# TegakARi: Augmenting Creative Drawing With Audio and Visual Cues

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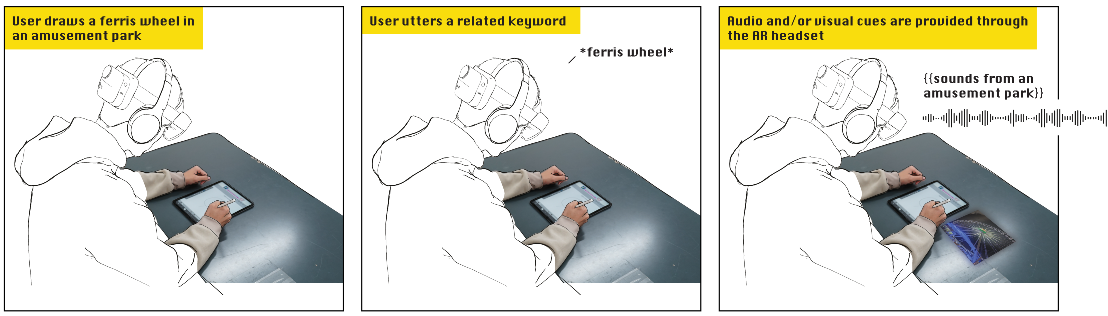


Fig. 1. TegakARi is an Augmented Reality Creativity Support System for expert drawers. As depicted here, users can utter a keyword related to their drawing, and TegakARi will provide them with related visual and/or audio cues. The interaction works hands-free, through voice inputs, and cues do not obstruct the drawing space. The photographic part of the figure represents what participants would see through their glasses, including the workspace and projected visual cues.

Creativity Support Systems for expert users usually focus on idea implementation, assuming that experts only need to materialize their idea, while support of idea exploration is relatively understudied. Recognizing potential in this area, we developed TegakARi—an Augmented Reality system that provides peripheral cues (visual and audio) to support experts' idea exploration. In a pilot and an evaluation study ($n = 6 + 18$), we found positive effects of unimodal support (audio or visual cues only) on external creativity ratings, but no effect of multimodal support. In addition, participants rated TegakARi's creativity support as generally comparable to other Creativity Support Systems, with above-average potential for collaboration. Qualitative findings indicate that audio cues tend to induce creative mood and inspire experts to enrich their drawings. Visual cues tend to support "getting the details right". We close with four design sketches to illustrate how our findings can inform future design of Creativity Support Systems.

CCS Concepts: • **Human-centered computing** → *Empirical studies in HCI*; **Graphics input devices**; **Empirical studies in interaction design**; **Interactive systems and tools**.

Additional Key Words and Phrases: Creativity Support Tools, Creativity Support Systems, Augmented Reality, Drawing, Divergent Thinking, Multimodal, Expert Users

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## 1 INTRODUCTION

Over the past months, tools such as Dall-E, Midjourney, and Stable Diffusion raised renewed concerns about the future of art. Media attention on "AI" winning a prestigious art competition [62] and a generative model "finishing" Beethoven's 10th symphony [20] raised reflection on the value of artistic practice and human creativity, in times where novel tools increasingly compete with artists in artistic media production. Such headlines that highlight the aesthetic quality of automatically generated products seem to reduce art to such outcomes—and further, overlook the key opportunities of how AI systems might support human creativity, rather than replace it.

This paper focuses on such artistic practice, human creativity, and how technology can support it. Instead of optimizing the outcomes alone, and replacing artists with algorithms, we focus on how technology can instead be used to support the artist in their creative practice. Hence, our project aims to support artists and experienced drawers in developing and exploring creative ideas and assist them in their self-expression. We approach this with a Creativity Support System (CSS) called TegakARi, which is drawn from the Japanese word *tegakari*—meaning clue or handhold. TegakARi, tailored to experienced drawers, is based on a simple verbal interaction—users can pull inspirational imagery and sounds by uttering conceptual keywords. We explored the use of TegakARi in a drawing study, in which we looked at how well the system supports creative drawing practices and how users experience such creativity support.

Taken together, we make the following three contributions. First, we introduce TegakARi, a hands-off Augmented Reality (AR) CSS for experienced drawers. Specifically, TegakARi uses audio and visual cues relating to what users draw in real time. Second, we report a pilot exploration and an evaluation study about how the different cue modalities help spark creative ideas, and how experienced drawers appropriate such cues during their creative drawing practice. Finally, we reflect on TegakARi and our findings using four concrete design sketches, which map a design space for future implementations.

## 2 RELATED WORK

The design of TegakARi draws from previous research on creativity support, more specifically cue-based assistance, and from work on creativity support using Extended Reality (XR) solutions. We summarize the key literature in this section.

### 2.1 Creativity Support Systems for Varying Expertise Levels

Creativity Support Systems (CSS) provide a wide range of support for different target users, from ideation and exploration of ideas to implementation [25]. Broadly speaking, we can differentiate between systems targeted at novice users [1, 13, 22, 45], experts [19, 30, 34, 75], and for non-specific or mixed audiences [18].

The type of support these systems offer tends to differ between these user groups. Systems geared towards novices often support basic steps to explore the tool and artistic space, and they help users produce first artifacts [13, 22, 24, 45]. An example is "Creative PenPal" [60], a co-creative "AI" tool to support sketching. Creative PenPal is a screen-based system with a conversational "AI" agent and two canvases, one for drawing and the other for the "AI" to present sketch inspirations. When the user draws something on their canvas, the "AI" generates a conceptually related drawing on the other canvas. Users can adopt these to develop new design ideas, which could be a helpful jumpstart for people with little day-to-day experience with drawing. Another example is Living Paper [16], an Augmented Reality (AR) based system that combines physical hand-drawn animations with programmable LED lights in a book format to help children create interactive storytelling experiences. It supports idea exploration for narratives that the children author by themselves. This blends together digital and tangible elements. Such exploratory support, as in Creative PenPal and Living Paper, facilitates the creative process to make it easily accessible for novices by defining a clear (restricted) space to work in.

Support systems for experts take advantage of their substantial domain knowledge and experience with their tools. Thus, they tend to focus less on exploration, and more on realizing already existing ideas (e.g., [25, 34, 44, 75]). In other words, they focus on the implementation stage. An example expert tool is CASSIE, a modeling system in Virtual Reality (VR) that supports freehand mid-air sketching to create 3D drawings. Users can create freehand 3D sketches in VR/AR, which are corrected with automatic stroke neatening of the freehand curves [77]. This is helpful for designers to express their existing ideas in a more aesthetic form. Another expert-oriented system is "SPARK", a Spatial Augmented Reality (SAR) based CSS for packaging design. SPARK helps visualize, track, and interact with virtual packaging models to help users implement interactive mixed prototypes [9]. Again, this is primarily geared at supporting the implementation and testing of sophisticated prototypes.

Recognizing exploration support for expert users as an area which is relatively understudied and with potential for further examination, we set upon looking into how to improve support for idea exploration by experts.

### 2.2 Cue-based Assistance and its Challenges for Expert Users

Assistance tools for creative exploration typically work with sensory cues, such as images [41, 68], sound [54, 81], or smells [31, 32]. They present such cues to the user to increase the chances of sparking new ideas through new associations [69, 78]. This approach integrates well with realistic creative practices, where ideation (e.g., selection of cues) and implementation (e.g., drawing) work as interdependent, continuous processes [2]. Cues can be selected automatically and flexibly, and they may direct users' attention in previously overlooked directions. For example, the Creative PenPal system described above does this through its virtual "AI" assistant [60].

However, cue-based assistance can also have problematic effects on creativity, which could affect expert users more strongly. For example, the selection of cues should be appropriate for what the users need. Expert users in particular may need more carefully and flexibly selected cues that align with their more elaborate creative process. They may need appropriate semantic granularity (e.g., differentiation between "food", "fruit", and "apple" as increasingly specific categories) and CSS should be able to flexibly support this.

In addition, cues take up space in the user interface. They can distract or even block valuable space (in visual tasks like drawing), which could otherwise be used for the creative task itself [29]. Expert users tend to tailor their user interface to their needs, so new or purposefully unexpected elements can become more obtrusive in such individualized setups [8, 42, 76]. Relatedly, the choice of cue modality plays an important role. One solution for the space issues would be to present cues through a different modality than the task itself, such as auditory (i.e., audio) or olfactory (i.e., smell) cues for visual tasks (e.g., drawing). However, modality may alter the cue's effect on the user, and the cues may represent different things. For example, audio elements are often used to create certain atmospheres and senses of space [5, 23, 53], but other concepts could benefit from visual presentation (e.g., maps). Some other modalities, such as smell, may require uncommon technical infrastructure. Thus, selecting appropriate sensory support for expert users remains a challenge.

Taken together, sensory cues are a common method to support creative exploration and divergent thinking. However, for expert users in particular, integrating such cues in a user interface without disturbing their established creative process can be challenging, because the cues need to align with their current stage of the creative process, avoid disturbing their creative practice, and meaningfully represent useful ideas with an appropriate modality. At present, these challenges have not been addressed comprehensively. In the next section, we argue why we think Augmented Reality (AR) systems can be a way to address some of these challenges.

### 2.3 Augmented Reality in Creativity Support for Advanced Users

Current Augmented Reality (AR) systems can address multiple problems with cue-based assistance for expert users. These include their flexibility of modalities, a solution for cluttered/individualized user interfaces (UIs), and interaction design that minimizes interference with creative practices. In current systems, audio (e.g., [49]) and visual (e.g., [16]) AR are most common, although other senses are also occasionally addressed (e.g., smell; [32]).

AR interfaces can also circumvent the problem of cluttered UIs. They can overlay traditional UIs and extend beyond them, thus not interfering with experts' existing setups. These existing setups may well include non-digital components that are otherwise difficult to incorporate. XR interfaces also allow for flexible forms of interaction, including hands-free methods [10, 61] such as voice interaction. All of this can help users engage in their personalized creative practice, while limiting distraction.

AR has already been explored as a mode of developing CSS (e.g., [14, 56, 59]). However, as it stands, these systems mostly address novice users (as with Living Paper described above) or do not focus on assistance in creative exploration for expert users. Nevertheless, as the examples above indicate, AR offers a range of advantages, particularly for expert users, that are worth exploring.

### 2.4 Summary and Outlook

The previous work on CSS offers a range of different solutions for specific needs of novices and experts. One area that tends to be overlooked however is exploration support for expert users. Cue-based support seems especially suitable for this, despite its challenges in terms of cue and modality selection, integration with UIs, and interference with the creative practice. One promising way to address these challenges is XR.

We took this opportunity as the starting point for designing an XR-enhanced, expert-oriented CSS we call TegakARi. TegakARi focuses on exploratory drawing support and targets experienced drawers, including ambitious hobbyists but also professionals. It is built around simple verbal interactions and can display multimodal (audio/visual) cues that semantically relate to the drawing in real-time.

## 3 DESIGNING THE TEGAKARI SYSTEM

To design TegakARi, we began with a pilot exploration, which informed the development and final shape of the system. Here, we first present the pilot, followed by a technical description of the implementation of TegakARi.

### 3.1 Pilot Exploration

The pilot exploration served to explore various design aspects but with a focus on comparing two different approaches to cue generation. Specifically, we were interested in whether conceptually closely related, and thus highly relevant cues would be more useful, or whether more distantly related cues that might induce more novel ideas would provide better support. Thus, the main goals of the pilot exploration were to a) get a better understanding of which types of audio, visual, and multimodal cues experts find useful while engaging in a drawing task, and b) to collect early feedback on the overall design and expected usefulness of such an AR Creativity Support System, from the perspective of expert users (here: experienced drawers).

*3.1.1 Setting.* We invited 6 university students (4 female, 2 male; age 19-22 ($M = 20.0$)) to our lab via snowball sampling. All participants were experienced drawers and members of drawing clubs at their universities. The pilot lasted around 105 minutes for each participant, and they were compensated with a 3000 Yen Amazon gift card.

We implemented the CSS using the Microsoft Hololens 2 (beta), a mobile holographic head-mounted display for AR applications. We developed the program using Unity with the Mixed Reality Toolkit (MRTK). Participants worked on a drawing task loosely based on Clark's Drawing Ability Test [15]. This test consists of 4 drawing tasks and measures ability and potential talent in the visual arts among students. We asked participants to draw either "an interesting house from across the street" or "a dog of your liking" (3 participants each). Each participant drew under nine conditions in counterbalanced order, each for 10 minutes. The conditions varied by presented cue type (closely related, distantly related, none) for both audio and visual cues (thus, a 3x3 variation). The visual cues were obtained using Google Image Search [1], while audio cues were obtained from ESC-50[2], an open-source environmental sound dataset. We prepared the cues beforehand: for closely related cues, we used "house" and "dog" (based on the drawing task) as search queries. For distantly related cues, we constructed a word2vec model learning on the Glove 6B dataset, and used "house" and "dog" as keywords with a similarity distance of $0.25 - 0.35$, which then served as search queries. We presented these cues at intervals of 2 minutes, 5 times throughout the drawing process. We presented the visual cues at eye level, at a distance of 5m from the headset, while audio cues were played at a default volume of 40 through the Hololens speakers. For drawing, participants used an Apple iPad Pro [3] using the Apple Pencil [4] and the "ibisPaint" drawing app [5]. After they finished, we conducted brief follow-up interviews to learn about their experience with the system.

*3.1.2 Takeaways from the Pilot Exploration.* The qualitative interview data indicated that, overall, participants favored closely related over distantly related cues. Some found unrelated cues disturbing during their creative practice. For example, one participant from the "house group" said: "*When there was a mismatch between my interpretation of visual and audio cues, I felt very uncomfortable and felt that it affected my creative work more*". Another participant from the same group said: "*Sometimes, when I could not think of anything to draw, I got inspiration from the image or audio. When there was a mismatch between the image and audio, it was confusing*". This seems to be in line with results from previous work by Chan et al. and Fu et al. that more creative and higher quality ideas are more often likely to emerge from drawing on nearby sources or stimuli rather than farther sources or stimuli [11, 26]. Based on this, we decided to proceed with semantically closely related cues.

In addition, we found that the experimental design with extensive drawing about the same topic caused some difficulties. Two participants expressed that, *"it's hard to do it on the same subject..."* and *"it's hard to draw several times on the same subject."* Thus, we decided to provide more flexible instructions in the final evaluation study.

Based on the pilot exploration, we refined our system in terms of cue presentation and drawing task selection. In sum, we defined three design goals for the final setup:

[1] https://images.google.com/
[2] https://github.com/karolpiczak/ESC-50
[3] https://www.apple.com/ipad-pro/
[4] https://www.apple.com/apple-pencil/
[5] https://ibispaint.com/product.jsp

(1) The cues presented by the system do not obstruct the creative process of the user. Specifically, audio cues are played at a non-disturbing volume and are adjustable, and visual cues do not obstruct the drawing task.
(2) The cues presented by the system closely relate to the drawing intent of the user. This was meant to minimize confusion as found in the pilot exploration.
(3) The system allows for hands-free interaction to minimize interference with experts' habitual drawing practices.

### 3.2 Final Technical Setup

*3.2.1 System Configuration.* We used a similar overall setup as in the pilot exploration, with the Microsoft Hololens 2 to present auxiliary multimodal cues (visual and audio) as participants performed a drawing task (see Figure 2 for a technical overview). We decided to implement cue selection through a Speech-to-Text interface, to make sure the cues relate to the users' current drawing process. On the one hand, this flexible interface helped solve the semantic relation problem (i.e., appropriate granularity). On the other, it could be operated in real-time and hands-free, which facilitated quick interactions.

On the software side, the final system consisted of two main programs running concurrently: A Unity XR program to display the cues, and a Python program to provide the Speech-to-Text interface and retrieve the audio and visual cues from online databases.

We used the MRTK in Unity 2022.f1 to script the program on a 5N-CML Mouse Laptop, which had an 8GB×2 dual-channel memory and NVIDIA GeForce RTX™ 2060 graphics card, to implement the XR program. For the Speech-to-Text interface, we used the Google Cloud Speech-to-Text API[6]. For the visual cue repository, we used the Google Images API[7]. For the audio cue repository, we used the Youtube Data API[8].

[6]https://cloud.google.com/speech-to-text
[7]https://pypi.org/project/Google-Images-Search/
[8]https://developers.google.com/youtube/v3

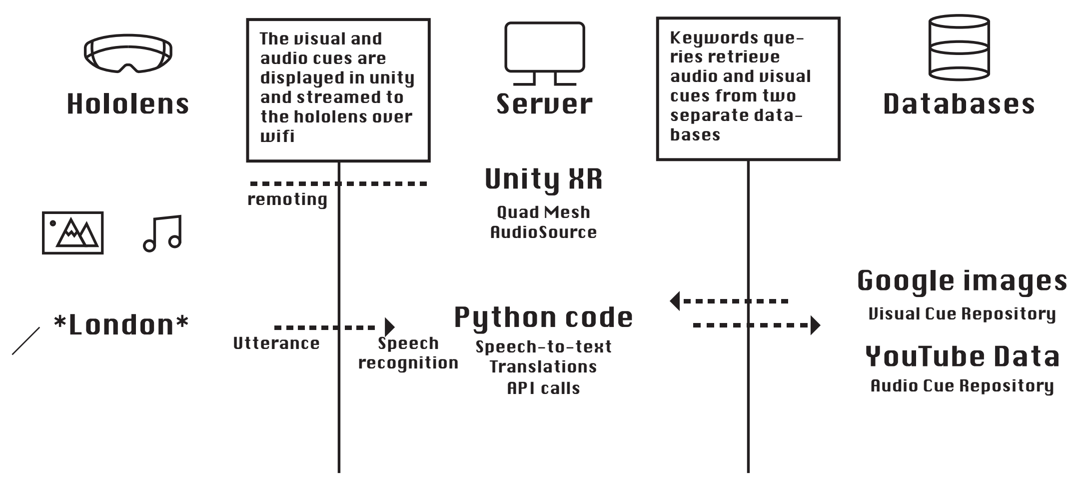


Fig. 2. Diagram of the system architecture and program workflows.

*3.2.2 Envisioned Flow of Interaction and Adaptations for the Evaluation.* The envisioned system provides audio and visual cues through a hands-free voice interface. Users can utter what they are drawing or thinking of drawing at any time. The Speech-to-Text interface picks up these utterances and uses them as keywords to query cues from the two repositories. For both audio and visual cues, it selects the first result ("best match") to the query, assuming they have high conceptual similarity. The cues are then displayed through the Hololens headset. Visual cues are displayed using Quad Mesh, at an angle of 30° to the drawing surface and coordinates of (-0.3m, -0.5m, 0.8m) relative to the coordinates of the user's eyes. The audio cues are retrieved as YouTube URLs, opened with the video hidden and only the audio streaming. The verbal interaction takes place while the users are drawing, and subsequently, display of cues occur in real time. They can interact with the system throughout the drawing activity.

During our evaluation study (see below), we included an additional processing step before the database queries. All participants were Japanese, and prior testing indicated that Japanese language querying often led to lower-quality results in our queries than English language querying. Thus, we first translated participants' utterances from Japanese to English using the DeepL API[9] before running the queries. In addition, in the final system design, the audio cues were intended to be played spatially through the Hololens speakers. However, in our evaluation study, we replaced this with headphones, to ensure stability of the execution of the program.

## 4 EVALUATION STUDY

We ran an evaluation study to test how TegakARi integrates into experts' drawing processes and supports creativity. We had two main research questions:

- **RQ1:** How does the modality of cues (audio/visual) affect experienced drawers' creativity?
- **RQ2:** How could AR Creativity Support Systems be appropriated by experienced drawers into their drawing practices?

To that end, participants engaged in a drawing task while receiving audio and visual cues through TegakARi. For the evaluation, we analyzed the produced drawings, participants' subjective creativity support from a questionnaire, and follow-up reflective interviews.

### 4.1 Method

*4.1.1 Participants.* We invited 18 participants (16 female, 2 male; age 19-24 ($M$ = 21.28)) via snowball sampling to our lab. All participants were experienced drawers who drew as a hobby or professionally, and they all practiced several times a month. Their drawing background was mixed: some belonged to art clubs at their university, and others were enrolled in an art degree program. In the introduction phase, 11 out of the 18 participants reported drawing with tablet-based drawing software more than twice a week, and barring one participant, all reported never having used AR. The study lasted 90 minutes on average, and participants received an Amazon gift card worth 3000 Yen, in accordance with university stipulations.

*4.1.2 Procedure.* We conducted the study in a lab in the engineering building at our university. Upon entry, the experimenter briefly explained the experimental setup, procedure, and the participants' task. Participants also signed a form explaining the anonymous data analysis, they gave their consent to recordings, and to their participation in the experiment. They also answered a brief pre-task questionnaire to gauge their age, experience with drawing software,

[9]https://www.deepl.com/pro-api

(a) A Ferris wheel, drawn during the 'use' task with atmospheric elements

(b) A 'Geometric Rose', drawn during the 'use' task

(c) A cat, drawn during the 'combine' task and using various geometric forms

(d) An archer from the 'complete' task, extending a given shape (marked here in red)

Fig. 3. Four example drawings illustrating the three conditions ('use', 'combine', 'complete') and how participants used atmospheric elements and colors. Note that in the 'complete' task, the shape was already drawn on the canvas, whereas in the 'use' and 'combine' tasks the shapes were provided separately on an instruction form.

and with AR. Participants then tried on the HoloLens 2 to confirm if they could see and hear the cues, and to make sure they could draw without major issues.

The experiment consisted of a drawing task adapted from the Figural Torrance Test of Creative Thinking, a divergent thinking test, which measures creativity in visual tasks such as drawing [46, 73]. Specifically, it consisted of three subtasks:

(1) **Use**: Participants draw an image of their choice, but they have to incorporate a predefined figure in their drawings. In our study, we chose a circle.
(2) **Combine**: Participants draw an image of their choice, but they have to incorporate a fixed set of shapes in their drawings. In our study, these were a rectangle, a circle, a trapezium, and a triangle.
(3) **Complete**: Participants complete an incomplete figure (an abstract scribble). They use this figure as a starting point to complete the drawing in their own way. All users got the same incomplete figure.

Some example drawings are depicted in Figure 3. In each subtask, participants were free to decide what they drew, and we asked them to draw as creatively as possible. Each participant completed the three tasks in four counterbalanced conditions: only audio cues presented, only visual cues presented, multimodal cues (i.e., both audio and visual cues) presented, and no cues presented (control condition). Thus, the experiment had a 2 (audio vs. no audio cues) by 2 (visual vs. no visual cues) within-participants design (see Figure 4).

When a drawing session under one condition started, participants performed all subtasks ("use", "combine", "complete") consecutively, without break. Between drawing sessions, they took a 2-minute break. After all tasks were complete, the participants filled in a questionnaire (see below). Finally, the instructor conducted a short, semi-structured interview in which they asked participants about their experiences and their subjective impression of how the setup influenced their creative process.

*4.1.3 Measures.* We included two creativity measures: An expert creativity rating of the drawings, and the Creativity Support Index (CSI; [12]) as a subjective rating of creativity support by the users themselves.

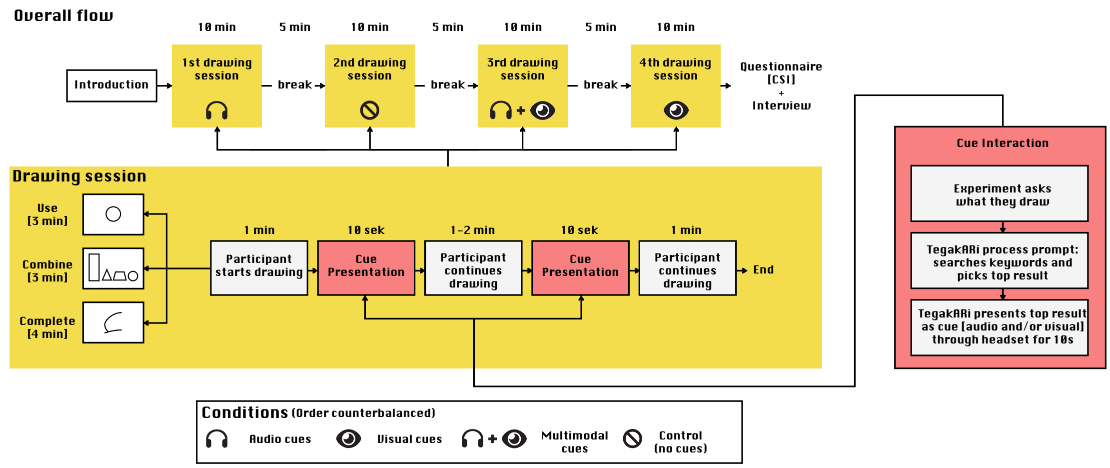


Fig. 4. Flowchart of the evaluation study.

*Expert Creativity Rating.* For the expert creativity rating, we engaged two university students studying arts, who additionally work as freelance artists. They independently rated the collected drawings following a set of criteria and were provided with compensation of around 10000 Yen (time-based compensation), following university stipulations.

The ratings were performed using a grading scale adopted from the scoring system of the Figural Torrance Test [46, 73]. The scale consists of 4 main creativity subscales: fluency, flexibility, originality, and elaboration, and 11 further creativity indicators: emotional expressiveness, storytelling articulateness, movement or action, expressiveness of titles, synthesis of incomplete figures, synthesis of circles, unusual visualization, internal visualization, extending or breaking boundaries, humor, richness of imagery, colorfulness of imagery, and fantasy. The experts rated the four creativity subscales in absolute numbers, based on the following criteria: fluency as the number of meaningful parts in the drawing, flexibility as the number of different categories of meaningful parts in the drawing, originality as the number of drawn objects not found commonly, elaboration as the number of embellishments such as color, shading, and other added details. These raw scores were then normalized to four scales ranging from 0 (e.g., least fluent) to 20 (e.g., most fluent). The further creativity indicators were scored on scales from 0 to 2. The four creativity subscale scores and the 11 creativity indicator scores were then summed up to get a final expert rating of the drawings, with a maximum score of 102. Interrater reliability was acceptable (Krippendorff's $\alpha = .61$), given the relatively broad dimensions (e.g., "humor" and "uncommon objects"). For further analysis, we averaged the two raters' scores for each drawing.

*Creativity Support Index.* After finishing the four drawing sessions, we asked participants to fill in the Creativity Support Index (CSI; [12]). The CSI is an established tool to measure the subjective ability of a Creativity Support System to assist the users' creative work. It has an overall score and 6 subscales with 2 items each: collaboration, enjoyment, exploration, expressiveness, immersion, and results worth effort. These scores are weighted using a paired-factor comparison method, with 15 comparisons between every pair of each subscale. Participants indicate which of the two is more important to them, which is then considered as one count for the more important subscale. These counts are then used as weights for the average factor scores. We included the CSI as a post-hoc, overall assessment of our setup to compare it with other CSS from the literature, and assess relative strengths and weaknesses. Internal consistency was good (Cronbach's $\alpha$ = .86).

The authors of the CSI suggest interpreting the overall score using the American school grade system [12], which we report below for TegakARi. Such school grades serve as an established, criterion-based assessment, and can be helpful as a first estimate. However, a downside is that it is not always clear what a certain grade expresses, and how to interpret it without further context. For creativity in particular, it is unclear where the 100%, "best possible grade" would lie, because of the undefined, open-ended nature of the concept (in contrast to, for example, a high school math exam).

Thus, to complement the criterion-based score, we additionally compared our system with CSI scores reported for similar CSS in the literature. To that end, we ran a literature search for CSS that cited the CSI [12], with the goal of creating a sample of comparable CSI-scored systems. We found an initial set of 101 papers that presented new system designs. However, not all of those articles reported the full CSI data. Some only used a changed or reduced version of the CSI, or did not report weighted data. We excluded those articles, non-English publications, and one duplicate system. This left us with a final set of 19 systems that accurately reported an overall CSI score. 14 of these also reported the 6 subscales (see Appendix for a list of included studies). Some of these papers reported multiple CSI scores for different conditions. In such cases, we first checked whether one condition is particularly relevant for our system design, in which case we selected the associated scores (e.g., the expert condition in [56]). If there was no clear candidate, we selected the condition with the highest overall CSI score (e.g., in [33, 45]).

In a final step, two authors independently assessed whether these systems supported drawing ($n$ = 1), used an XR interface ($n$ = 2), or were directed at expert users ($n$ = 14). Multiple coding was allowed. Initial agreement was high (51 out of 57 codes), and we resolved the remaining six codes in an ensuing discussion.

*4.1.4 Qualitative Interviews and Analysis.* Finally, we conducted follow-up, semi-structured interviews. These focused on participants' subjective experiences of interacting with TegakARi, on creativity support, and technical issues/future improvements. The interviews were also meant to provide further insight in case of unclarity about the quantitative findings.

## 5 RESULTS

### 5.1 Quantitative Findings

*5.1.1 Expert Ratings: Higher Creativity Only in Unimodal Conditions.* Our first analysis tested how the different support modalities influenced drawing creativity, as rated by the external expert reviewers. We assumed that all support variants would be better than control, and that the multimodal interaction would outperform the unimodal settings. To test this, we ran a 2x2 repeated measures ANOVA with the independent variables audio cues (audio cues vs. no audio cues) and visual cues (visual cues vs. no visual cues), and with the averaged expert creativity rating as dependent variable.

We found a significant interaction effect ($F(1, 17) = 5.07$, $p = .04$, $\eta_p^2 = .23$; see Figure 5). Pairwise comparisons with the baseline condition ("no support") revealed a higher expert creativity rating in the condition with only audio support ($t(17) = 3.35$, $p = .00$) and in the condition with only visual support ($t(17) = 2.20$, $p = .04$). However, against our expectations an despite a trend, the multimodal support condition (audio and visual) did not lead to a significantly higher expert creativity rating than control ($t(17) = 1.96$, $p = .07$).

In sum, this analysis confirms higher expert creativity ratings for both types of unimodal cues, but not for multimodal cues.

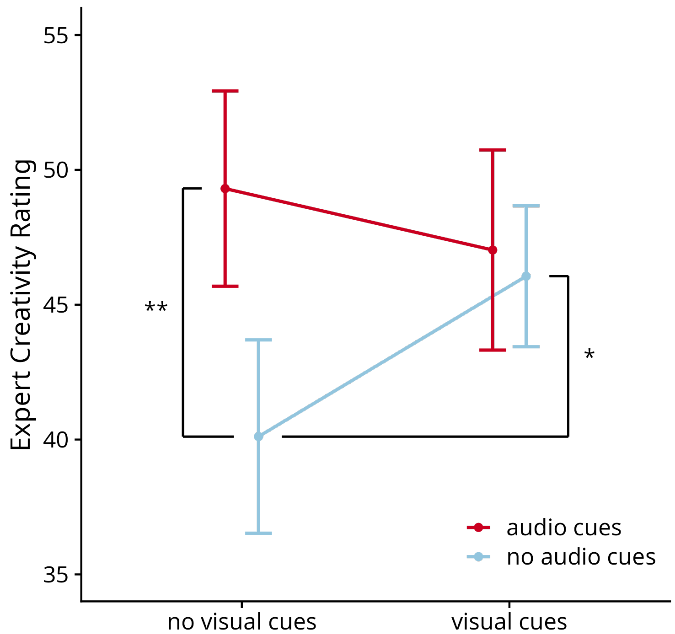


Fig. 5. Expert Creativity Rating for the four conditions. Error bars represent Standard Errors.

*5.1.2 Creativity Support Index: Average Scores With High Collaboration Potential.* The CSI scores are reported in Table 1. Our system had an overall CSI score of 66.94, which translates into the school grade D. Although this seems relatively low, our comparative assessment with other systems draws a different picture (see Figure 6). We ran exploratory, undirected, one-sample t-tests[10] to compare our system with the respective average scores of related systems. For the overall CSI score, our system was in line with the average ($\mu_{others} = 69.69$, $t(17) = 0.59$, $p_{crit} = .008$, $p = .57$). Similarly, there was no significant difference in exploration ($\mu_{others} = 45.59$, $t(17) = 1.14$, $p_{crit} = .017$, $p = .27$), expressiveness ($\mu_{others} = 36.89$, $t(17) = 0.32$, $p_{crit} = .007$, $p = .75$), immersion ($\mu_{others} = 23.87$, $t(17) = 0.72$, $p_{crit} = .01$, $p = .48$), and results worth effort ($\mu_{others} = 31.36$, $t(17) = 0.6$, $p_{crit} = .01$, $p = .56$). Enjoyment scores were relatively high but missed significance ($\mu_{others} = 31.03$, $t(17) = 2.09$, $p_{crit} = .025$, $p = .052$). Finally, participants reported a significantly higher potential for collaboration than the average ($\mu_{others} = 15.21$, $t(17) = 3.97$, $p_{crit} = .05$, $p = .00$). This is somewhat surprising given our single-user setup, but the qualitative analysis below indicates why this may have been the case.

In sum, our system was within the overall average of CSS in the comparable literature. The collaboration score was significantly higher than average, and all other subscale scores were not significantly different from the average.

### 5.2 Qualitative Findings

Following the quantitative analysis and our interest in how participants used TegakARi, we defined the following guiding questions for our qualitative analysis:

[10] We used the Holm method [39] to control for alpha error accumulation

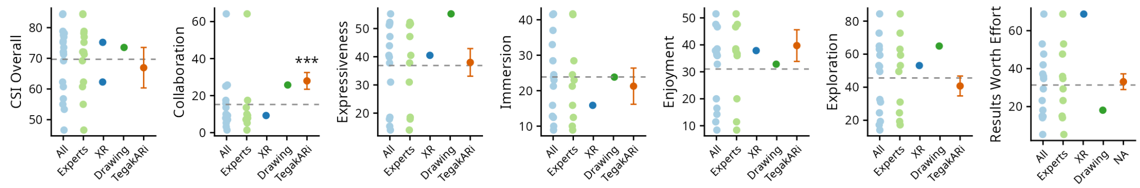


Fig. 6. Comparison of TegakARi with other related systems using the CSI overall score and the six subscales. "All" includes all other systems. The other three categories ("Experts", "XR", "Drawing") only include systems that are designed for experts, that use XR, or that are about drawing (the same system could be in multiple categories). Error bars represent 95% confidence intervals. The horizontal, dashed line represents the mean score of all related systems, excluding our own.

(1) Given that both unimodal conditions but not the multimodal condition had a positive effect on expert creativity ratings: How did audio and visual support interact with each other (e.g., support/inhibit)?
(2) Given the CSI effects:
   (a) which opportunities did participants see for collaboration?
   (b) although "enjoyment" only had a (non-significant) positive trend, what did participants enjoy about the interaction?
   (c) generally, how did they think the system supported their creativity?
(3) For insights about design/future improvements: Which technical issues did participants experience and where did they see opportunities for improvements?

We first transcribed all interviews in standard Japanese and then translated them to English, which served as the data set for an ensuing Thematic Analysis [6, 7]. Specifically, we followed a "codebook" approach [47, 48] that allowed for a combination of deductive and inductive coding. We developed a broad a priori coding template and adapted it in three iterations (see supplementary material for the template and iterations). First, two independent coders (authors 1 and 2) used the a priori template to code six of the eighteen interviews and integrated their findings in a follow-up discussion. Then they repeated this process twice with six further interviews in each iteration. This led to a preliminary final codebook based on all interviews. Next, authors 1 and 3 used this final codebook to code all eighteen interviews once more. Finally, all three coders discussed the codebook in a follow-up discussion. Based on that, we developed themes that address the guiding questions and further insights from the interviews.

Table 1. Creativity Support Index (CSI) Scores of TegakARi. M = mean, SD = standard deviation.

| Scale | Factor Count | | Factor Score | | Weighted Score | |
|---|---|---|---|---|---|---|
| | M | SD | M | SD | M | SD |
| Collaboration | 2.28 | 0.57 | 11.76 | 4.42 | 27.96 | 13.62 |
| Expressiveness | 2.61 | 0.50 | 14.39 | 4.36 | 38.00 | 14.73 |
| Immersion | 1.78 | 1.22 | 13.06 | 4.82 | 21.28 | 15.36 |
| Enjoyment | 3.00 | 0.77 | 13.18 | 4.55 | 39.73 | 17.67 |
| Exploration | 2.72 | 0.67 | 14.54 | 4.45 | 40.74 | 18.08 |
| Results Worth Effort | 2.61 | 0.61 | 12.83 | 4.16 | 33.11 | 12.44 |
| Overall | | | | | 66.94 | 19.87 |

*5.2.1 Modality-Specific Creativity Support: A Spectrum of Inspiration from Atmosphere to Detail.* Our first theme relates to how modality influences the drawing process, thus complementing the quantitative analysis of the expert ratings. Participants reported how different modalities could be useful in different ways to augment their drawing practice. All in all, the cues helped by creating certain moods for the artists to draw, as inspiration to create more atmospheric drawings, as a surprise that led the drawing in a new direction, and as a reference to draw details of an object correctly.

On one end, creative atmosphere or mood was more associated with audio cues. Such atmosphere might not have a precisely identifiable impact on the drawing, but it did influence the drawer's mood and immersion. As phrased by one participant: "*The sounds presented created a fun and scary atmosphere, which pulled me in and influenced me.*" The audio cues were perceived as helping to "*get in the mood and have fun drawing*" or being "*more pleasant than silence.*" This mood induction and higher immersion may also have contributed to the "enjoyment" of TegakARi.

Audio cues were also associated with another noteworthy effect, namely to inspire the participants to augment their drawings by including some of that "atmosphere" in it:

> "*When I was drawing the picture of a "hand", the hand ASMR* [hand touching sounds] *was presented and inspired me about the texture of the hand, and I was able to think of something with a higher resolution than what I had expected.*"

Other participants got inspired to add "*effects* [...] *to the drawing when hearing sound, for example an electric spark*", or "*when I was drawing the birds, the chirping sound played and I thought of adding it.*" These dynamic elements can be supported particularly well with audio cues, which lend themselves to represent movement and activity.

Visual cues, on the other hand, were easier to use as direct templates to draw from, thus supporting the fidelity of the drawing. Participants described these as assets to "*use directly*", or that they could "*incorporate visual ones* [cues] *directly*". This was useful to help participants recollect details about the object they were drawing:

> "*It is difficult for me to remember the details of things, especially when I try to remember them myself. When I thought about what I should draw to make it look more genuine, and I had the support of images, I was able to remember and draw it more like that.*"

Finally, some unexpected cues served as surprising inspiration. These were in part based on translation errors within our setup, which generated misunderstandings that can become culturally insensitive. One participant mentioned that "*when I said "fat uncle," a nuclear Fatboy came up* [translation error]*: I sometimes received unexpected inspiration.*" Thus, random or erroneous cues may be inspiring, but also need to be carefully curated.

In sum, we found a range of cue-based support, which helps understand how TegakARi supports creativity and joyful drawing (guiding questions 2b and c): from more atmospheric, mood-inducing support more closely associated with audio cues, to more concrete ideas and shapes supported by visual cues.

*5.2.2 Human-"AI" Collaboration: Fine Line Between Useful Inspiration and Over-support.* In reflections about the use of technical tools, specifically "AI" support tools for creativity, participants expressed concern about the loss of human touch in the drawing process. Although such tools are intriguing, the participants highlighted the joy and satisfaction connected with artistic self-expression. One participant described that "*as someone who usually creates original works, I think it is more satisfying to express my intentions and feelings when I do it myself.*" Participants also stated that they value "*drawings about my own ideas with my own hands.*" The unease expressed by the participants was not about technological support in general, but rather the extent to which these systems remove the human in the process. Some described "AI" systems as working not unlike a person drawing—drawing from memory to produce expressive outputs.

Through this lens, it is hard to separate the role of the artist and the "AI" support system. In other words, there is a tension between the useful support reported above (e.g., mood induction, support with details) and providing too much with a tool.

In contrast, participants highlighted that support as provided through the cues in TegakARi can be useful: "*when I want to draw my own ideas, I think it is better to present cues like this only.*" One participant stated that, in the end, the resulting art remains strongly dependent on the artist:

> "*I find it satisfying for me to draw a complete picture without AI [...] From the point of view of creativity, I think the process of creating something from scratch itself is fun. Also, in case of humans, instead of everyone drawing the same picture, the form of drawing changes from person to person.*"

In light of guiding question 1, there may be a fine line between the right amount of cue-support and overdoing it. Such "over-support" may explain the non-significant effect of multimodal support (as of guiding question 1), even though participants described both audio and visual support as helpful in their own ways.

A somewhat puzzling finding for us was the high CSI score on the "collaboration" dimension, given that participants drew on their own. One explanation for this could be that some participants construed TegakARi as an "AI" collaborator. However, they saw the role of "AI" more as a supportive/assistant collaborator, rather than one taking the lead (see also [64]). One participant described how they see drawing as a meaningful activity where "AI" can help but not take the main stage:

> "*Obviously, it is meaningful to draw with yourself as the main character. Drawing is meaningful in the act itself, reflecting one's subjectivity and identity. If you make it the function of a machine, it is difficult to be satisfying. I think AI is meaningful if it can act as an assistance in improving quality.*"

Another participant remarked that "AI" could be helpful in the idea conception stage but the final artifact should be drawn by the artist themselves:

> "*It would be okay to have "AI" draw the picture at the conception stage, but when I want to draw my own ideas, I think it is better to present cues like this only* [as with TegakARi, in contrast to "AI"-based systems]"

In sum, the high collaboration value of the CSI may be due to the interactive role of giving some degree of control to TegakARi (i.e., about cue selection), but not involve it too much. This way, TegakARi took an assistive role, but did not reduce the artist's autonomy.

*5.2.3 Drawing with TegakARi: Pros and Cons of the Technical Implementation.* Finally, and as of our guiding question 3, we were curious to see how well TegakARi worked on a technical level. When comparing TegakARi with a traditional computer setup, participant opinions were mixed.

Participants saw strengths of the systems in its arrangement of cues, close to the drawing in their field of view while not obstructing: "*I think AR is easier to work with. Because it is more immersive and doesn't get in the way of the creative process.*" Another benefit of TegakARi was its hands-off nature and the mobility of the system. One participant stated: "*I think the strength of AR is that you can work anywhere.*", and another: "*since AR can be used to draw in various poses, I personally would like to use it if it can be put to practical use.*"

Of course, TegakARi was also affected by existing issues of AR interfaces. Some participants were still unfamiliar with it, and therefore preferred a screen-based system. Some also reported discomfort while wearing the headset (e.g., from wearing them with glasses or because of the heavy weight). For this drawing task specifically, the lack of color fidelity was a shared concern with the visual cues. Nevertheless, several participants found the overall experience enjoyable.

## 6 DISCUSSION

This paper introduced TegakARi, a cue-based AR Creativity Support System (CSS). We tested how TegakARi can support creativity and exploration of experienced drawers. Specifically, we studied how multimodal cues affect creativity (RQ1), and how experienced drawers appropriate TegakARi in their drawing practices (RQ2). Although the system could provide both audio and visual cues to support the creative process, we only found that unimodal (audio *or* video) cues led to more creative drawings, as rated by an external expert. Multimodal support did not significantly increase creativity of the drawings, which may be due to a perceived over-support when providing too many cues. The drawers' subjective assessment of our system's creativity support positions it within the overall average of CSS in the literature, with above-average potential for collaboration support. This effect on collaboration support despite the single-user setting may in part be explained by a perceived collaboration with the system—in which case TegakARi's assistive support was seen as more favourable than a more sophisticated "AI"-system that "takes the lead". As far as specific effects of different modalities are concerned, audio cues tended to provide more indirect creativity support, immersing drawers in a creative mood and inspiring them to include more atmospheric elements in their drawings. Conversely, visual cues tended to help "get the details right" for specific objects. Finally, participants reflected on preserving the "human touch" in their drawings and valued drawing as a practice of self-expression, rather than only focusing on the outcome. Overall, we found that TegakARi can successfully support creativity, but we also see several ways to further enhance the support from the system. In the following, we suggest four distinct ways forward as opportunities for future systems designs.

### 6.1 Designing for Augmented Creativity

The study illustrated how TegakARi supports creative drawing practices—although not as initially envisioned. Here, we position TegakARi as a stepping stone for future AR-based systems, and reflect on how it could be extended. As we found a stronger effect of unimodal support on creativity compared with multimodal support, we focus on each modality separately. Further, we speculate on how AR can be used for "removing" unimodal sensory input—or help being more present in the moment. These directions are described using four future CSS using AR, and exemplified using illustrative design sketches. This methodological approach is inspired by scenario-based design for HCI [27] and used in research work in HCI [38, 43, 63]. The sketches are not intended to describe clear and implementable design suggestions, but rather to serve as a stronger grounding for discussions on what future systems could be: as a form of design-driven discussion.

In discussion with participants, it was clear how audio and images often inspire at very different frequencies. Additionally, building on the need for systems to not over-support users, we believe that audio-based CSS offer a promising path forward—one where the system can set a context-specific atmosphere, to even '*strengthen the imagination*' of users. Our audio-only proposal **AmbientInspo** in Figure 7 would rely on simple sensor reading, such as a camera feed and voice cues from the user.. The system would pull from descriptions of the cue and create a collage of sounds to set the atmosphere and sonically depict details of the scene: patching together inspiring soundscapes. In creative practices like drawing, visual augmentation can compete for attention, whereas audio can complement the process more freely. While audio AR got much attention in earlier research in HCI, such as around museum guides and direction-specific audio cues[71, 80], and still gets researched to some extent [3, 35, 49], it is a modality that is much overlooked compared

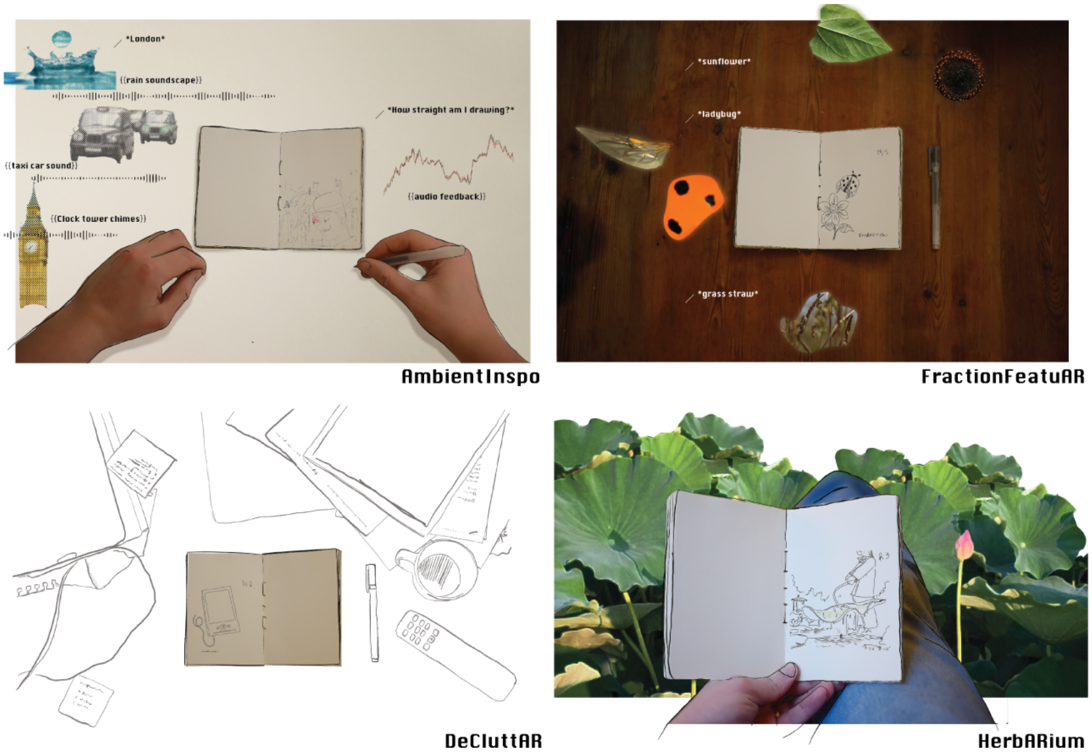


Fig. 7. Four design suggestions for augmented creativity. AmbientInspo: audio only system for sketching. FractionFeatuAR: a system that provides decontextualized details for supporting drawing ideation. HerbARium: a mobile AR moodboarding system implemented on a wearable AR headset.

with the research around visual augmentation. We encourage the collection of larger free audio cue datasets for future research.

On a similar token, we saw that the most common use of visual cues was to use the images as a way of recalling elements of detail, where the creative vision is limited by "hazy memory". In line with the unease of removing the human touch from the drawing practice, and with full images easily overtaking the imagined shape and form of the drawing (leading to only copying rather than inspiration), we suggest a future system that solely focuses on specific details, not whole images. We call these systems high-pass inspiration. Our suggested system in Figure 7 works similarly to the system in use in the pilot exploration: through the use of speech cues, it presents images to the user in near proximity to the drawing. However, **FractionFeatuAR** uses a combination of image generation, object identification, and cropping to present only small sections of the whole. Expanding the notion of high-pass inspiration, we see how systems such as these could prove useful in other creative settings as well. Many creative processes face the same challenge, where the subjective, creative process competes with suggestions from "AI" systems that are far too complete to only serve as a vague pointer of direction. Where inspiration was previously limited by the context and depiction of other artists (such as the perspective of a photo or the material properties of a sketch), generative systems can be nearly endlessly tweaked to seemingly "match" the "preexisting vision" of the creator—although the underlying cognitive processes are more fragile and indefinite, and tend to be influenced by such external cues (e.g.,[17]). We see the need for a new form of creative influence: one where only details, not full images, support the art of creating in a less intrusive way. As a promising side effect, such taking-out-of-context of visual elements may induce productive ambiguity [28].

Further, our study suggests that an over-saturation of sensory information may hinder creativity, even though the tidy lab setting already minimized visual clutter. More specifically, our participants described the system already as "immersive" in that it lets the user focus on the art. Taking this further, if we understand AR not solely as a way to add elements, using it to occlude existing visual and audio elements extends the XR design space. This could be done using phantom objects [63] or visual camouflage of distractions [36]. Going further than simply not providing multimodal stimulation, a future AR system could instead ease the user's focus by occluding existing stimulation of the user, even beyond current on-device approaches such as focused writing apps. For example, **DeCluttAR** would couple visual stimulation with auditory noise-cancelling technologies. Conversely, it could overlay possibly distracting visual cues with "white noise" or visual noise cancelling [40, 65]. Our sketch in Figure 7 illustrates this as a system that fades out all information except the drawing surface—leaving the user with only an empty white void. Systems such as this do not necessarily need to block either nothing or all visual clutter. We could imagine future work with modifications such as optical illusions (e.g., to alter the perception of the surface the user draws on [50, 57]), slight alterations of "real" objects (e.g., showing a smartphone on the table but hiding its notifications), or highlighting only one or two objects on the table while visually overlaying the rest.

Lastly, we found that moving the inspiration from the current standard of a screen to a wearable device unlocked new ways of bringing the technology away from the desk, supporting other styles of drawing. Several participants described the system as promising in how it could work anywhere or in any posture. We suggest further exploring how AR systems could not only open up these interactions but also how a system such as TegakARi could benefit from being used in new settings. In this design suggestion in Figure 7, which we call **HerbARium**, we imagine the user with a head-mounted AR system on the go to sample surrounding inspirational elements. This vaguely borrows from sampling practices in biology, with the artist as a collector of "rare species" to catalogue in their (virtual) archive. Another metaphor would be "mood boards" used in design, or more broadly, collections and combinations of material into an aesthetically interesting mix. HerbARium could support such collections of (visual or audio) samples and help experienced drawers cross-contextualize them in a targeted way. They could catalogue immersive, rich experiences and revive them later while drawing in the comfort of their home. Alternatively, they could mix and match elements between their catalog and current surroundings, such as adding flowers to a lake of lotuses as in the image, and akin to mood-boards sharing these experiences with friends and colleagues. Further exploration would thus be needed to assemble the felt experience and whether sharing these experiences could support the sharing of ambiance and inspiration.

### 6.2 Limitations

The study setup and procedure led to various technical and practical challenges, which resulted, altogether, in a gender-unbalanced and relatively small sample. On the one hand, we had explicitly looked for experienced drawers, which reduced the pool and may have led to a higher percentage of female participants (representing 3 out of 4 art students in Japan[11]). On the other hand, the in-person setting, high-maintenance prototype with limited hardware availability, and expert-based creativity rating implied time-consuming and expensive testing, which we plan to optimize in future

[11] https://www.japantimes.co.jp/news/2021/12/10/national/professors-judges-japan-male/

studies. An implication of this is a relatively low test power, which means that findings about insignificant differences remain somewhat inconclusive.

We also faced a few further technical challenges throughout the study. As mentioned earlier, we translated the utterances from Japanese to English, to improve the quality of the results. However, this also led to a few mistranslations, including a potentially problematic one that led to the presentation of a nuclear bomb cue, out of context. Our system relied on external APIs in this proof-of-concept stage, so we had limited control over the cue quality and cultural implications. Future systems should mitigate such potentially negative side effects, for example through curated databases.

Finally, our literature search for CSS evaluated with the CSI led to only 19 comparable reports out of the corpus of 101 systems. Although this gives us a good first clue how TegakARi compares with other CSS overall, we initially intended to run more detailed comparisons with comparable systems that specifically either support domain experts, drawing, or use some form of XR. However, we found relatively poor reporting of results in the majority of CSI-evaluated systems in the literature. Several papers omitted the collaboration scale, a practice addressed and explicitly advised against by the original authors [12]. Other papers did not apply the weighting transformation, or the authors did not report the CSI scores at all. Thus, although the CSI can be useful as a comparative evaluation method, such work would profit from better data sharing.

## 7 CONCLUSION

How can technology be used not only to produce beautiful artwork but also to enhance the creative and artistic process of drawing? Our study about TegakARi, a cue-based AR Creativity Support System for experienced drawers, indicated a tension between cue-based stimulation, modality-specific strengths and weaknesses to support creativity, and subjective experiences of the creative process. We found that unimodal but not multimodal cues significantly increased creativity as rated by experts. In addition, audio cues tended to induce a more intangible creative mood or atmosphere, whereas visual cues helped drawers "get the details right". Thus, the right level of creativity support, coupled with carefully selected modality and cue curation, can help produce satisfying experiences and creative outcomes for experts in their artistic practice. Our four design sketches open up a future design space for expert Creativity Support Systems, focused on exploration and self-expression, and tensions between the different approaches. In that sense, whether the drawings themselves represent valuable examples of "artistic outcomes" or not—TegakARi exemplifies one approach to support drawing as a valuable activity, which creates meaningful experiences for the drawers.

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Table 2. Overview of papers included in the CSI comparative analysis and our categorization.

| Reference | Title | Supports Drawing? | Uses XR? | For Experts? |
|---|---|---|---|---|
| [1] | InspirationWall: Supporting Idea Generation Through Automatic Information Exploration | no | no | no |
| [4] | HowDIY: Towards Meta-Design Tools to Support Anyone to 3D Print Anywhere | no | no | yes |
| [21] | Compressables: A Haptic Prototyping Toolkit for Wearable Compression-based Interfaces | no | no | yes |
| [32] | I Smell Creativity: Exploring the Effects of Olfactory and Auditory Cues to Support Creative Writing Tasks | no | no | no |
| [33] | What Shall I Write Next?: Subliminal and Supraliminal Priming as Triggers for Creative Writing | no | no | no |
| [34] | Creative and Progressive Interior Color Design with Eye-tracked User Preference | no | no | yes |
| [37] | Audio and Text Conditioned Abstract Sound Synthesis through Human-AI Interaction | no | no | yes |
| [51] | Assessing a Collaborative Application for Comic Strips Composition | no | no | no |
| [52] | Anisma: A prototyping toolkit to explore haptic skin deformation applications using shape-memory alloys | no | no | yes |
| [55] | XRtic: A Prototyping Toolkit for XR Applications using Cloth Deformation | no | yes | yes |
| [56] | Manipulating Puppets in VR | no | yes | yes |
| [58] | Exergy: A Toolkit to Simplify Creative Applications of Wind Energy Harvesting | yes | no | no |
| [66] | AI-Assisted Design Concept Exploration Through Character Space Construction | no | no | yes |
| [67] | CharacterChat: Supporting the Creation of Fictional Characters through Conversation and Progressive Manifestation with a Chatbot | no | no | yes |
| [70] | Playsound.space: Improvising in the browser with semantic sound objects | no | no | yes |
| [72] | Supporting Creativity through the Interactive Exploratory Search Paradigm | no | no | yes |
| [74] | Phosphenes: Crafting Resistive Heaters within Thermoreactive Composites | no | no | yes |
| [75] | An ubiquitous smart guitar system for collaborative musical practice | no | no | yes |
| [79] | Interactive exploration-exploitation balancing for generative melody composition | no | no | yes |