EyeDraw: Investigating the Perceived Effects of Shared Gaze on Remote Collaborative Drawing

ERYN MA, Pomona College, USA and Carnegie Mellon University, USA
PRIYA DIXIT, ANDY HAN, NICHOLAS MARSANO, BROOKE SPARKS, ASHLEY SUN, and LUCAS TIANGCO, Pomona College, USA
TONGYU ZHOU and JEFF HUANG, Brown University, USA
ALEXANDRA PAPOUTSAKI, Pomona College, USA

Shared gaze, where collaborators can see each other's point of gaze visualized on their screen in real time, is a novel non-verbal mechanism that augments remote collaborations and increases shared awareness and common grounding. While past studies have focused on well-structured tasks and analyzed task performance and efficiency, our study explores the domain of collaborative drawing for recreational purposes and focuses on collaborators' own perceptions. We surveyed 75 users of online collaborative drawing platforms who mostly drew collaboratively for recreation and artistic growth; they reported the importance of communication but also of retaining individual space despite the collaborative setting. Informed by this and prior research on shared gaze, we evaluate collaboration by allowing two collaborators to draw synchronously on a shared canvas and share their point of gaze. We conducted a study with 24 pairs that drew collaboratively under all combinations of shared gaze and voice communication. Combining voice and shared gaze was perceived to reach the best balance between tightly coupled collaboration and parallel individual execution. Shared gaze led to higher spatial awareness and less turn-taking was observed in conditions that shared gaze was present. Surprisingly, many participants found the lack of any communication medium to afford the highest degree of divergent thinking. Our findings provide guidelines for adaptive tools that consider individual preferences as well as the nature of the task to better support remote collaborations that are open-ended and prize creativity.

CCS Concepts: • **Human-centered computing → Collaborative and social computing systems and tools**; *Synchronous editors.*

Additional Key Words and Phrases: Eye tracking, shared gaze, collaborative drawing, creativity

ACM Reference Format:
Eryn Ma, Priya Dixit, Andy Han, Nicholas Marsano, Brooke Sparks, Ashley Sun, Lucas Tiangco, Tongyu Zhou, Jeff Huang, and Alexandra Papoutsaki. 2025. EyeDraw: Investigating the Perceived Effects of Shared Gaze on Remote Collaborative Drawing. *Proc. ACM Hum.-Comput. Interact.* 9, 1, Article GROUP17 (January 2025), 24 pages. https://doi.org/10.1145/3701196

1 Introduction

The increasing popularity of remote collaborations has been accompanied by heightened research in finding ways to assist and improve them. One such line of work has introduced shared gaze—the

Authors' Contact Information: Eryn Ma, erynm@andrew.cmu.edu, Pomona College, Claremont, CA, USA and Carnegie Mellon University, Pittsburgh, PA, USA; Priya Dixit; Andy Han; Nicholas Marsano; Brooke Sparks; Ashley Sun; Lucas Tiangco, Pomona College, Claremont, CA, USA; Tongyu Zhou; Jeff Huang, Brown University, Providence, RI, USA; Alexandra Papoutsaki, Pomona College, Claremont, CA, USA, apaa2017@pomona.edu.

ACM 2573-0142/2025/1-ARTGROUP17
https://doi.org/10.1145/3701196

process by which collaborators can see a graphical representation of each other's point of gaze visualized on their screen in real time. Shared gaze has been proposed as a facilitator of communication and as a non-verbal cue [19], which is vital in in-person interactions but often inhibited in remote group collaboration [27, 38]. Shared gaze has been shown to increase shared awareness, common grounding, and intention understanding and facilitate tightly coupled collaboration among pairs in diverse settings, such as co-writing [36], programming [17], and game playing [37]. Nevertheless, all these applications, even those from domains that can be seen as more recreational or creative, have presented well-structured tasks and have focused on how shared gaze affects task performance and efficiency. For example, the study on co-writing [36] focused on summarizing a provided text, and the one on game playing [37] contained tasks with a single correct answer (finding the one true criminal among suspects). It is unclear how shared gaze would affect the perception of collaboration in environments with more open-ended tasks and where creativity is a major component of a successful collaboration. Prior literature has shown that tightly coupled collaboration does not always lead to improved creativity because it can stifle divergent thinking [28]. This paper applies shared gaze in the novel setting of collaborative drawing for recreational purposes where collaboration is more open-ended, and creativity is prized. Additionally, rather than using hard metrics used in well-structured tasks, we focus on the collaborators' own perception of the quality of collaboration.

Collaborative drawing can be seen as the process of a group of two or more collaborators drawing together on a shared canvas. Collaborative drawing is often used for educational, therapeutic, social, or recreational purposes [63, 66, 72]. Its advantages include improving learning and understanding, supporting idea generation and brainstorming, increasing attention and involvement, fostering a sense of community, and promoting positive emotions [10, 62, 69–71]. Drawing has always been seen as an expression of creativity in visual arts, and open-ended collaborative drawing has been found to promote creativity, starting from young ages [35]. During in-person collaborative drawing sessions, participants draw on one big canvas that can accommodate everyone simultaneously or take turns drawing on a smaller canvas. However, technological advances have moved it online, with remote collaborative drawing platforms like Aggie.io and Drawpile.net, allowing multiple collaborators to work simultaneously on a shared, synchronous canvas.

As a first step to better understanding the current landscape of remote collaborative drawing, we surveyed 75 users of popular online collaborative drawing platforms. The survey responses reported that such platforms are popular among hobbyists who seek to socialize, advance their artistic skills, and promote their creative flow by drawing together with friends from real life, online connections, and even strangers. Communication, achieved with built-in or external text/voice/video chats or even directly on the canvas, is vital while negotiating the direction of the shared drawing. Meanwhile, participants emphasized the importance of expressing themselves artistically and coveted their individual space despite the collaborative setting. Shared gaze could enhance these tools, especially in relation to the perceived quality of collaboration. At the same time, this tightly coupled collaboration could also very well hinder divergent thinking and, thus, creativity [28] due to the expected increased shared awareness and improved communication. Thus, collaborative drawing can be seen as an illustrative setting to evaluate the perceived effects of shared gaze on open-ended collaborative tasks that value creativity.

With these questions in mind, we built a simple collaborative tool inspired by prior research on shared gaze that acts as a platform to study its effects on collaborative drawing. We conducted a within-subjects experiment on 24 pairs who drew collaboratively, focusing on the perceived quality of collaboration. To explore the effects of the communication medium, we exposed our participants to four communication conditions: the baseline conditions of no communication medium and voice only, which represent current common communication setups in remote collaborative drawing, and their enhancements where shared gaze only and both shared gaze and voice are supported, respectively.

Post-task questionnaires supplemented by post-study interviews, show that combining voice communication with shared gaze was perceived to uniquely balance tightly coupled collaboration and parallel individual execution. These have been found to positively affect *domain-relevant skills* (abilities in a specific content domain) and *creative-thinking skills* (divergent thinking), respectively [3, 28]. Additionally, shared gaze extensively supported spatial awareness between the collaborators, thus leading to less turn-taking compared to utilizing voice, which is inherently verbose and untimely. This makes the use of shared gaze in collaborative drawing, surprisingly, closer to that in visual search tasks [12] rather than tasks like writing [17, 36] and game playing [37] that also entail elements of creativity and recreation. Interestingly, when solely focusing on *creative-thinking skills*, participants' reflections revealed that the no communication condition, where neither voice nor shared gaze was present, created the most space for individual agency and supported divergent thinking.

The divergent preferences of our participants based on different aspects of collaboration shed light on the need for adaptive tools where different perspectives can be accommodated. Incorporating shared gaze in collaborative drawing platforms has the potential to augment voice communication by creating individual space for divergent thinking beyond maintaining efficient communication for collaboration. Meanwhile, our study points to the value of minimizing communication when divergent thinking is the main focus. This indicates that designers of collaborative platforms that support open-ended tasks must consider user values toward collaboration and creativity and allow flexibility for tools to adapt based on user interactions and the nature of the collaborative task.

2 Related Work

Gaze has long been understood as a powerful non-verbal cue in face-to-face communication, and there have been multiple research efforts to bring gaze awareness to remote collaborative settings. Through an evolution of early systems that promoted gaze awareness by projecting live embodiments of collaborators' upper bodies to today's graphical representations of their point of gaze, shared gaze has shown promise in overcoming common obstacles found in multiple remote settings [19]. Nevertheless, the current interpretation of shared gaze as a graphical representation of a collaborator's point of gaze has not been explored in collaborative settings where tasks are more open-ended, creativity is also important, and its effects would be unclear. One such setting is collaborative drawing which involves a group that negotiates, coordinates, and communicates during the creation of a common drawing and for which multiple collaborative drawing tools have been created to enable it in virtual spaces [8].

2.1 Gaze as a Non-Verbal Cue

In our daily communication and social interaction with others, humans rely extensively on gaze as a non-verbal cue to monitor and regulate interactions, convey emotions and meaning of relationships, and manage information exchanged during conversations [5, 6, 25, 31]. Mutual gaze (i.e. looking at each other's eyes), partial gaze awareness (i.e. knowing the direction of another's gaze), and full gaze awareness (i.e. knowing the object of another's visual attention) [40] appear to be innate and have repeatedly been observed in humans as early as infancy [47]. Gaze as a signal of attention and intention [31] has a central role in coordination and communication [33], anchoring conversations [67] and providing spatial references [45]. Objects that are relevant to a collaborative task attract gaze for large amounts of time [7], and joint attention is considered a prerequisite for cooperation [61].

There has been prior work on the relationship between drawing and gaze, with most studies focusing on individual (e.g., comparing eye and hand movements between beginners and experts [60]) instead of collaborative drawing. In in-person collaborative drawing settings, prior studies have found that gaze is an important part of communication, drawing distinctions between the encoding (information-gathering) and signaling (communicating) functions of gaze [22]. In a study of face-to-face conversations that involved spontaneous drawing with communicative intent, when one

person was actively drawing, lack of eye contact was connected to a performative aspect of drawing, with the person watching the other drawing behaving similarly to theatre audience [55]. Another study asked children to draw side-by-side on an iPad and on paper [46]. It found that the gaze of both participants being directed at the drawing was indicative of shared attention while looking away from the shared artifact indicated distraction.

2.2 Shared Gaze for Remote Collaboration

With gaze's importance in communication and speech being well understood for face-to-face interactions, researchers have sought ways to replicate it in virtual spaces. The first tools to support remote collaborative settings involved groupware systems that exchanged live embodiments of the collaborators' upper bodies, mainly with the goal of supporting mutual gaze [34]. They varied widely in the infrastructure used (e.g., half-silvered mirrors [1] or phase-dispersed liquid crystal screens [52]) and in the number of collaborators supported (from two [16] to bigger groups [42]).

Joint workspaces soon emerged, and gaze awareness was combined with workspace awareness [24]. Ishii and Kobayashii [30] created the first such system, ClearBoard, which aimed to support collaborative drawing. ClearBoard projected the upper bodies of two collaborators on a joint canvas, allowing them to sustain mutual gaze and infer the direction of their gaze. Around the same time, LookingGlass [50] was developed to support again remote collaborative drawing, with the primary difference being that it used a computer mouse instead of a tablet. Other digital tools, such as ImmerseBoard [26], have supported collaborative drawing by mimicking in-person collaboration, simulating standing side-by-side at a whiteboard so that the collaborators can infer the direction of each other's gaze.

Over the years, groupware systems that supported gaze awareness evolved to what we understand today as *shared gaze*: a graphical representation of one's collaborator's point of gaze on a shared artifact instead of superimposing live embodiments. By omitting body language and facial expressions, these systems have isolated the effect of precisely knowing the object of one's visual attention. Shared gaze now relies on dual eye-tracking technology, which has long allowed researchers to better study and understand collaboration [9, 43, 53]. Synchronously sharing the gaze of collaborators can allow for new and enhanced interactions and provide insights into the quality of the collaboration. In particular, visualizing joint attention between users during hands-on activities encourages them to be more productive and learn from their collaborators [48]. Our evaluation tool, EyeDraw, follows this line of research of a graphical representation of shared gaze instead of live embodiments of the upper body that have previously been explored in collaborative drawing.

On a shared desktop screen, shared gaze has been explored within collaborative tasks such as co-writing [36], pair programming [13, 17, 56], problem solving [18, 45, 65], visual search [54], and collaborative and competitive game playing [37, 41]. Most of these works introduced shared gaze on top of voice-enabled communication and often contrasted it with voice-only communication. In these contexts, shared gaze was shown to enhance voice-based communication by acting as a proxy for a pointer, reducing deictic ambiguity, and replacing verbose descriptions, especially those of specific locations. A notable exception is Brennan et al.'s [12] study on visual search (finding an 'O' among a field of 'Q's), which additionally studied pairs when they did not have any way of communicating and when shared gaze was the only means of communication. In that setting, shared gaze alone led to the most efficient identification of the target. Although our task is significantly more complex, we still include the same four communication conditions as they correspond to current common setups in collaborative drawing and their potential enhancements with shared gaze.

Shared gaze has been found to increase mutual understanding by indicating a user's intention. It contributes to a greater sense of presence and community by allowing group members to confirm that other members are engaged and following their words. Other improvements to user interaction include better coordination, greater awareness and engagement, and increased division of

labor [19, 37, 54]. In a review of the current state of shared gaze research [19], D'Angelo and Schneider categorized current literature into eight task domains: *conversation*, *education*, *intention understanding*, *instruction*, *physical tasks*, *problem solving*, *co-writing*, and *visual search*. These groupings show the lack of research on shared gaze in creative, non-competitive collaborative settings. In this context, socialization, improving mental health, and learning for personal growth can be the key focus. In contrast, shared gaze research so far has emphasized task performance, efficiency, profit gains, and competence. Even studies on shared gaze in the domain of collaborative game playing [37, 41] emphasize efficiency (e.g., participants were evaluated based on the fastest completion or the highest accuracy) and promote competition (e.g., a strategy game with opponents).

Prior studies on *co-writing* are informative, as drawing was the predecessor of writing [8, 68]. Writing and drawing can both serve as the final product of a task and an intermediate means of communication. They contain variance and free space for individual expression—there are multiple ways to achieve a goal. However, instead of focusing on the creative aspect of writing (outlet of inner thoughts), where participants can freely experiment and enjoy the creative process itself, existing studies on *co-writing* evaluated shared gaze from the aspect of cultivating mutual understanding (the intake of information) in academic or professional development settings. Participants were given well-structured instead of open-ended tasks, such as debugging in programming [13, 17] or summarizing excerpts of text in co-writing [36].

2.3 Creativity and Collaboration in Collaborative Drawing

In a survey of collaborative drawing tools (CDTs), Peng [44] defined four primary aspects of collaborative drawing: i) *events*: spatial (collocated or remote) or temporal (synchronous or asynchronous); ii) *information*: action-oriented (sketching, writing, talking, gesturing, or gazing) or representation-oriented (graphical or not); iii) *tools*: homogeneous (each group member uses the same tools) or heterogeneous (each group member uses a different tool); and iv) *ownership*: individual (only one user can modify a drawing) or group ownership (any group member can modify or remove a collaborator's drawing at will). Our paper focuses on remote, synchronous, action-oriented collaborative drawing among pairs with homogeneous tools and group ownership. Relevant work includes VideoDraw, a video-based paired prototyping tool allowing participants to see their partner's synchronous drawing and accompanying gestures [59], and Commune, a distributed drawing surface supporting multiple users [39]. Those early prototypes laid the foundation of current popular CDTs like Aggie.io and Drawpile.net, which support synchronous multi-user collaboration and voice or chat communication.

A prior study identified three collaborative drawing strategies: *parallel* (drawing independently), *scribe* (one participant dominates), and *interactive* (through drawing, gesturing, and speaking) [8]. Participants in that study gravitated towards the *parallel* strategy for a significant portion of both remote and in-person drawings, suggesting that the CDTs "did more than enable parallel activity for some groups—they actually suggested it" [8]. While working in parallel increases efficiency, it also impedes shared focus and results in longer integration time for the final artifacts [8, 58].

Past literature on creativity differentiated between *domain-relevant skills* (abilities regarding a specific domain) and *creative-thinking skills* (divergent thinking and association abilities for new pathways) [2, 3, 28], leading to a dichotomy with collaboration. Some studies highlighted that collaboration synergized the domain-relevant skills of the individuals, leading to innovative solutions through inspirational motivation, organizing feedback and contributions, and eliciting and appreciating different viewpoints [57]. Others found that collaboration, which entails the convergence of opinions, obstructs individual creative-thinking skills, which are inherently divergent [28]. Drawing as a creative process requires both *domain-relevant skills* (e.g., knowing how to draw a dragon) and *creative-thinking skills* (e.g., an individual coming up with the idea to draw a butterfly in place of a

How do you define what collaborative drawing means for you?
What software/websites do you use when engaging in collaborative drawing?
How do you communicate with your remote collaborator(s)?
Why do you engage in collaborative drawing?
Where do you find people to engage in collaborative drawing?
What do you like about the process of drawing with others?
What do you dislike about the process of drawing with others? How could this process be improved?
When engaging in collaborative drawing, how do you use the canvas?

Table 1. Questions asked in our online survey on the current state of collaborative drawing. The questions have been condensed for legibility.

head). This indicates that a successful collaborative space needs both tightly coupled collaboration to improve *domain-relevant skills* and parallel individual execution to facilitate *creative-thinking skills*.

Another unique feature of collaborative drawing is that the creation process itself often contains more information than the final artifact [58]. While many existing CDTs use the cursor as a proxy to visualize such a process, it cannot encompass all aspects of creation. For example, while the cursor can express a finalized idea, it does not provide information on how the idea is generated. Shared gaze, which is fast-moving and seamless, has been reported useful in indicating one's thought processes [49], making it well-suited for creative settings.

Our paper presents a study on shared gaze that focuses on the collaboration process rather than evaluating the final products, examining the perceived effects on overall collaboration quality, including creativity. While shared gaze has been reported as beneficial to collaborative tasks in a variety of settings, as D'Angelo and Schneider [19] point out, its positive effect might be task-relevant. The unique interplay between collaboration and the need for individual artistic expression motivated us to investigate whether shared gaze carries such benefits to collaborative drawing for creative purposes.

3 Survey on Current State of Collaborative Drawing

Existing literature covers the history of collaborative drawing tools [8], but no recent studies have explored their current state in terms of how and why they are used. In addition, it is unclear what forms of creativity participants value in collaborative drawing. To address these questions, we conducted a survey where participants were recruited from online art communities, clubs, and Discord servers (Drawpile.net, Malmal.io, iScribble.net, Drawesome, UCF Art Club, Pixel Canvas, Drawception) that cater to users of collaborative drawing platforms. The online survey was approved by our institution's Human Subjects Protection Committee, and participants could enter a raffle for a 50 USD Amazon gift card. We received 127 responses and were left with 75 after removing incomplete responses. Fifty-six participants were between 18 and 24 years old, 15 between 25 and 30, and four between 30 and 37. Twenty-six identified as female, 26 as male, 14 as non-binary, and the rest preferred not to disclose. All participants had drawn collaboratively before. Fifty-two participants engaged in online collaborative drawing at least once a month in the past year.

Table 1 presents a condensed version of the questions that we asked in our online survey. Three of the authors open-coded the responses and agreed on a final codebook. Participants consistently defined collaborative drawing as drawing on a shared canvas. All but one of the participants drew collaboratively on websites. Most of those websites are dedicated to hosting multiple users on a canvas and giving them tools to draw, such as Aggie.io or Drawpile.net. Six participants cited online games as a method of drawing collaboratively, such as the game Gartic Phone and using the pen tool in the online game VRChat. Sixty-one participants primarily cited platforms such as Discord

as their main way to communicate, which features voice, text, and video communication, but also used built-in features (e.g., a chat box or even writing on the canvas).

When asked why participants engage in collaborative drawing and how they define collaborative drawing, sixty-five participants reported drawing collaboratively primarily as a fun and recreational activity. Forty-four participants considered online collaborative drawing platforms as environments that supported socialization. Participants also mentioned they participate in collaborative drawing for artistic growth, such as acquiring and experimenting with new skills (n = 25), getting inspired and becoming more creative (n = 16), and participating in collaborative storytelling by having drawings interact (n = 16). Forty-four participants indicated their collaborators are friends, while 28 reported drawing with strangers. Our participants identified people to draw together among friends and acquaintances through shared classes and social clubs, as well as strangers and friends they met in online communities and servers dedicated to collaborative drawing.

Corroborating previous research [28], our online survey revealed two forms of creativity that can be stimulated in this collaborative context. *Domain-relevant skills* benefit from interaction with collaborators—"You get inspired by each other, while talking you also get to interact about what you draw in real time and get feedback on how you draw and also get to give feedback to friends who ask for it immediately. Also when you see others draw in actual time, you pick up much more on their process and learn from it automatically,"—while individual divergent thinking stimulates *creative-thinking skills*—"I love how it keeps me loose and lets my creative mind flow seeing what others create."

However, there can also be tension: ten participants mentioned being protective of their artwork, like not allowing others to draw over or alter their drawings, despite being in a collaborative setting. They noted the importance of avoiding "ruining others' drawings" and got annoyed when one "violated other people's original drawings and their personal space." To resolve this, they often adopted a division strategy (e.g., by dividing tasks, entities, areas, or layers) similar to [8]. More specifically, 58 participants mentioned some form of division. When negotiating the direction of their shared work, conflicting ideas could arise, but the overall value of collaboration still outweighs these concerns—"Collaboration can be difficult when creatives want their vision to be seen the most, but I define it as a chance for two styles/perspectives to turn into something that would've never before existed beforehand." This requires good communication and shared awareness: "it requires a lot of communication and boundaries, and following internet etiquette to get along with the other artists sharing the same space."

Shared gaze has the potential to augment collaborative drawing by improving communication and enhancing *domain-relevant skills* [19]. It could also assist in spatial division [12], which might additionally benefit *domain-relevant skills*. It is unclear, however, how *creative-thinking skills* would be affected by the presence of shared gaze. On the one hand, spatial division can leave room for more divergent thinking. On the other hand, increasing shared awareness and improved communication could negatively affect divergent thinking. Our work aims to augment our understanding of how shared gaze would affect different needs and aspects of creativity in the novel collaborative drawing setting.

4 Experiment

4.1 EyeDraw

To examine the effects of shared gaze on remote collaborative drawing, we developed EyeDraw, a web-based collaborative drawing platform for pairs that continuously visualizes each participant's gaze and strokes onto a synchronous, shared canvas, similar to existing systems that have supported shared gaze (e.g., [17, 36]). The collaborative canvas was built using SVG.js. It features vector-based strokes and uses Firebase to exchange stroke and gaze data over an Internet connection. Since we wanted to investigate the effects of shared gaze on creativity and collaboration, independent of individual user

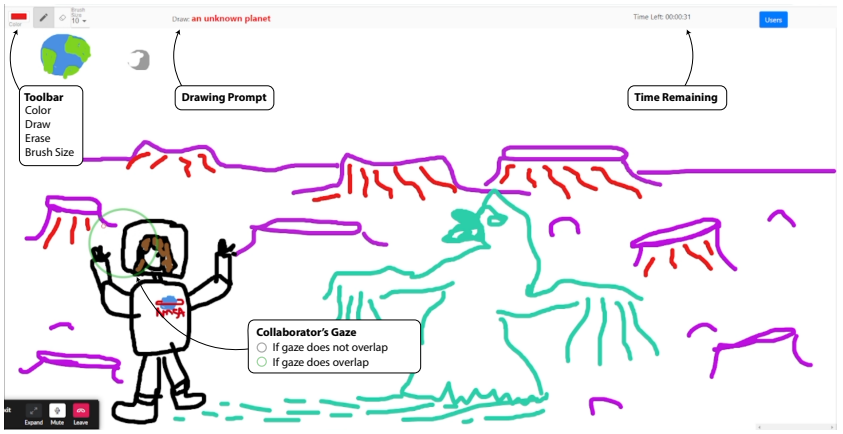


Fig. 1. EyeDraw supports two users, here P21, drawing on a shared synchronous canvas. A gray circle shows the collaborator's gaze, but here, since both users are looking at the astronaut, it turned green. A simple toolbar with color and brush size controls is available along with the prompt and a countdown timer for the experiment.

skill level, we kept the drawing interface simplistic, only allowing for basic line drawing, as shown in Figure 1. On the top left corner is a toolbar for erasing strokes and changing the color and size of the brush. A "Users" drop-down menu indicates the collaborators that are online. For the study, we added a prompt for the drawing tasks, which is displayed in red text, and a countdown timer.

Since our goal was to isolate the perceived effects of shared gaze on the novel domain of collaborative drawing, we turned to existing literature to build EyeWrite. Researchers have explored a variety of visualizations of the signal of shared gaze based on different tasks [19]. We chose to use a circular visualization since it is one of the most common options. We conducted a preliminary study with two pairs that were exposed to different diameters of the circular visualization. We chose a diameter of 160 pixels, a diameter that was found to be perceptible but unobtrusive for the screen size of our study. Seeing one's own gaze can be distracting [19], so each participant could only see the point of gaze of their collaborator. The circular visualization of the participant's partner's gaze was an unobtrusive gray until their gazes overlapped, subsequently turning green, as in Figure 1. Green has been used to indicate overlapping before [17, 36] and was chosen for consistency with prior literature.

4.2 Participants

Forty-eight participants were recruited through our university mailing lists to match the demographics of the online survey. We excluded individuals with a history of epilepsy or who use a cardioverter-defibrillator on the recommendation of our eye tracker manufacturer. Participants with vision impairments were asked to wear contact lenses to maximize the accuracy of eye tracking. To avoid confounds introduced by the type of relationship between collaborators, we recruited individuals to be paired up later, rather than pairs who knew each other. The recruiting criteria did not require prior experience with collaborative drawing to control for different levels of experience with collaborative drawing. Participants were informed upfront that the task would involve drawing, that no significant background in visual arts was necessary, and that the task would include drawing in pairs, with their partner being introduced to them at the beginning of the study. Participants signed up for the study as individuals and were later paired by the experimenters based on their availability. Thirty-three identified as female, eight as male, six as non-binary, and one preferred not to disclose. All participants were between the ages of 18 and 24. Fourteen participants had used

Fig. 2. The experiment set up. Participants wore noise-canceling headsets to communicate during the voice-enabled conditions, V and B, and faced away from each other for the duration of the experiment. Eye trackers were mounted at the bottom of the monitors. The point of gaze of each participant is visualized on their collaborator's screen in real time.

online collaborative drawing tools before this study. The study was approved by our institution's Human Subjects Protection Committee. Participants were each reimbursed 15 USD in cash.

4.3 Apparatus

The experiment apparatus consisted of two identical monitors with mounted Tobii 4C eye trackers. The monitors faced inward on opposite sides of the study room so that the participants would be facing away from each other. Participants were given noise-canceling headsets and were instructed not to turn around to simulate a remote collaborative experience, a common setup in prior studies on shared gaze (e.g., [36, 37]). Figure 2 illustrates the experimental setup. The participants' screens and voice information were recorded throughout the study, as well as their gaze during the shared gaze conditions. Participants were supplied with verbal and written instructions throughout the study and were instructed to complete their tasks collaboratively.

4.4 Procedure

We conducted a within-subjects experiment in which pairs were given a drawing task to complete collaboratively on the shared canvas of EyeDraw under four communication conditions:

- **No gaze and no voice (N):** No means of communication beyond the shared canvas.
- **Gaze only (G):** Participants saw their collaborator's gaze visualized in real-time on EyeDraw.
- **Voice only (V):** Participants could talk to each other via an voice-call.
- **Both gaze and voice (B):** A combination of conditions G and V.

Our experimental design employs the same four communication conditions as Brennan et al. [12]. This and other research (e.g., [17, 36, 37]) in shared gaze have explored various combinations of its use independently (similar to our G condition) and in conjunction with voice communication (akin to our B condition) and have contrasted it with voice communication alone (similar to our V condition) and no communication at all (akin to our N condition). These studies indicate that while shared gaze does not drastically alter the dynamics of voice communication, it does qualitatively enhance it. Exposing our participants to all four conditions offers a more comprehensive understanding of how different communication conditions affect collaboration and creativity.

The counterbalanced conditions were randomized, with each of the 24 unique permutations occurring once. In each condition, participants were given up to 2 minutes to complete a warm-up drawing task intended to familiarize them with the interface and communication condition. Participants were then given up to 5 minutes to complete a more elaborate main task. Rather than allowing participants to draw anything they wanted, which would fully embrace open-endedness, we provided short prompts that would allow us to consistently compare the different communication conditions. We purposefully left the full execution of the prompt up to the pair. Table 2 contains

Table 2. Prompts for the warm-up and main tasks for each communication condition.

Condition	Warm-Up Task	Main Task
N	Draw a flower and a butterfly	Draw a dancing creature
G	Draw a tree	Draw a vehicle from the future
V	Draw a sports drink	Draw a stylish castle
B	Draw a sky night filled with stars	Draw an unknown planet

the prompts for the warm-up and main tasks for each communication condition. Each prompt corresponded to a unique condition to limit the required permutations. The prompts for the main tasks were tested in the pilot session to be of comparable difficulty and were restructured to have an open-ended adjective or prepositional phrase that encouraged creativity (e.g., stylish) and a noun that corresponded to a complex object with multiple components (e.g., castle). The mean ± standard deviation of task completion duration is reported for each condition. N: 3.89 ± 1.44 min, G: 3.99 ± 1.21 min, V: 4.30 ± 1.07, and B: 4.40 ± 0.81 min. There was one outlier in the V and one outlier in the B conditions. Both outliers came from pairs who completed their drawing tasks unusually quickly, in 1.63 min and 2.01 min, respectively. The differences in task completion duration across the four conditions were not statistically significant, $\chi^2(3) = 6.75, p = .08$. The lack of statistical significance corresponded with D'Angelo and Begel's study on shared gaze in pair programming [17]. Like their study, our instructions encouraged natural collaboration without competing for the fastest completion.

After each main task, participants completed a survey assessing their perceived levels of collaboration and creativity, followed by a free-form text response on their thoughts about the communication condition. The adapted questionnaires were:

- **Creativity Support Index.** Participants completed the 12 agreement statements from the most recent iteration of the Creativity Support Index (CSI) by Cherry and Latulipe [14]. The CSI measures a tool's ability to support creativity and is structured around six factors: *collaboration, enjoyment, exploration, expressiveness, immersion,* and *results worth effort.* Each theme has two associated agreement statements assessed on a 0–10 Likert scale. We chose not to administer the paired factor comparison test of the CSI, which is to be administered after each distinct task. The paired factor comparison test is designed to facilitate comparison between distinct tasks. Because we varied the communication mode and not the task itself, asking task-level questions would not have been helpful.
- **Collaboration.** Adapted from Kim et al. [32] and Gupta et al. [23], the questionnaires examine different aspects of collaboration. Gupta et al. focus more on the quality of communication and copresence, while Kim et al. center on three types of awareness–what, where, and who. They contain some overlapping questions about the overall subjective experience of collaboration. Statements were assessed on the original 0–10 Likert scale for Kim et al. and 0–6 Likert scale for Gupta et al.

After a participant pair completed their fourth and final drawing, they had an informal, semi-structured interview. Two experimenters asked the questions below, following up to seek clarifications. Pairs were encouraged to explain their reasoning and discuss their answers between themselves.

(1) What did you think about voice vs. no-voice communication?
(2) What did you think about the addition of shared gaze?
(3) In what condition did you feel the most creative?
(4) In what condition did you feel the most collaborative?
(5) In what condition did you feel the most present with your partner?

4.5 Limitations

We want to acknowledge the limitations of our study upfront. The first was the omission of pointer sharing, a common practice in shared gaze literature (e.g., [12, 18]) to avoid occlusion, distraction, and redundant information. In settings where shared gaze has been combined with voice communication *and* the pointer was present (e.g., in co-writing [36]), shared gaze still improved collaboration. Given that we additionally explored the no gaze and no voice (N) and gaze only (G) communication conditions, we did not pursue this direction to minimize the number of experiment conditions.

Relatedly, EyeDraw transmitted strokes only when the mouse was released. One reason was for better performance, as the sheer number of points led to the interface lagging; more importantly, we removed extraneous points to achieve smoother strokes. This design choice usually did not interrupt the workflow because participants mostly drew incrementally. However, sometimes, if a participant were doing a long stroke (e.g., coloring the whole background), a large stroke would suddenly appear on their partner's screen. Some participants reported noticing such "lagging" and relied on shared gaze to guess the stage of their partner's drawing, even in the presence of voice. For example, if they verbally agreed to color the sky, if one participant saw the other's gaze moving back and forth across the whole canvas, they would wait for the other to finish before drawing the stars in the sky.

In our study, the gaze circle was grey, a relatively unobtrusive color, only turning green upon gaze overlap. We noticed that in B, some participants chose a dark background for the prompt "Draw a sky night filled with stars." Low contrast between the background and gaze visualization made it hard to decipher the location of their partner's gaze. In the future, we would like to explore the choice of visualization further (e.g., having the visualization adapt its contrast based on the underlying drawing).

5 Results

Post-task questionnaires and post-study interviews focused on different aspects of the perceived quality of collaboration during collaborative drawing.

5.1 Post-task questionnaires

For the analyses reported below, since statements were ranked on ordinal Likert scales, we performed the omnibus non-parametric Friedman test with repeated measures across the four communication conditions. The test does not make any assumptions about the distribution the data comes from. We followed with a post hoc analysis with Bonferroni correction ($\alpha = 0.005$) to identify the pairs of conditions that led to statistically significant differences in the measures.

5.1.1 Creativity Support Index Questionnaire. We started by analyzing the responses for the Creativity Support Index (CSI) [14], which explicitly asked about the communication modes in contrast to the other two questionnaires. We followed a design suggested by the CSI authors and analyzed statistical differences between agreement statement scores. We found that scores for N and G were consistently lower than those assigned during V and B, as shown in Figure 3.

Each category of the CSI questionnaire has two statements that ask the same thing in slightly different terms. The scores for all paired items of *collaboration* (C1 and C2), *enjoyment* (C3 and C4), and *exploration* (C5 and C6) demonstrated statistically significant increases from N to V, N to B, G to V, and G to B. Voice, either alone or when augmented with shared gaze, greatly contributed to the ease of communication. The scores for *expressiveness* (C7 and C8) exhibited different statistical patterns for the paired items. This led us to take a closer look at the post-study interviews to investigate the different interpretations of expressiveness and creativity. The scores for *immersion* (C9 and C10) showed that shared gaze did not impede participants from focusing on their tasks. While there was no statistically significant difference across pair-wise comparisons in C10, only B was rated statistically significantly higher than G in C9. It was hard to ignore gaze when it was the sole indication of one's

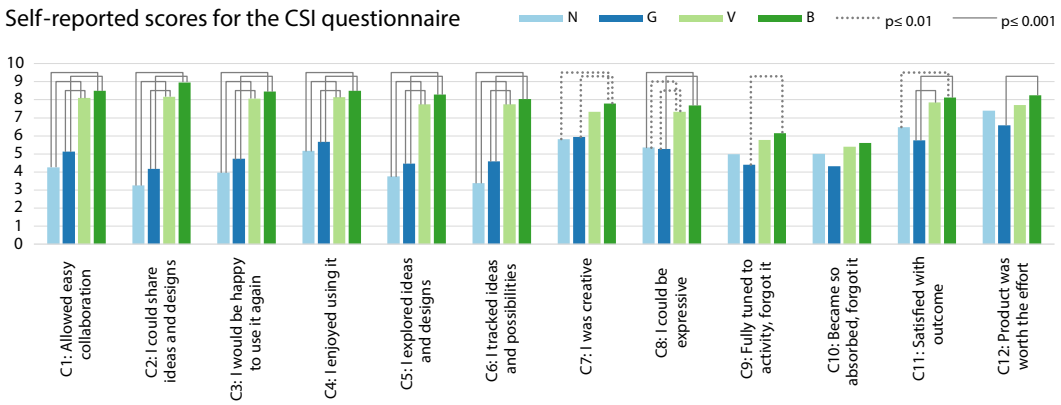


Fig. 3. Mean Likert scores per condition (0 = Strongly Disagree, 10 = Strongly Agree) using the CSI questionnaire [14]. Statements were trimmed for legibility; lines denote statistically significant pairwise differences.

partner's activity. However, in the B condition, where voice was also present, participants could opt to focus on shared gaze only when necessary. Additionally, the lack of statistical difference from G to V may reflect the nuanced improvements that shared gaze brings to voice communication.

In evaluating the *results worth effort* metric (C11 and C12), we found a notable preference for all conditions (N, V, B) over G. Specifically, C11 showed a statistically significant increase in perceived worthiness when comparing G to V, G to B, and N to B. Similarly, C12 revealed a statistically significant improvement from G to B. These findings underscore the importance of voice communication in collaborative tasks. Interestingly, participants expressed higher satisfaction with the N condition compared to G in C9, C10, C11, and C12. Although we cannot draw conclusions from these statistically insignificant increases in averages, this may suggest that the increased autonomy, unrestricted nature of collaboration, and the potential for surprise in the absence of any communication tools (N) were sufficient to offset the lack of voice communication. This highlights the complex interplay between communication modalities and participant satisfaction in collaborative efforts.

5.1.2 Gupta et al. Collaboration Questionnaire. We continued with analyzing the responses for the seven questions from the Gupta et al. [23] questionnaire. As seen in Figure 4, we noticed patterns consistent with the CSI questionnaire results. The scores for co-presence and communication (G1, G2, G3, and G4) illustrated statistically significant increases from N to V, N to B, G to V, and G to B, again highlighting the influence of voice. The scores for focus (G6) showed statistically significant increases from G to B, N to B, and G to V, which is in accordance with our analysis of CSI *immersion* (C9 and C10). The scores for correctness (G7) displayed no statistically significant differences, showing that participants felt they could accomplish the drawing task regardless of the communication mode. Interestingly, G5, which asked about the overall enjoyment of the experience, demonstrated statistically significant increases from only N to B and G to B. In contrast, CSI *enjoyment* (C3 and C4), which asked about the enjoyment of the communication mode specifically, also found statistically significant increases from N to V and G to V. This indicates that while gaze and voice improve the enjoyment of the communication mode, the overall experience is most improved when gaze and voice are combined.

5.1.3 Kim et al. Collaboration Questionnaire. Figure 5 summarizes the results of the six subjective sub-scales of the Kim et al. [32] questionnaire. Scores of receiving and delivering information (K2 and K3) showed statistically significant increases from N to V, N to B, G to V, and G to B, corroborating the importance of the presence of voice. The communication mode appeared to have no significant effect

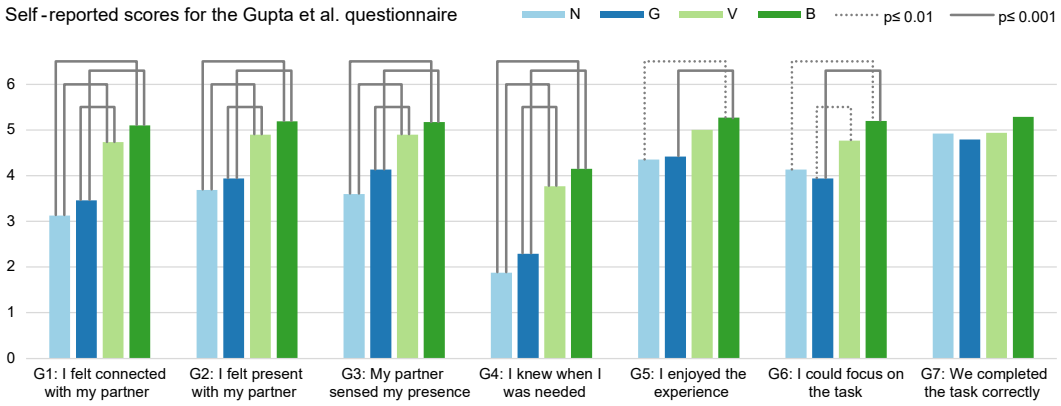


Fig. 4. Mean Likert scores per condition (0 = Strongly Disagree, 6 = Strongly Agree) adopting the Gupta et al. questionnaire [23]. Statements were trimmed for legibility; lines denote statistically significant pairwise differences.

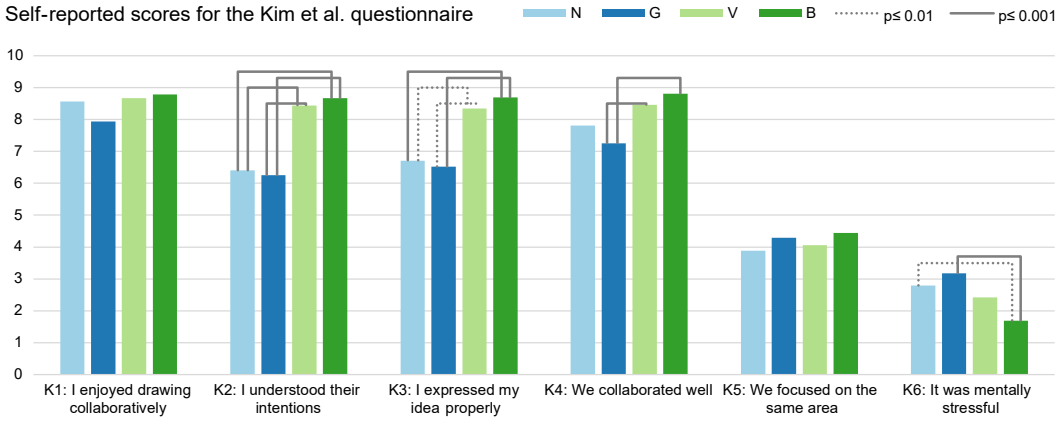


Fig. 5. Mean Likert scores per condition (0 = Strongly Disagree, 10 = Strongly Agree) adopting the Kim et al. questionnaire [32]. Statements were trimmed for legibility; lines denote statistically significant pairwise differences.

on shared area of focus (K5). This contrasts previous work [17, 37], which found that shared gaze makes people look more often in the same area of interest. Interestingly, scores of the enjoyment of collaboration (K1) also showed no statistically significant differences, despite the varied opinions on the ease of collaboration (C1) for different conditions. K4 and K6 echoed the above discussion about CSI *immersion* (C9 and C10) and *results worth effort* (C11 and C12), showing the least preference for the G condition. Scores of how well participants collaborated (K4) demonstrated statistically significant increases from G to V and G to B. Scores of the mental stress of communication (K6) showed a statistically significant increase from G to B and N to B, indicating that the compounding effect of shared gaze and voice communication, and not shared gaze alone, was what led to more expressive and less stressful communication.

5.1.4 Findings across the Questionnaires. The results of the CSI, Kim, and Gupta questionnaires indicate that voice, with or without gaze, almost always enhanced the ease of communication and participants' subjective collaboration experience. For example, voice made communication easier

(C1) because participants could explicitly exchange information (C2, C8, K2, K3, and G4) and explore their own ideas (C5 and C6). Similarly, voice increased the sense of co-presence (G1, G2, and G3) and enjoyment of the communication mode (C3 and C4).

Communication condition B, both gaze and voice, was consistently rated the highest among the four conditions across all post-task questionnaires. The addition of shared gaze bridged the gap between physical and remote collaborations and augmented the strengths of voice-based communication.

5.2 Post-Study Interviews and Free-Form Text Responses

In addition to the standardized post-task questionnaires, we collected qualitative feedback about the participants' experience through free-form text responses and a post-study semi-structured interview with each pair. Participants were encouraged to discuss their thoughts and answers with their partners. We applied inductive thematic analysis [11] to qualitatively analyze the responses, providing insights into how participants interacted with shared gaze and their thoughts on how collaboration and creativity were affected during the four communication modes. Relevant quotes are attributed to the appropriate pair; for example, P1 would be attributed to the first pair.

5.2.1 Reactions Toward Voice-Based Communication. Responses from the post-study interviews echoed questionnaire results and past studies: voice is the biggest communication facilitator. When asked about their thoughts on voice, 19 of the 24 pairs said that voice communication in conditions V and B made the task easier by allowing them to distribute tasks efficiently and know exactly what their partner intended to do or needed help with. Participants also reported being able to create more complex drawings with voice. P5 explained that without voice, "The only reason we can even add that level of complexity is because we based [the drawing] on something that was a preexisting character; we could not have deviated from something like that and have the complexity we did."

Not all reactions toward having voice-based communication were positive, though. When voice was present, participants felt obligated to ask for permission before proceeding with their own ideas, limiting their agency. This was in contrast with conditions without voice. For example, P8 compared the V and G conditions: "When we were talking, I felt like we had to ask, 'should I do this?' first, but then with [only] the gaze thing, I just went for it. At some point, we tried to connect our ideas subconsciously. It was cooler because you could be more creative and spontaneous." P24 added, "When we had audio availability, I actually almost didn't want to talk because I felt like it was distracting me from dwelling in the drawings." P7 mentioned that voice-based conditions increased the fear of being judged about their artistic skills and choices, "Speaking makes it easier to communicate, but at the same time, I felt the pressure of her criticism for every second, whereas if there's just gaze, I could literally do whatever. [...] I think part of the liberation was just being able to do whatever I want and have no judgment. It also meant that I didn't care what she's doing. I just knew it's going to be good. I think it cut the burden of knowing that you were the worse drawer. You think about what you are doing far more often [with voice]."

5.2.2 Reactions Toward Shared Gaze. When asked about shared gaze, participants shared thoughts that were often contradictory. Eleven pairs found shared gaze helpful, useful, and informative. The reactions toward the compounding effect of shared gaze and voice-based communication were consistent with the high ratings observed in the post-task questionnaires. Participants reported finding the B condition more like an in-person drawing session; for example, one participant in P19 mentioned, "It felt most similar to drawing with someone in person because you could talk to them and also like it kind of gives you the idea that someone's watching over your shoulders of what you are doing." Participants also repeatedly reported B as the condition they felt the most present. This contrasts with statements from participants who reported the stress of being watched when they did not know what to draw. One participant in P19 further explained, "At times, it was

stressful because knowing where they were looking made me feel perceived and made me worry about having the same idea accidentally." Fifteen pairs reported that they forgot about or ignored the gaze visualization for some part or the entirety of the task. This was particularly true for the B condition, where some participants found the shared gaze feature "redundant" and "extraneous" and relied on voice communication only. P23 reported "not being exact and not being fully sure what the other person wants to draw or the details of what they want to draw." Six pairs developed an appreciation for shared gaze as the study progressed, though, especially after moving to conditions that did not include shared gaze. One participant in P6 mentioned, "In the beginning, I thought the shared gaze feature was unnecessary because I didn't really use it when I was drawing in the beginning, but then when I started to only use voice or without shared gaze and even with no voice, I started to appreciate the shared gaze feature." Another one in P20 similarly explained, "Once you took the eye tracking away, I kind of missed it because I was like, wait, I noticed it last time, but when there was only voice, I was thinking, what if we erased the same thing, what if we drew the same thing?" In condition V, participants usually only asked about *what* instead of *where*, which led to unwelcome overlapping, as indicated by P11: "We were not specifying which part, so often we were overlapping in the same area." In contrast, shared gaze was explicitly mentioned as being used to avoid overlapping because of the explicit spatial awareness that could reveal intentions. For example, one participant in P5 reported that in G, "I liked that we were able to see when we were in the same area—as in my head that suggested that I should move somewhere else so that we both wouldn't be trying to draw overlapping things with each other." This was echoed in the comments of another participant in P15 for condition B, "[I enjoyed] being able to see what my partner was working on and showing her where I was currently working so that our separate components of the drawing wouldn't overlap."

The post-study interviews and free-form text responses showed that shared gaze was helpful for task planning. Eighteen of the 24 pairs said that they found shared gaze helpful because it allowed them to see where their partner worked. Eleven pairs reported that they found shared gaze useful for dividing drawing tasks and responsibilities. Participants reported that shared gaze helped them understand their collaborators' intangible, internal planning and thought processes. Knowing those intermediate thoughts can help participants understand their partner's intention in a faster, more comprehensive, and non-verbal way. One participant in P8 explained, "This time, it was more helpful as I was able to predict some of my partner's next steps based on where they were looking. I could tell they wanted to draw stars when they looked in the upper corners." In turn, they can better plan their own tasks as indicated by a participant in P14: "to work around [their partners], help them out, or leave the area to themselves for a bit." Furthermore, imagining what their collaborator would create through the gaze trace inspired participants. One participant in P11 stated, "Because I was trying to think what you are doing there, I was trying to imagine what you are doing, that made me be like, oh what should I do?"

Shared gaze was not only leveraged on the canvas but also when interacting with the toolbar, as stated by a participant in P9: "This signaled to me that they were probably transitioning or working on a different aspect within the drawing." One participant in P5 noted, "When I saw [her] changing colors, I'd be like, okay, she's gonna do a new thing now, when her eyes went to the top left [toolbar], so I'd make sure to continue what I was doing and add more details until she has started creating something."

Figure 7c provides an illustrative example of a common shared gaze experience, with P24 in the B condition completely dividing their unknown planet in half. They used voice to coordinate a plan, P24_1 drawing a fire half-planet while P24_2 drawing a water half-planet, which were abstract ideas hard to convey by gaze only. Then, without specifying who should work on which half, they simultaneously started drawing without overlapping using the shared gaze movements. They then worked relatively silently for a while, mostly only verbally asking for permission when they wanted to draw a new entity. P24_1 explained in the post-study interview that they almost felt voice could not let them dwell on their drawings, so they did not speak even if they had the option. Their gaze

stayed mostly on their half of the canvas, occasionally overlapping when they needed to consult each other to create parallel components, for example, an alien with flame-like hair and an alien with a fish head. While exploring their own ideas, they constantly checked the other's progress for inspiration. At one point, P24_1 burst into laughter because of the fish head P24_2 drew. Without verbal explanation, P24_2's gaze instantaneously located where P24_1 was looking, showing that P24_2 inferred what P24_1 was laughing about from their gaze location. When both of them were almost done with the basic structure of their half-planet, they crossed over each other's demarcated regions after some brief discussion. They started drawing something complementary to each other's work, accompanied by exchanging gaze or audio information. Seeing P24_2's gaze selecting colors at the upper left corner and then moving to the blank space of P24_1's half-planet, P24_1 successfully predicted that P24_2 would draw volcanoes and verbally asked for confirmation.

6 Discussion

6.1 Collaboration and Creativity

Condition B consistently had the highest ratings on all post-task questionnaires. G5, which focused on the overall enjoyment of the experience, and C7, which directly tackled creativity, both demonstrated statistically significant increases from N to B and G to B only, without significant increases from N to V and G to V. This showed that the combination of gaze and voice, not voice alone, contributed to enhanced experience. The presence of two communication channels allowed participants to switch between tightly coupled collaboration and parallel individual execution with less friction. This smooth interplay reduces mental effort, corresponding with the statistically significant decrease in mental stress from N to B and G to B in K6. No statistically significant decrease was observed from N to V and G to V. Switching between communication channels enabled participants to customize their working style and information inflow based on their needs. While they could work closely together and synergize their *domain-relevant skills* by learning, being inspired, and negotiating with each other, they could also rely solely on shared gaze if they wanted to be silent and focus on their own artistic expression to stimulate their *creative-thinking skills*.

Positive attitudes toward B were reflected in the post-study interviews, with B serving as a middle ground between creativity and collaboration. One participant in P8 elaborated, "I think the planet one, which was both. That's what I felt most creative and collaborative because I felt we were equally contributing to the planet, but [...] we could just put our own ideas in there." Their partner echoed, "I agree with that; I think that one was a good example of them [creativity and collaboration] overlapping. In general, having more communication allowed for more collaboration, because we were able to build off of what each other's doing, and when there's not as much communication, you just have to go off of whatever you are thinking, which is more creative."

Post-study interviews revealed contradictory interpretations of creativity compared to post-task questionnaire responses. An explanation might be found in the difficulty of defining creativity. One quantitative study [14] found a high similarity between the terms creative and expressive, which is reflected in our results. The similarity between the score pattern of "creativity" and "expressiveness" in C7 and C8 suggests that our participants might have interpreted creativity solely as expressiveness during the post-task questionnaires. Under such an interpretation, participants would rank higher conditions that facilitate more complex and intricate end results. This can explain why conditions V and especially B, which better support the synergizing effect of *domain-relevant skills*, were better received during the post-task questionnaires. On the other hand, understanding creativity as divergent thinking—an interpretation participants often adopted during post-study interviews—could lead to voice-based conditions being perceived as reducing individual agency and promoting convergent opinions, which can hinder *creative-thinking skills*.

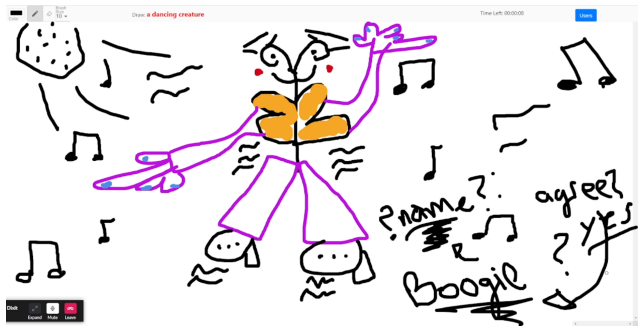


Fig. 6. An example of a drawing under the N condition from P14. The lack of communication encouraged divergent thinking, for example, by replacing the head of the dancing creature with a butterfly.

This interpretation was supported in the post-study interviews with twenty pairs mentioning that N and G particularly encouraged creativity. Being unable to coordinate closely enabled participants to create unconventional drawings, like Figure 6. One participant in P16 explained, "[Without voice,] we just have to go for it and see what happens then. It will be a little more strange and creative because we are both throwing things out without ... you didn't have to convince somebody to let you do it." After hearing their partner rating G as the most creative condition, another participant in P11 agreed, "I didn't think it that way, but now you say that I do kind of agree. I had to think a lot more [in G], but it did push me to go out of my comfort zone a little bit more."

Seventeen pairs highlighted N's ability to promote creativity, and six pairs singled it out as the most "fun" and "enjoyable" condition. Besides the already-mentioned spontaneity for voiceless conditions, N strengthened individual agency, thus enriching the creative process. In N, participants felt they avoided the judgment of voice and the sense of being perceived by shared gaze. A participant in P19 noted, "I didn't feel perceived at all, so I just drew something silly." Another group, P14, supported the sentiment that in N, their opinions did not have to converge, "I think definitely we didn't have to [say] 'oh are you sure this is okay', 'how should we approach this', I felt that that let us do what just came through our mind without consulting anybody."

Our analysis shows that B has the potential to best balance tightly coupled collaboration and parallel individual execution, thus facilitating both *domain-relevant skills* and *creative-thinking skills*. At the same time, the absence of communication, especially in conditions that do not support voice communication, encourages the most divergent thinking and can thus promote *creative-thinking* in certain situations.

6.2 Strategies of Collaborative Drawing

Coordination in collaborative tasks has been studied using the grounding framework [15], which suggests that partners adapt their behavior to minimize their collective effort and costs incurred during joint activities [12, 21]. Although we did not suggest any strategies, we observed that participants unanimously devised a *divide-and-conquer* strategy on the fly across all communication conditions, echoing the parallel strategies identified in [8] and our online survey.

We observed three main ways that a divide-and-conquer strategy was employed: i) task division, ii) entity division, and iii) spatial division, as shown in Figure 7. Task division involved both participants working on the same element but each undertaking unique tasks, for example, one participant drawing the outline of an element and the other participant filling in the details of this outline. During entity division, two collaborators would draw different objects in parallel, and each was responsible

for their own entity's outlines, colors, and details. With spatial division, participants broke the canvas into smaller, non-overlapping sections.

6.2.1 Division with Voice. Voice facilitated the division of labor by easing communication. Participants often verbally divided their drawing task at the beginning of the drawing session and during the transitions between different stages of their drawings. In V, where voice was the only source of communication, the most common divisions were entity division and task division. Voice was well-suited for such conceptual divisions because it supported a precise description with higher abstraction and complexity. For example, one participant in P19 asked their partner, "Do you want to start drawing the outline [of the castle], and I could add stuff?" When talking, participants often only specified *what* they would draw without stating *where*. However, not all tasks and entities have inherent spatial information, leading to different expectations and interpretations if voice was the sole way of communicating. For example, if a pair wanted to draw a dragon near the castle as in Figure 7a, it was unclear where precisely it should be placed in relation to the castle. Often, participants appeared to intuitively select an available area to draw instead of using location-specific language to describe where they were planning to draw something. The lack of spatial awareness and the omission of spatial information from verbal communication sometimes caused turn-taking behavior. When a participant was unsure of where their collaborator was focusing on, they waited to see their collaborator's strokes before proceeding with their own rather than interrupting their flow to verbally communicate. Overall, while verbal communication enabled the division of tasks and entities through higher-level descriptions of plans, it was not often employed for conveying spatial information, which led to more prominent turn-taking behavior.

6.2.2 Division with Shared Gaze. In conditions G and B, shared gaze allowed participants to accurately follow their partner's gaze on their screen, which ensured that participants avoided working exactly where their collaborator was drawing. Participants easily worked in close spatial proximity to each other as well as when maintaining a distance from each other. The always-live feedback of shared gaze enabled participants to continuously monitor their partner's attention anywhere on the screen and not overlap without them needing to talk or actively draw to reveal their intentions. One participant in P4 explained how they used shared gaze to decode their collaborator's intentions and avoid duplicating their work: "I noticed that several times the circle became green. I could know that we were thinking to do the same thing, so I would just change to do another thing." Overall, shared gaze increased spatial awareness between the two collaborators leading to less turn-taking in both G and B conditions. In many cases, participants went back to edit each other's work, for example, to fill

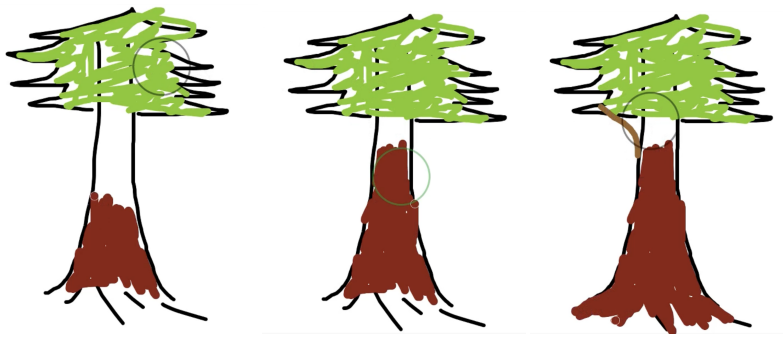
(a) task division (b) entity division (c) spatial division

Fig. 7. Examples of collaborative art created during our study employing different divide-and-conquer strategies. Figure 7a is an example of task division from P19: one participant worked on the outline of the castle, and the other added details, such as windows. Figure 7b is an example of entity division from P17: one participant drew a radio, and the other one a sea creature. The gaze visualization can be seen on the sea creature at the top right corner. Figure 7c shows an example of spatial division from P24: the pair divided the canvas and worked on distinct halves of the planet. The gaze visualization is located at the bottom left quadrant.

in an element that their collaborator drew with color or add an additional one on top of their collaborator's work. With shared gaze, regardless of the size of the elements they drew, participants worked on the canvas simultaneously without needing to wait for each other and take turns; instead, they either spatially divided the task, worked on independent elements, or even worked on the same element.

When looking at G, the presence of a shared gaze enabled participants to more confidently draw simultaneously and in close proximity, despite not being able to communicate verbally with each other. One participant in P12 provided a concrete example of how their pair used shared gaze in G to separate tasks despite the lack of verbal communication: "I saw his gaze was focusing on the upper part of the leaves, so I just focused my gaze on the root part, so we know how we should divide our jobs and draw different parts." Figure 8 demonstrates a chronological replay of this sequence of interactions and use of shared gaze to facilitate spatial awareness and enable participants to monitor and avoid interfering on each other's work while also being able to work close to each other. In contrast, in N, we observed an initial phase of turn-taking with each participant waiting for their collaborator to complete their strokes before proceeding with their own and often with one participant dominating the drawing. This was followed by a phase of increased distance between the strokes of collaborators since participants could not infer their collaborator's intentions lacking both spatial awareness in the absence of shared gaze and ability to explicitly articulate their thoughts in the absence of voice-enabled communication.

Voice and shared gaze appeared to be best suited to answer questions about *what* would be drawn and *where* it would be drawn, respectively. While shared gaze provided live feedback of a collaborator's gaze and, therefore, their attention on the shared canvas, voice-based communication enabled collaborators to plan what they would draw collaboratively or individually. In conditions where voice communication was enabled, our participants rarely used language to communicate spatial information. For example, when drawing a "stylish castle," often one collaborator would start drawing the main tower of the castle at the center of the canvas, and their collaborator would then communicate that they will continue with drawing "other towers", or "the lake", or "the bridge" without specifying their location. Our observations showed that turn-taking behavior arose when collaborators were unsure of where each other's attention was, and they did not want to overstep. Shared gaze provided precise and continuous information about their partners, thus simultaneous drawing and less turn-taking occurred.



(a) initial task (b) overlap (c) new task

Fig. 8. An example of how P12 used shared gaze in N to negotiate space. Screenshots are shown in chronological order from the perspective of P12_1. Figure 8a: P12_2 was drawing leaves while P12_1 was coloring the trunk; Figure 8b: After P12_2 finished drawing the leaves, they started scanning P12_1's work, which was indicated by the shared gaze visualization turning green; Figure 8c: Even in close proximity with P12_1, P12_2 avoided the trunk area and started drawing branches instead.

In the visual search experiment by Brennan et al. [12], participants used shared gaze to divide the search space. In both B and G, participants followed a more dynamic strategy: they looked away and worked somewhere else after realizing the presence of their partner's gaze on the area they originally intended to draw. This resulted in an immediate spatial division which varied in scale. Since the drawing was continuously evolving, new divisions were frequently negotiated. Such on-the-fly spatial division could not happen without shared gaze: the instantaneous nature of shared gaze assisted in the delivery of real-time information. By simply moving their gaze to an unclaimed canvas region when the location of their partner's gaze changed, participants spontaneously reset the boundaries of individual activity without the delay involved when using voice. A participant in P5 noted, "It was also a quicker way to communicate 'I'm drawing here' or 'Don't draw here' than if we didn't have the shared gaze."

Our findings may be in tension with previous literature on potential creative tasks, such as co-writing [36] and game playing [37], which reported that shared gaze encourages collaborators to look and work at the same area of interest more often. However, in our study, most intentional gaze overlaps in G and B were quick and happened when participants rapidly scanned their collaborator's developing drawing. Extended gaze overlaps were often caused by participants working in close proximity without actually interacting with each other's drawings. Other extended overlaps occurred when participants waited for their collaborator to initiate a task or finish a long stroke or even when they passively watched their collaborator drawing. Our study points to the use of shared gaze in collaborative drawing being closer to that of visual search [12], where spatial division is also common, but creativity is of no particular interest. Brennan et al.'s [12] work suggested that shared gaze was used for spatial division to lower coordination costs and enhance efficiency during visual search. Our work indicates that our participants utilized shared gaze to avoid overlapping, which can be desirable in creative tasks: in our online survey, users of collaborative drawing tools reported that they valued their individual space within the shared canvas. This, in turn, could encourage divergent thinking, thus facilitating *creative-thinking skills*.

6.3 Implications for Design

Our study demonstrated that participants did not have unanimous definitions for creativity and that reactions toward shared gaze varied based on the lens through which they examined collaborative drawing. Their varied reactions highlight the necessity to dive deeper, starting with a more comprehensive understanding of behavior patterns during collaborative drawing. This can help us identify opportune moments for novel technological solutions, such as when to offer a shared gaze option. Our online survey offered a glimpse into how users of current collaborative drawing tools perceive their use, but it relied on their own interpretations rather than direct observations. Observational studies, ideally with researchers joining collaborative drawing sessions in the wild, could further explain how these tools are used in practice and offer insights into when it is preferable to support tightly coupled collaboration compared to parallel instances of individual execution.

A better understanding of these mechanisms can lead to more intelligent creative collaboration systems that consider individual preferences and adapt based on the nature and phase of the collaborative task. An initial evaluation of user preferences could be used to assess the right communication mode before a collaborative task commences. For example, preferences towards *domain-relevant skills* versus *creative-thinking skills*, the importance of self-expression and autonomy, concerns about one's contribution being judged and desire to reach group consensus, and the importance of time efficiency could be coupled with questions about the nature of the task (e.g., an intricate or out-of-the-box final product). Another simple idea that requires less preparation would be to follow an opt-out procedure similar to the one described in [36], where the individual user can turn on and off the visualization of

the gaze of their collaborator. This can be particularly important in scenarios where long-term collaborations are necessary (e.g., an intricate drawing) and where, naturally, collaborators would want to switch between tight and loose interactions, but it still requires some manual effort by each individual.

More advanced systems can use natural language processing developments to detect when different communication modes can be beneficial. Current literature already hints at that, for example, with shared gaze being turned on when the instructor makes a reference [51]. We can similarly imagine a natural language system that, when it detects a request for spatial information from one user, visualizes their partner's gaze on the screen. Future adaptive systems augmented by artificial intelligence could also provide different communication modes based on the predicted intentions of users. For example, if the system predicts that one partner is initiating a new task or transitioning to a new stage of the drawing, shared gaze could be momentarily turned on. If extended gaze overlaps are detected, shared gaze could be turned off since participants are likely working in close proximity with already increased awareness. If extended silences with pauses of work are detected, based on participants' past personal history, shared gaze could be either turned on or off to initiate communication with the goal of inspiration or give more individual space for divergent thinking.

Although our study explored collaborative drawing in a recreational setting, we believe certain insights are transferable to other domains that utilize collaborative drawing, such as design, architecture, and education [4, 10, 20, 64]. For example, art students could observe how their instructors conduct hand-eye coordination through shared gaze, thus enhancing their *domain-relevant skills*. Drawing proficiency has been shown to influence gaze patterns during drawing [29], with advanced sketchers' gazes preceding the creation of lines and indicating work checks. We hesitate to make broader recommendations for all types of collaborative creative tools but recognize that novel tools such as shared gaze will encourage innovative solutions and new insights in remote collaborations.

7 Conclusion

This paper applies shared gaze in collaborative open-ended tasks that highlight creativity, focusing on collaborators' perceptions. Through an online survey, we identified that current collaborative drawing tool users might benefit from synergizing their *domain-relevant* through communication while still retaining individual space to promote *creative-thinking skills*. Our gaze-sharing collaborative drawing tool, EyeDraw, was inspired by prior literature on shared gaze to enable 24 pairs to draw synchronously under four within-subjects communication conditions: shared gaze only, voice only, both shared gaze and voice, and no communication. Participants' responses confirmed the differing needs for the two forms of creativity. The compounding effect of voice and gaze struck an ideal balance and allowed a seamless transition between the two. For *creative-thinking skills* specifically, voice-absent conditions, especially no communication at all, cultivated space for individual autonomy. Finally, participants unanimously adopted variations of division strategies; shared gaze, with its instant response and inherent spatial information, led to on-the-fly negotiation of space and predictive planning and allowed for simultaneous work in close proximity. In contrast, conditions that did not include shared gaze lacked spatial awareness and included frequent turn-taking. For future collaborative tools that prize open-endedness and creativity, voice and shared gaze may address the weakness of each modality. However, some users' preference for having no communication indicates that adaptive systems should first consider the unique aspects of the collaborative task and users' needs in accomplishing those tasks.

Acknowledgments

This research was supported by the National Science Foundation under grant IIS-1948517. We would also like to thank Ulaş Ayyılmaz for his help with the preparation of the camera-ready submission.

References

[1] Stephen R Acker and Steven R Levitt. 1987. Designing videoconference facilities for improved eye contact. *Journal of Broadcasting & Electronic Media* 31, 2 (1987), 181–191.

[2] Teresa M Amabile. 2011. *Componential theory of creativity.* Harvard Business School Boston, MA.

[3] Teresa M Amabile. 2018. *Creativity in context: Update to the social psychology of creativity.* Routledge.

[4] Michael Anderson, Spence Chanthavane, Adam Broshkevitch, Paul Braden, Colton Bassford, Matthew Kim, Michael Fantini, Seth Konig, Trent Owens, and Carl Sorensen. 2022. A survey of web-based tools for collaborative engineering design. *Journal of Mechanical Design* 144, 1 (2022), 014001.

[5] Michael Argyle. 2013. *Bodily communication.* Routledge.

[6] Michael Argyle, Mark Cook, and Duncan Cramer. 1994. Gaze and mutual gaze. *The British Journal of Psychiatry* 165, 6 (1994), 848–850.

[7] Michael Argyle and Jean Ann Graham. 1976. The central Europe experiment: Looking at persons and looking at objects. *Environmental psychology and nonverbal behavior* 1 (1976), 6–16.

[8] Kregg John Aytes. 1993. An empirical investigation of collaborative drawing tools. (1993). https://repository.arizona.edu/handle/10150/186306 Publisher: The University of Arizona.

[9] Daniel Belenky, Michael Ringenberg, Jennifer Olsen, Vincent Aleven, and Nikol Rummel. 2014. Using Dual Eye-Tracking to Evaluate Students' Collaboration with an Intelligent Tutoring System for Elementary-Level Fractions. In *Proceedings of the annual meeting of the Cognitive Science Society*, Vol. 36.

[10] Sara A. Bly. 1988. A use of drawing surfaces in different collaborative settings. In *Proceedings of the 1988 ACM conference on Computer-supported cooperative work*. ACM Press, Portland, Oregon, United States, 250–256. https://doi.org/10.1145/62266.62286

[11] Virginia Braun and Victoria Clarke. 2006. Using thematic analysis in psychology. *Qualitative Research in Psychology* 3, 2 (2006), 77–101.

[12] Susan E Brennan, Xin Chen, Christopher A Dickinson, Mark B Neider, and Gregory J Zelinsky. 2008. Coordinating cognition: The costs and benefits of shared gaze during collaborative search. *Cognition* 106, 3 (2008), 1465–1477.

[13] Shiwei Cheng, Jialing Wang, Xiaoquan Shen, Yijian Chen, and Anind Dey. 2022. Collaborative eye tracking based code review through real-time shared gaze visualization. *Frontiers of Computer Science* 16, 3 (2022), 163704.

[14] Erin Cherry and Celine Latulipe. 2014. Quantifying the Creativity Support of Digital Tools through the Creativity Support Index. *ACM Transactions on Computer-Human Interaction* 21, 4 (Aug. 2014), 1–25. https://doi.org/10.1145/2617588

[15] Herbert H Clark and Susan E Brennan. 1991. Grounding in communication. *Perspectives on Socially Shared Cognition* (1991), 127–149.

[16] Criminisi, Shotton, Blake, and Torr. 2003. Gaze manipulation for one-to-one teleconferencing. In *Proceedings Ninth IEEE International Conference on Computer Vision.* 191–198 vol.1. https://doi.org/10.1109/ICCV.2003.1238340

[17] Sarah D'Angelo and Andrew Begel. 2017. Improving Communication Between Pair Programmers Using Shared Gaze Awareness. In *Proceedings of the 2017 CHI Conference on Human Factors in Computing Systems (CHI '17)*. ACM, 6245–6290. https://doi.org/10.1145/3025453.3025573

[18] Sarah D'Angelo and Darren Gergle. 2016. Gazed and Confused: Understanding and Designing Shared Gaze for Remote Collaboration. In *Proceedings of the 2016 CHI Conference on Human Factors in Computing Systems (CHI '16)*. ACM, 2492–2496. https://doi.org/10.1145/2858036.2858499

[19] Sarah D'Angelo and Bertrand Schneider. 2021. Shared Gaze Visualizations in Collaborative Interactions: Past, Present and Future. *Interacting with Computers* (May 2021), iwab015. https://doi.org/10.1093/iwcomp/iwab015

[20] Gerard Cesar Gabriel and Mary Lou Maher. 2002. Coding and modelling communication in architectural collaborative design. *Automation in construction* 11, 2 (2002), 199–211.

[21] Darren Gergle, Robert E Kraut, and Susan R Fussell. 2004. Language efficiency and visual technology: Minimizing collaborative effort with visual information. *Journal of language and social psychology* 23, 4 (2004), 491–517.

[22] Valéria Gonçalves da Cruz Monteiro, Jade Antunes Nascimento, Paulo Rodrigo Bazán, Shirley Silva Lacerda, and Joana Bisol Balardin. 2022. Group synchronization during collaborative drawing using functional near-infrared spectroscopy. *Journal of Visualized Experiments* 186 (Aug 2022). https://doi.org/10.3791/63675

[23] Kunal Gupta, Gun A. Lee, and Mark Billinghurst. 2016. Do You See What I See? The Effect of Gaze Tracking on Task Space Remote Collaboration. *IEEE Transactions on Visualization and Computer Graphics* 22, 11 (Nov. 2016), 2413–2422. https://doi.org/10.1109/TVCG.2016.2593778

[24] Carl Gutwin and Saul Greenberg. 2002. A descriptive framework of workspace awareness for real-time groupware. *Computer Supported Cooperative Work (CSCW)* 11 (2002), 411–446.

[25] Joy E Hanna and Susan E Brennan. 2007. Speakers' eye gaze disambiguates referring expressions early during face-to-face conversation. *Journal of Memory and Language* 57, 4 (2007), 596–615.

[26] Keita Higuchi, Yinpeng Chen, Philip A. Chou, Zhengyou Zhang, and Zicheng Liu. 2015. ImmerseBoard: Immersive Telepresence Experience using a Digital Whiteboard. In *Proceedings of the 33rd Annual ACM Conference on*

Human Factors in Computing Systems (Seoul, Republic of Korea) *(CHI '15)*. ACM, New York, NY, USA, 2383–2392. https://doi.org/10.1145/2702123.2702160

[27] Pamela Hinds and Sara Kiesler. 2002. *Distributed Work*. MIT Press. https://books.google.com/books?id=3aAwmlgC7YMC

[28] Martin Hoegl and K Praveen Parboteeah. 2007. Creativity in innovative projects: How teamwork matters. *Journal of engineering and technology management* 24, 1-2 (2007), 148–166.

[29] Bryan Howell, Asa River Jackson, Alexandra M Edwards, Katherine Kilbourn-Barber, Kaylee Bliss, and Addie Payne Morgan. 2023. Assessing Eye Gaze Patterns between Intermediate and Advanced Design Sketchers. *Proceedings of the Design Society* 3 (2023), 657–666.

[30] Hiroshi Ishii and Minoru Kobayashi. 1992. ClearBoard: a seamless medium for shared drawing and conversation with eye contact. In *Proceedings of the SIGCHI conference on Human factors in computing systems*. ACM Press, Monterey, California, United States, 525–532. https://doi.org/10.1145/142750.142977

[31] Adam Kendon. 1967. Some functions of gaze-direction in social interaction. *Acta psychologica* 26 (1967), 22–63.

[32] Seungwon Kim, Mark Billinghurst, and Gun Lee. 2018. The Effect of Collaboration Styles and View Independence on Video-Mediated Remote Collaboration. *Computer Supported Cooperative Work (CSCW)* 27, 3 (Dec. 2018), 569–607. https://doi.org/10.1007/s10606-018-9324-2

[33] Chris Kleinke. 1986. Gaze and eye contact: a research review. *Psychological bulletin* 100, 1 (July 1986), 78,Äî100. http://europepmc.org/abstract/MED/3526377

[34] Martin Küchler. 2010. *Groupware devices that support gaze awareness and workspace awareness to improve remote collaboration*. ETH Zurich.

[35] Tiina Kukkonen, Sandra Chang-Kredl, and Benjamin Bolden. 2020. Creative collaboration in young children's playful group drawing. *The Journal of creative behavior* 54, 4 (2020), 897–911.

[36] Grete Helena Kütt, Kevin Lee, Ethan Hardacre, and Alexandra Papoutsaki. 2019. Eye-Write: Gaze Sharing for Collaborative Writing. In *Proceedings of the 2019 CHI Conference on Human Factors in Computing Systems*. ACM, Glasgow Scotland Uk, 1–12. https://doi.org/10.1145/3290605.3300727

[37] Grete Helena Kütt, Teerapaun Tanprasert, Jay Rodolitz, Bernardo Moyza, Samuel So, Georgia Kenderova, and Alexandra Papoutsaki. 2020. Effects of Shared Gaze on Audio- Versus Text-Based Remote Collaborations. *Proceedings of the ACM on Human-Computer Interaction* 4, CSCW2 (Oct. 2020), 136:1–136:25. https://doi.org/10.1145/3415207

[38] Albert Mehrabian. 2017. *Nonverbal Communication*. Routledge.

[39] Scott L Minneman and Sara A Bly. 1991. Managing a trois: A study of a multi-user drawing tool in distributed design work. In *Proceedings of the SIGCHI conference on human factors in computing systems*. 217–224.

[40] Andrew F Monk and Caroline Gale. 2002. A look is worth a thousand words: Full gaze awareness in video-mediated conversation. *Discourse Processes* 33, 3 (2002), 257–278.

[41] Joshua Newn, Fraser Allison, Eduardo Velloso, and Frank Vetere. 2018. Looks can be deceiving: Using gaze visualisation to predict and mislead opponents in strategic gameplay. In *Proceedings of the 2018 CHI Conference on Human Factors in Computing Systems*. 1–12.

[42] David Nguyen and John Canny. 2005. MultiView: spatially faithful group video conferencing. In *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems* (Portland, Oregon, USA) *(CHI '05)*. ACM, New York, NY, USA, 799–808. https://doi.org/10.1145/1054972.1055084

[43] Jennifer K. Olsen, Vincent Aleven, and Nikol Rummel. 2017. Exploring dual eye tracking as a tool to assess collaboration. In *Innovative assessment of collaboration*. Springer International Publishing, Cham, Switzerland, 157–172. https://doi.org/10.1007/978-3-319-33261-1_10

[44] Chengzhi Peng. 1992. Survey of collaborative drawing support tools: Design perspectives and prototypes. *Computer Supported Cooperative Work (CSCW)* 1, 3 (Sept. 1992), 197–228. https://doi.org/10.1007/BF00752438

[45] Pernilla Qvarfordt, David Beymer, and Shumin Zhai. 2005. RealTourist: a study of augmenting human-human and human-computer dialogue with eye-gaze overlay. In *Proceedings of the 2005 IFIP TC13 international conference on Human-Computer Interaction (INTERACT'05)*. Springer-Verlag, Berlin, Heidelberg, 767–780. https://doi.org/10.1007/11555261_61

[46] Mona Sakr. 2018. Multimodal participation frameworks during young children's collaborative drawing on paper and on the iPad. *Thinking Skills and Creativity* 29 (2018), 1–11. https://doi.org/10.1016/j.tsc.2018.05.004

[47] Michael Scaife and Jerome S Bruner. 1975. The capacity for joint visual attention in the infant. *Nature* 253, 5489 (1975), 265–266.

[48] Bertrand Schneider. 2019. Unpacking Collaborative Learning Processes During Hands-on Activities Using Mobile Eye-Trackers. *13th International Conference on Computer Supported Collaborative Learning (CSCL) 2019* (June 2019), 41–48. https://repository.isls.org//handle/1/1597 Publisher: International Society of the Learning Sciences (ISLS).

[49] Bertrand Schneider and Roy Pea. 2017. Real-time mutual gaze perception enhances collaborative learning and collaboration quality. *Educational Media and Technology Yearbook: Volume 40* (2017), 99–125.

[50] Stephen AR Scrivener, Sean M Clark, and N Keen. 1993. The LookingGlass distributed shared workspace. *Computer Supported Cooperative Work (CSCW)* 2 (1993), 137–157.

[51] Kshitij Sharma, Sarah D'Angelo, Darren Gergle, and Pierre Dillenbourg. 2016. Visual augmentation of deictic gestures in MOOC videos. Singapore: International Society of the Learning Sciences.
[52] Shinichi Shiwa. 1991. A large-screen visual telecommunication device enabling eye contact. In *Digest SID Int'l Symp.* 327–328.
[53] Anna Shvarts and Dor Abrahamson. 2019. Dual-eye-tracking Vygotsky: A microgenetic account of a teaching/learning collaboration in an embodied-interaction technological tutorial for mathematics. *Learning, Culture and Social Interaction* 22 (Sept. 2019), 100316. https://doi.org/10.1016/j.lcsi.2019.05.003
[54] Harri Siirtola, Oleg Špakov, Howell Istance, and Kari-Jouko Räihä. 2019. Shared Gaze in Collaborative Visual Search. *International Journal of Human–Computer Interaction* 35, 18 (Nov. 2019), 1693–1705. https://doi.org/10.1080/10447318.2019.1565746 Publisher: Taylor & Francis.
[55] Jaime Snyder. 2013. Drawing practices in image-enabled collaboration. In *Proceedings of the 2013 Conference on Computer Supported Cooperative Work* (San Antonio, Texas, USA) *(CSCW '13)*. ACM, New York, NY, USA, 741–752. https://doi.org/10.1145/2441776.2441858
[56] Randy Stein and Susan E. Brennan. 2004. Another person's eye gaze as a cue in solving programming problems. In *Proceedings of the 6th international conference on Multimodal interfaces (ICMI '04)*. ACM, 9–15. https://doi.org/10.1145/1027933.1027936
[57] Simon Taggar. 2002. Individual creativity and group ability to utilize individual creative resources: A multilevel model. *Academy of management Journal* 45, 2 (2002), 315–330.
[58] John C Tang. 1991. Findings from observational studies of collaborative work. *International Journal of Man-machine studies* 34, 2 (1991), 143–160.
[59] John C Tang and Scott L Minneman. 1991. VideoDraw: a video interface for collaborative drawing. *ACM Transactions on Information Systems (TOIS)* 9, 2 (1991), 170–184.
[60] John Tchalenko. 2009. Segmentation and accuracy in copying and drawing: Experts and beginners. *Vision research* 49, 8 (2009), 791–800.
[61] Michael Tomasello, Brian Hare, Hagen Lehmann, and Josep Call. 2007. Reliance on head versus eyes in the gaze following of great apes and human infants: the cooperative eye hypothesis. *Journal of human evolution* 52, 3 (2007), 314–320.
[62] Remko Van der Lugt. 2002. Functions of sketching in design idea generation meetings. In *Proceedings of the 4th Conference on Creativity & Cognition*. 72–79.
[63] Alieke M Van Dijk, Hannie Gijlers, and Armin Weinberger. 2014. Scripted collaborative drawing in elementary science education. *Instructional science* 42 (2014), 353–372.
[64] Gokula Annamalai Vasantha, Hari Prakash Ramesh, Chandra Mouli Sugavanam, Amaresh Chakrabarti, Jonathan Corney, and Andrew Wodehouse. 2017. Interactional differences and effects between collocated and distributed design. In *Research into Design for Communities, Volume 1: Proceedings of ICoRD 2017*. Springer, 933–944.
[65] Boris M. Velichkovsky. 1995. Communicating attention: Gaze position transfer in cooperative problem solving. *Pragmatics & Cognition* 3, 2 (Jan. 1995), 199–223. https://doi.org/10.1075/pc.3.2.02vel Publisher: John Benjamins.
[66] Patricia R. Van Velsor and Deborah L. Cox. 2000. Use of the Collaborative Drawing Technique in School Counseling Practicum: An Illustration of Family Systems. *Counselor Education and Supervision* 40, 2 (2000), 141–152. https://doi.org/10.1002/j.1556-6978.2000.tb01245.x
[67] Roel Vertegaal. 1999. The GAZE Groupware System: Mediating Joint Attention in Multiparty Communication and Collaboration. In *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems* (Pittsburgh, Pennsylvania, USA) *(CHI '99)*. ACM, 294–301. https://doi.org/10.1145/302979.303065
[68] Dahlia W. Zaidel, Marcos Nadal, Albert Flexas, and Enric Munar. 2013. An evolutionary approach to art and aesthetic experience. *Psychology of Aesthetics, Creativity, and the Arts* 7, 1 (Feb. 2013), 100–109. https://doi.org/10.1037/a0028797
[69] Mengyao Zhao. 2015. Building teams over distance: A solution through digital art mediated practices. In *2015 IEEE Symposium on Visual Languages and Human-Centric Computing (VL/HCC)*. 287–288. https://doi.org/10.1109/VLHCC.2015.7357230
[70] Mengyao Zhao, Yi Wang, and David Redmiles. 2015. Strengthening collaborative groups through art-mediated self-expression. In *2015 IEEE Symposium on Visual Languages and Human-Centric Computing (VL/HCC)*. 177–181. https://doi.org/10.1109/VLHCC.2015.7357214
[71] Mengyao Zhao, Yi Wang, and David Redmiles. 2017. Using Collaborative Online Drawing to Build Up Distributed Teams. In *2017 IEEE 12th International Conference on Global Software Engineering (ICGSE)*. 61–65. https://doi.org/10.1109/ICGSE.2017.3
[72] Mengyao Zhao, Yi Wang, and David Redmiles. 2017. Using Playful Drawing to Support Affective Expressions and Sharing in Distributed Teams. In *2017 IEEE/ACM 2nd International Workshop on Emotion Awareness in Software Engineering (SEmotion)*. 38–41. https://doi.org/10.1109/SEmotion.2017.3

Received May 2024; revised August 2024; accepted October 2024