of workspace awareness was not fully utilized. Subjects viewed and interacted with the visual cues only when they felt the need to explore who created the latest action, content details, emerging information, the order of actions, etc. These behaviors were infrequent, random, and exploratory. In most cases, participants were rarely concerned with the system's visual area. Perhaps it inspires us that visualization can be an assistive means at minor cost to aid users in perceiving the meeting, rather than an alternative to replace original physical or electronic furniture in practical application.

Moreover, we also found that visual cues did not motivate attendees to produce more contributions significantly. Conversely, they invested more energy in discussion deeply, together with fewer meaningless behaviors, such as doodles. The inspiration from these results is that in the actual design, perhaps we could consider how to furnish functional affordance of such content transparency in varying degrees for diverse usage scenarios. For example, for a meeting that emphasizes contribution quality, these visual cues are appropriate. For meetings that expect to produce as many outputs as possible, such as brainstorming, it might be feasible to reduce or eliminate such visual cues. This suggestion is in line with previous research revealing that content anonymity in brainstorming, i.e., participants are unable to know who generated an idea, renders greater satisfaction and better team performance (Ivanov, & Zelchenko, 2019). In practice, one possibility is to exploit a toggle button to show or not show such workspace awareness cues to accommodate meeting scenarios with various needs.

The other potential opportunity is visualizing user events in more concise levels of summary. In our design, we have nearly captured every user event, thus generating large amounts of action nodes. This over-capturing method might bring the burden of users to interact with visual nodes. Sometimes, they have to look through redundant nodes to find the information they want to query, which reduces the readability and practical value of visual cues. Hence, we should improve the simplicity of visualization by summary or category at different levels. For instance, we can ponder merging actions with the same type from the same user, and abstracting nodes by exploiting semantic relationships (e.g., dependency or concurrency) between them instead of the connection simply by timeline. We can also partition user events following the diverse phase of the task flow, or transfer the initiative to users to determine what content should be captured.

In future work, we will further survey how to facilitate users to explore their collaborative sharing events during the meeting and quickly review historical information at subsequent times, aiming to enhance the potential function of visual cues.

8. Limitations

In terms of visual mode, users' interactive activities were dynamically displayed in forms of event-sequence chains. The limitation is that this dynamic movement could distract participants, although our experimental results show its negligible effect. It remains unclear that whether other visualization methods, such as force-directed-graph and Sankey diagrams, would work better or worse. A similar limitation has also been mentioned in (Shi et al., 2017).

Moreover, in our simulated meeting scenario, all attendees can interact only in the whiteboard interface, but no other media such as real-time chat or audio communication are provided. In realistically distributed meetings, however, participants probably use various media such as text chat, voice, or video, except for online sharing ones. Nevertheless, our system allows team members to input any content they share and discuss on the whiteboard. Using the whiteboard medium is sufficient for virtual teams to solve the job selection problem. Also, our work mainly concerns the impact of workspace awareness cues of visualizing user knowledge sharing behaviors on meeting outcome, but does not exhaustively explore other additional factors. In future work, we can consider broader contextual factors, such as social cues (e.g., gaze, gesture, laughter) visualized by audio, as well as content cues in our study, or a combination of both in real meeting settings. In this way, it will provide a richer understanding of how these cues together affect meeting outcome and what weights they play.

Further, despite small probabilities, it is inevitable to encounter concurrency conflicts amongst user actions in real-time collaborative environments. In this paper, we did not address this potential problem specifically because inconsistent visual effects caused by concurrent actions only slightly affect several visual details, but do not influence participants' overall sharing experience. However, adopting targeted strategies (Gu, Yang, & Zhang, 2005; Xia et al., 2014) to circumvent this problem may yield users' collaborative experience more perfect.

Finally, regarding the task itself, although we have pre-informed users that all advantages and disadvantages are equal in strength, subjects still perceive subjective bias for each candidate's qualification in importance. Thus, it would render results low successful, convincing, and controllable. In the future, we can consider verifying our research questions in the task scenario with high demonstrability, such as a murder mystery (Verma et al., 2013; Stasser, & Stewart, 1992).

9. Conclusion

In this paper, grounded in the expansive AT framework, we simulate ActVis, a shared whiteboard system to sustain attendees to share contents collaboratively. Its visual area allows participants real-timely to perceive WA cues, such as their sharing events, collaborative process, and action dynamics, during a distributed meeting. With the support of the system, using AT as the analytical framework, we conduct a controlled study with 42 participants to explore how the visual cues influence meeting's effectiveness, productivity, and satisfaction under the problem-solving task scenario. We also dig user feedback on system affordance. Our findings demonstrate that visual cues stimulate users to notice the quality of their contributions rather than the quantity produced, spend more effort in discussion, and exhibit fewer nonsense behaviors like doodles. Participants with visual aids had a higher probability of completing the task successfully. Moreover, we observe that subjects do not feel distracted by the visual cue because it was used only when necessary. Compared with the baseline, participants in visual condition were less satisfied with team efficiency and perceived the task more difficult, perhaps because they spent more energy in deeper discussion before struggling to overcome all divergences for group consensus. This study provides several implications for future design in distributed meeting scenarios on how to exploit AT as a guideline framework for design and analysis, maximize the utilization of visual cues by supporting users to perceive their interactive behaviors in more concise and optional ways, and regard them mainly as adjunct means instead of an alternative.

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Appendix A. Who Is the Best Candidate? (Stefan et al., 2006; Schulz-Hardt, & Mojzisch, 2012)

Candidate A	Candidate B
– **can anticipate dangerous situations**	– **keeps calm in a crisis**
– **is able to see complex connections**	– **known to be 100% reliable**
– **has excellent spatial vision**	– **good at assessing weather conditions**
– **has very good leadership qualities**	– **has excellent computer skills**
– is sometimes not good at taking criticism	– can be grumpy
– can be unorganised	– can be uncooperative
– is regarded as a show-off	– has a relatively week memory for numbers
– is regarded as being not open to new ideas	– makes nasty remarks about his colleagues
– is unfriendly	– is regarded as pretentious
– eats unhealthily	– sometimes adopts the wrong tone when communicating
Candidate C	**Candidate D**
– can make correct decisions quickly	– **responds to unexpected events adequately**
– handles stress very well	– **can concentrate very well**
– creates a positive atmosphere with his crew	– **solves problems extremely well**
– is very conscientious	– **takes responsibility seriously**
– understands complicated technology	– is regarded as arrogant
– puts concern for others above everything	– has relatively weak leadership skills
– **has excellent attention skills**	– is regarded as a "know-it-all"
– **has difficulty communicating ideas**	– has a hot temper
– **is regarded as egocentric**	– is considered moody
– **is not very willing to further his education**	– is regarded as a loner

Note: four candidates A, B, C, and D's soft skills are listed above, in which shared information is given in bold.

Appendix B. Post-meeting Questionnaire (all items are rated on a 5-point Likert Scale, 1: strongly disagree, 5: strongly agree)

Questions	Supporting Literature
Perception of Achieving the Task 1. I felt it difficult to complete the team task. 2. As a team, we were willing to learn from one another. 3. As a team, our efforts were well coordinated and consistent. 4. During the collaborative process, we negotiated divergence in friendly and effective ways.	(Cherubini et al., 2009; Hunter, et al, 2011)
Satisfaction with the Meeting 1. I was satisfied with the performance of our team. 2. I was satisfied with the efficiency of our teamwork. 3. I was satisfied with the results of our teamwork. 4. I was satisfied with my contribution in the collaborative process.	(Siemon et al., 2017; Hunter, et al, 2011)
System Affordance 1. With this system, I could conveniently share contents with others (Sharing Convenience). 2. With this system, I could conveniently communicate with others (Communication Convenience). 3. It was easy to tell who is sharing what contents at when in this system (Content Readability). 4. This system aided me to see the historical actions of my own and others (Helpfulness). 5. I was reminded of aspects of meeting details I had not previously thought of (New Details). 6. This system offered a good representation of our teamwork process (Visual Encoding). 7. The important or key points of meeting were represented in the system (Informativeness). 8. The system's impact on my retrieving meeting was positive (Valence). 9. This system was distracting (Distraction).	(Chandrasegaran et al., 2019; Shi et al., 2018)