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Possibilities and Limitations of Experiential Learning: Complementarity of Experimental Research and Design Practice in Color Vision Diversity Education

(Kemungkinan dan Batasan Pembelajaran Berasaskan Pengalaman: Saling Melengkapi antara Penyelidikan Eksperimen dan Amalan Reka Bentuk dalam Pendidikan Kepelbagaian Penglihatan Warna)

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ABSTRACT

This case study examines the possibilities and limitations of experiential learning in color vision diversity education. We conducted an experimental study using a game-based educational tool and developed an exhibition piece "Parallel Marchés" based on the findings. The experiment (N=40) compared experiential and control groups on comprehension tests and subjective evaluations. No significant differences were found in test scores (immediate: t(38)=0.43, p=.671; follow-up: t(30)=-0.16, p=.873). In subjective evaluations, three items related to self-efficacy showed a tendency toward lower self-ratings in the experiential group (not statistically significant). Exploratory analysis of free descriptions revealed more introspective responses in the experiential group, suggesting awareness of knowledge limitations. The exhibition was designed to create situations where information accessibility advantages reverse depending on information design, allowing visitors to experience how design choices determine who benefits. This study suggests that introspective changes not captured by comprehension tests may be observable in exhibition practice, indicating that experimental research and design practice may complementarily capture different dimensions of learning.

Keywords: Experiential Learning, Color Vision Diversity, Universal Design Education, Design Practice, Case Study

ABSTRAK

Kajian kes ini mengkaji kemungkinan dan batasan pembelajaran berasaskan pengalaman dalam pendidikan kepelbagaian penglihatan warna. Kami menjalankan kajian eksperimen menggunakan alat pendidikan berasaskan permainan dan membangunkan karya pameran "Parallel Marchés" berdasarkan penemuan tersebut. Eksperimen (N=40) membandingkan kumpulan pengalaman dan kumpulan kawalan melalui ujian kefahaman dan penilaian subjektif. Tiada perbezaan signifikan ditemui dalam skor ujian (segera: t(38)=0.43, p=.671; susulan: t(30)=-0.16, p=.873). Dalam penilaian subjektif, tiga item berkaitan efikasi kendiri menunjukkan kecenderungan penilaian kendiri yang lebih rendah dalam kumpulan pengalaman (tidak signifikan secara statistik). Analisis penerokaan deskripsi bebas mendedahkan lebih banyak respons introspektif dalam kumpulan pengalaman, mencadangkan kesedaran tentang batasan pengetahuan. Pameran ini direka untuk mewujudkan situasi di mana kelebihan kebolehcapaian maklumat bertukar bergantung pada reka bentuk maklumat, membolehkan pelawat mengalami bagaimana pilihan reka bentuk menentukan siapa yang mendapat manfaat. Kajian ini mencadangkan bahawa perubahan introspektif yang tidak dapat ditangkap oleh ujian kefahaman mungkin dapat diperhatikan dalam amalan pameran, menunjukkan bahawa penyelidikan eksperimen dan amalan reka bentuk boleh saling melengkapi dalam menangkap dimensi pembelajaran yang berbeza.

Kata Kunci: Pembelajaran Berasaskan Pengalaman, Kepelbagaian Penglihatan Warna, Pendidikan Reka Bentuk Universal, Amalan Reka Bentuk, Kajian Kes

INTRODUCTION

Color Vision Diversity refers to the fact that color perception varies among individuals. While medical literature often uses the term Color Vision Deficiency (CVD), this study adopts "Diversity" to emphasize the perspective of diversity. In Japan, approximately 5% of males and 0.2% of females have what is termed "color vision characteristics" (Japanese Ophthalmological Society, 2024). With growing interest in diversity, the importance of education promoting understanding of this diversity has been recognized.

However, color vision diversity is a topic prone to superficial understanding. Simply knowing that "some people have difficulty distinguishing red from green" can create a false sense of comprehension. Understanding of what actual difficulties arise and what accommodations are effective tends to remain superficial.

To address this challenge, experiential approaches where learners directly encounter altered visual conditions through games and structured activities have been attempted. Such approaches are expected to lead to deeper understanding than passive instruction alone. However, the extent to which experiential learning produces measurable learning outcomes, and what constitutes "deepened understanding" in this context, remain unclear. In particular, whether experiential learning promotes qualitative cognitive changes such as awareness of one's own knowledge limitations that are not captured by conventional assessment methods has received little attention.

This study examines the possibilities and limitations of experiential learning using color vision diversity education as a case study. Specifically, we describe an experimental study using game-based educational materials and the subsequent creation of the exhibition piece "Parallel Marchés" as an integrated case study.

BACKGROUND OF THE STUDY

Experiential Learning and Color Vision Diversity Education

Experiential learning, as theorized by Kolb (1984), is a process whereby knowledge is created through the transformation of experience. Kolb's experiential learning cycle comprises four stages: concrete experience, reflective observation, abstract conceptualization, and active experimentation. This cyclical model, building on the philosophical foundations of Dewey (1938) who argued that genuine education comes through experience, emphasizes that learning is not merely the acquisition of information but an active process of meaning-making through direct engagement with phenomena. This stands in contrast to traditional instructional approaches such as lectures, reading materials, and guideline-based learning where learners receive information passively and are expected to apply it.

Experiential Learning has garnered attention as an approach emphasizing meaning-making through learners' own experiences (Kolb, 1984). In color vision diversity education, experiential approaches using altered visual conditions have been reported. However, evaluating how insights from experience become established as understanding is challenging, and concerns have been raised that experiences may remain at the level of superficial empathy.

Theoretical Frameworks for Analyzing Experiential Learning

When considering the effects of experiential learning, how we conceptualize "understanding" becomes crucial. In educational psychology, models describing learning progression as "stages of competence" (Broadwell, 1969; Burch, cited in Adams, 2004) have been referenced. The transition from "unconscious incompetence" to "conscious incompetence" that is, realizing "I do not yet fully understand" is considered an important turning point in learning.

Related to this, Rozenblit and Keil (2002) identified the "illusion of explanatory depth." People tend to overestimate their understanding, only recognizing its superficiality when asked to explain in detail. Experiential learning may provide situations in which learners become aware of such illusions, prompting a shift toward conscious incompetence. Furthermore, Mezirow's (1991) transformative learning theory provides a framework for understanding how such cognitive disruptions can lead to meaningful learning. Mezirow argues that "disorienting dilemmas" experiences that challenge existing frames of reference can trigger critical reflection and perspective transformation. The self-efficacy disruption observed in experiential learning may represent such a disorienting dilemma.

Connecting these frameworks to Kolb's (1984) experiential learning cycle, the present study examines how each stage manifests in color vision diversity education: concrete experience (the fishing game with color transformation), reflective observation

(subjective evaluation and free description), abstract conceptualization (comprehension tests measuring knowledge organization), and active experimentation (the exhibition "Parallel Marchés" as an extended application context). Finally, cognitive load theory (Sweller, 1988) and principles of multimedia learning (Mayer, 2009) provide important perspectives for examining why experiential learning may not always produce expected outcomes. When information presented during learning is excessive or unstructured, working memory capacity becomes strained, reducing learning efficiency. In experiential content, where multiple elements (game mechanics, visual transformation, decision tasks) are presented simultaneously, cognitive load management becomes a critical design challenge.

RESEARCH QUESTIONS

The central problem motivating this research is the disconnect between the promise of experiential learning and the ability to evaluate its effects. In color vision diversity education, experiential approaches are increasingly adopted based on the assumption that direct experience promotes deeper understanding. However, the learning effects of such approaches have primarily been evaluated through knowledge-based assessments, which may fail to capture qualitative cognitive changes such as shifts in self-perception of understanding. Furthermore, the relationship between controlled experimental research and open-ended design practice in evaluating experiential learning remains underexplored. This study addresses the following questions:

i. Does experiential learning enhance comprehension compared to reading materials alone?
ii. Does experiential learning produce qualitative changes not measurable by tests?
iii. How can experimental research and design practice complement each other's limitations?

ANALYTICAL FRAMEWORK

Part 1: Experimental Study Using Game-Based Educational Materials

Educational Material Design**:** To promote understanding of color vision diversity, we created a fishing game combining physical manipulation of actual fish and fishing rods with visual transformation processing of camera images. The game format was adopted because operations are intuitive, relationships between decisions and outcomes provide immediate feedback, and conditions can be easily controlled for experimental purposes.

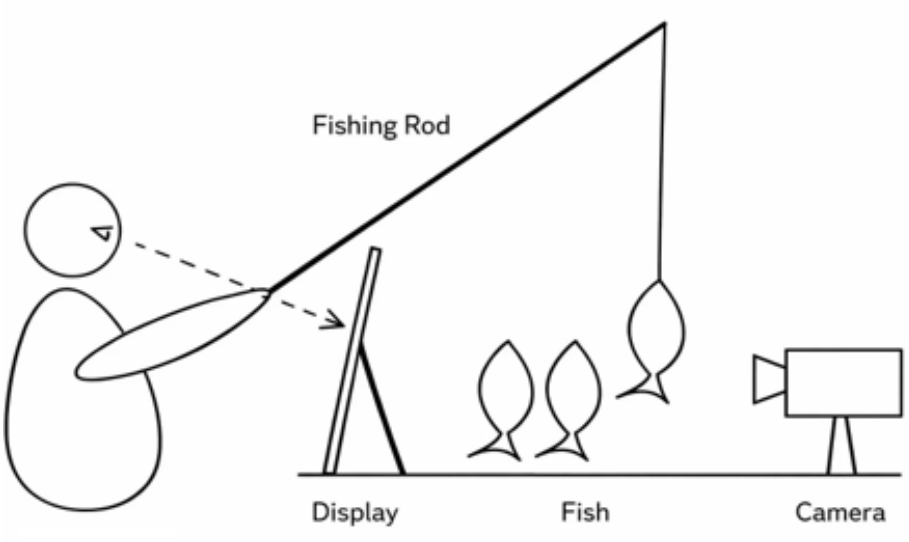

FIGURE 1. System configuration of the fishing game educational material. Participants operate the fishing rod while viewing camera images on the display to catch actual fish.

In this educational material, participants use a fishing rod to catch actual fish created with a 3D printer with unified shape and size. Participants operate while viewing camera images presented on a monitor, with color vision transformation matrices applied to the displayed images (RGB) frame by frame. Lighting, camera placement, display equipment, and operation procedures were unified across both conditions, with video processing varying only in whether the color transformation matrix was applied (transformation condition / no-transformation condition).

The color transformation referenced Brettel et al.'s (1997) LMS color space transformation model as theoretical background, while implementation used Machado et al.'s (2009) RGB transformation matrices for approximation. This enabled approximate reproduction of how colors appear under Protanopia (type 1 dichromacy, L-cone deficiency), Deuteranopia (type 2 dichromacy, M-cone deficiency), and Tritanopia (type 3 dichromacy, S-cone deficiency). Additionally, fish were given not only colors but also patterns (dots, borders, waves, etc.), designed to enable participants to experience the potential usefulness of "visual cues not relying solely on color."

FIGURE 2. Variations of 3D-printed fish. Shape and size are unified while varying colors (yellow, purple, red, green, orange, brown) and patterns (dots, borders, waves, etc.).

FIGURE 3. Scenes from using the fishing game educational material (sequential photos showing the flow of experience). Left: Participant operating fishing rod while viewing monitor. Center top: Overall view from side. Right top: Scene of hooking a fish. Center bottom: During catching (half of fish shows color vision transformed image, half shows actual color). Right bottom: Scene after fully catching (actual color visible).

Experimental Method: Participants were 40 university students (all self-identified as having typical color vision; no color vision testing was conducted). This study examines learning effects in typical color vision individuals, not the accuracy of reproducing color vision characteristics. Participants were randomly assigned to control group (n=20) or experiential group (n=20).

Procedure: (1) Reading materials on color vision diversity and color universal design (both groups, approximately 5 minutes), (2) Fishing game experience (experiential group only, approximately 10 minutes), (3) Comprehension test (immediate), (4) Subjective evaluation questionnaire and free description, (5) Follow-up test (2 weeks later).

Evaluation Measures: Comprehension test (100

points total, 10 questions, 10 points each; consisting of knowledge questions about how colors appear for each color vision type and application questions judging appropriateness of color schemes), subjective evaluation questionnaire (12 common items on 5-point Likert scale, 3 free description questions: memorable aspects, new insights, future application intentions), exploratory textual analysis of free descriptions.

TABLE 1. Comprehension Test Results

	Control	Experiential	t	p
Immediate	64.00 (11.42) n=20	62.50 (10.70) n=20	0.43	.671
Follow-up	67.06 (15.72) n=17	68.00 (17.40) n=15	-0.16	.873

Note: Standard deviations in parentheses. Due to non-responses in follow-up test, degrees of freedom are reduced (t(30)).

Results: No significant differences were found between groups on comprehension tests (Table 1). Both groups showed an upward trend in scores from immediate to follow-up tests, but attrition bias should be noted (experiential group 25% attrition, control group 15% attrition). Attrition was higher in the experiential group and may have been biased toward participants with lower immediate test scores, potentially skewing follow-up results favorably toward the experiential group.

In subjective evaluations (control group n=20, experiential group n=20), no significant differences were found across all 12 items. The following analysis did not apply multiple comparison corrections and is positioned as exploratory analysis. For three items related to self-efficacy, the experiential group's means were lower than the control group. Meanwhile, for "want to contribute to creating inclusive environments," the experiential group showed a higher tendency (Table 2).

TABLE 2. Subjective Evaluation Results (Excerpt)

Item	Control	Experiential	t	p
I understand correctly	2.65 (0.93)	2.30 (1.03)	1.13	.267
Confident in explaining	2.60 (0.94)	2.15 (0.81)	1.62	.114
Confident in creating materials	2.85 (1.04)	2.60 (0.94)	0.80	.430
Want to contribute to inclusion	3.65 (1.14)	4.10 (0.79)	-1.45	.154

Note: Standard deviations in parentheses. 5-point Likert scale (1-5). df=38. No significant differences on any item.

For free description analysis, we conducted an exploratory textual analysis, including word frequency comparison and TF-IDF-based feature extraction. Preprocessing involved removing punctuation and stop words, with noun extraction via MeCab morphological analysis. This analysis is positioned as exploratory analysis to visualize differences in focus between groups, not for statistical testing. TF-IDF analysis extracted "experience," "impression," and "seeing" as feature words for the experiential group, while the control group showed concrete color names from materials such as "red," "black," and "color scheme."

In the control group, responses centered on facts from materials, with abstract expressions regarding future application (e.g., "I want to be mindful of color schemes that accommodate people with color vision deficiency," "I'll be careful during presentations"). In the experiential group, introspective insights were frequent (e.g., "It was a good opportunity to actually consider things from the perspective of someone with color vision characteristics," "I realized my understanding was superficial"). The experiential

group also showed references to specific design techniques (e.g., "distinguish using not just color but brightness differences and patterns"). Emotionally, stronger expressions like "surprise" and "shock" were more common in the experiential group.

Part 2: Design Practice "Parallel Marchés"

Design Challenges from Experiment**:** The experimental results suggested that experience may change learners' cognition while also revealing that such changes cannot be fully captured within experimental measurement frameworks. The experimental framework had the following limitations: (1) Artificiality of controlled environment participants understood the learning purpose beforehand, creating different context from serendipitous awareness in daily life, (2) Dependence on measurability introspective changes are difficult to reflect in scores, (3) Lack of social context dialogue and comparison with others are unlikely to occur.

Therefore, this case study selected exhibition as an open design practice, a different framework not aimed at measurement. Exhibition formats can provide venues where visitors encounter works without learning purposes and make meaning through serendipitous insights and dialogue with others. These characteristics correspond to the three limitations identified in the experiment. We expected that the "wavering of self-efficacy" observed in the experiment awareness of insufficient understanding would be externalized as dialogue with others in the exhibition.

Design and Implementation**:** The reason for choosing "marché (market)" was to show that information accessibility issues arise within everyday choice-making. Markets contain information directly relevant to decisions such as price tags, expiration dates, and allergy information choices cannot be made without access to information. Additionally, markets are spaces shared with others where social dialogue readily occurs.

We designed two stalls: "Everyday Marché" with information design optimized for naked-eye viewing, and "Parallel Marché" with information design optimized for viewing with Parallel Glasses. These two were positioned as structural contrast showing how advantages and disadvantages can change depending on information design, not as "good/bad." Everyday Marché is easier to see with naked eyes, while Parallel Marché becomes easier to see when wearing Parallel Glasses. Through this reversal, visitors experience that "who finds it easy to use" changes depending on information design assumptions.

Parallel Glasses are self-made glasses with red and polarizing filters attached to commercially available non-prescription frames. This work's purpose is not to medically reproduce perception of specific color vision types, but to temporarily create a state where access to hue information is restricted, enabling visitors to experience structural differences in information design who is advantaged and who is disadvantaged.

Furthermore, polarizing filters were attached to price tags, creating a mechanism where different numbers are visible with naked eyes versus when wearing glasses. For example, a price tag that appears as "¥6400" with naked eyes appears as "¥640" through the glasses. This enables visitors to experience situations where not only is something "hard to see," but the accessible information itself differs.

The stalls used in the exhibition adopt a mobile structure. The stalls are designed to fit in standard elevators, intended to be taken not only to university exhibition spaces but also to educational settings and public spaces. This portability positions the work not as a fixed exhibition piece but as a device whose experiential meaning can change according to different contexts.

FIGURE 4. Two stalls of the exhibition piece "Parallel Marchés". Left: Everyday Marché (optimized for naked-eye viewing). Right: Parallel Marché (optimized for viewing with Parallel Glasses).

FIGURE 5. How Everyday Marché appears. Left: With naked eyes, price (¥640) and expiration date are clearly readable. Right: With Parallel Glasses, this information becomes difficult to read.

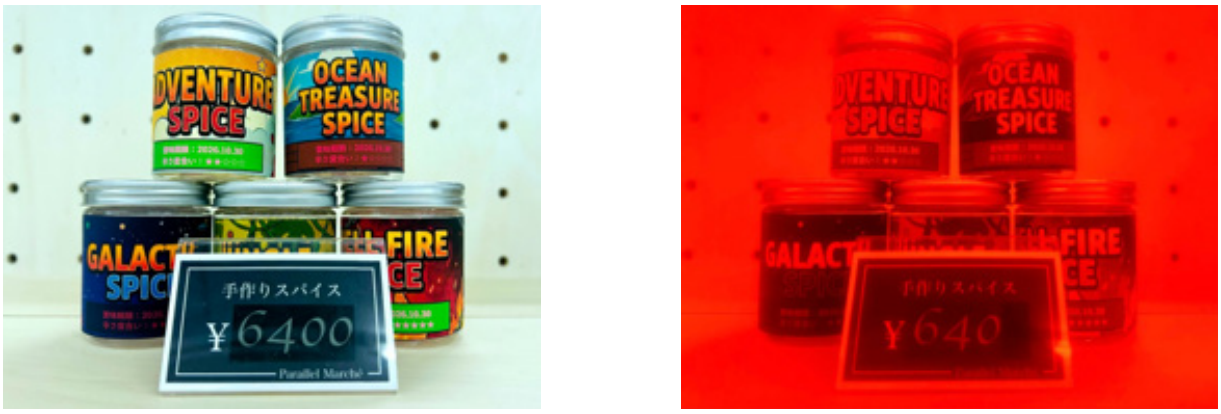

FIGURE 6. How Parallel Marché appears. Left: With naked eyes, price appears as "¥6400". Right: With Parallel Glasses, price (¥640) becomes readable and expiration date becomes easier to see.

Exhibition and Feedback**:** Exhibited on December 18, 2025, at the University of Tsukuba Design Department Graduation Exhibition. Participants included 29 presenting students, 12 faculty members, and dozens of visiting current students. The following description is positioned as design reflection rather than research based on systematic data collection. Observation was conducted by the creator (first author), with visitor behaviors and verbal comments recorded as notes.

Observed behaviors: Repeatedly putting on and taking off glasses to confirm visual changes, moving back and forth between the two stalls to compare differences, dialogue with companions ("Can you read this?" "This one is easier to see," etc.).

Feedback received: Instructions prompting experiential behavior (e.g., "Please select ingredients for curry") make it easier to act; insufficient explanation of premises makes the significance of Parallel Marché (reversal of advantages/disadvantages) difficult to convey.

RESEARCH IMPLICATIONS AND RECOMMENDATIONS

Interpretation of Experimental Results: Possible factors for no differences in comprehension test scores include the following. First, cognitive load issues. In experiential content, multiple elements (color transformation, game operation, decision tasks) were presented simultaneously. According to Sweller's (1988) cognitive load theory, this information overload may have strained working memory, leaving little room for organizing knowledge. Second, evaluation format issues. Comprehension tests measure "retention of correct knowledge" and are a format where qualitative cognitive changes through experience are difficult to reflect.

Meanwhile, the tendency for lower self-efficacy in the experiential group can be interpreted as transition to "conscious incompetence." Through experience, participants may have realized their understanding was superficial, making it harder

FIGURE 7. Exhibition scenes. Left: Visitor picking up Parallel Glasses. Center: Visitor examining products while wearing glasses. Right: Multiple visitors experiencing the stalls.

to feel they "fully understand." The statement "I realized my understanding was superficial" found in free descriptions is consistent with this interpretation. However, decreased self-efficacy does not necessarily lead directly to learning promotion, and the possibility of negative effects such as confusion or anxiety cannot be denied. This study interprets this change only as one stage in the learning process, and these differences are treated as tendencies since they are not statistically significant.

Complementarity of Experiment and Design Practice**:** Experimental research serves to reveal one aspect of learning through measurable indicators. Exhibition practice, on the other hand, serves to make visible insights, dialogue, and opportunities for introspection that are difficult to measure. The two are not in opposition but capture learning in different dimensions.

In the exhibition "Parallel Marchés," visitors were observed encountering the work without learning purposes, feeling discomfort or surprise, and making meaning through dialogue with others. These are serendipity and social interactions unlikely to occur in experiments.

Educational Implications**:** For topics like color vision diversity where superficial understanding is easy, recognizing the insufficiency of one's understanding itself holds important meaning rather than improving understanding. Experiential learning may provide situations in which learners become aware of the "illusion of explanatory depth" identified by Rozenblit & Keil (2002).

Practices like "Parallel Marchés" are characterized by creating "situations confronting questions" rather than providing "correct answers," and are applicable to education addressing diversity and accessibility in general.

For future educational material design, the following directions are suggested: (1) Cognitive load management designs that narrow experiential elements and present them progressively, (2) Support for introspection incorporating opportunities to consider "why it appeared that way" after experiences, (3) Integration of experience and knowledge structuring clear correspondences between text information and visual experiences.

Limitations**:** Limitations of this study include: limited experimental sample size (N=40), no effect size estimation, participant color vision based on self-report without color vision testing, attrition in follow-up tests potentially biasing results as the experiential group (25%) was higher than control group (15%), no multiple comparison correction in subjective evaluation analysis, exhibition observations obtained in a specific context (graduation exhibition), and inability to verify long-term attitude and behavior changes.

CONCLUSION

This study examined the possibilities and limitations of experiential learning in color vision diversity education, addressing experimental research and exhibition-based design practice as an integrated process. Three key findings emerged: (1) no significant differences were found between experiential and control groups on comprehension tests, suggesting that experiential learning did not directly enhance knowledge retention within this study’s framework; (2) the experiential group showed tendencies toward lower self-efficacy and more introspective free descriptions,

indicating qualitative cognitive changes not captured by conventional assessment; and (3) exhibition practice revealed dimensions of learning including serendipitous awareness and social dialogue that are unlikely to occur in controlled experimental settings. The following insights were obtained for the three research questions presented.

For the first question (comprehension enhancement through experiential learning), within this study's framework, no between-group differences were detected in comprehension tests (immediate: $t(38)=0.43$, $p=.671$; follow-up: $t(30)=-0.16$, $p=.873$). However, responses suggesting disruption of the self-perception of "thinking I understood" tendencies toward decreased self-efficacy and introspective free descriptions were observed.

For the second question (qualitative changes not captured by measurement), introspective insights such as "I realized my understanding was superficial" and references to specific design techniques such as "distinguish using brightness differences and patterns" were confirmed in the experiential group. Therefore, this study positioned this not simply as "no effect" but as an opportunity to reconsider the scope of measurement indicators.

For the third question (complementarity of experiment and design practice), we responded through the creation and exhibition of "Parallel Marchés." In the exhibition, aspects of learning unlikely to occur in experiments, such as serendipity and dialogue with others, were observed.

This case study suggests the possibility that experimental research and design practice can be in a complementary relationship. By recognizing each approach's limitations and connecting them, we believe it becomes possible to capture the value of experiential learning multidimensionally. We hope this serves as an example demonstrating the possibility of connecting experiment and practice in design research.

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