

Paper Vision Town: Designing an Interactive System to Experience Color-Vision Diversity and Color Universal Design

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ABSTRACT

Understanding the diversity of human color vision is essential for creating inclusive environments and products; however, opportunities for non-experts to experientially understand color-vision differences remain limited, making it difficult to apply color universal design (CUD) in practice. To address this issue, this study proposes PaperVision Town, an experiential learning system that enables intuitive understanding of color-vision diversity through hands-on exploration. The system consists of a paper-based city environment with two versions: one for typical color vision and another simulating deuteranopia, with identical layouts but differing visual representations of signs, maps, and information. Participants complete tasks using theme cards, allowing them to compare experiences between the two environments and observe how color-vision differences affect visibility, recognition, and usability. Through this process, participants gain awareness of challenges faced by individuals with color-vision deficiencies and the effectiveness of CUD strategies such as luminance contrast and redundant visual cues. Emphasizing experiential learning over abstract explanation, the system encourages reflection and empathy, and can be applied in educational and design training contexts. This study contributes to applied human factors and ergonomics by demonstrating that hands-on comparative experiences are effective in promoting awareness and practical application of inclusive design principles.

Keywords: Color universal design (CUD), Education

INTRODUCTION

Human color vision exhibits substantial individual variability. Differences in spectral sensitivity and neural processing produce a wide range of color-perception experiences that affect how people recognize information, make decisions, and interact with their environments. In Japan, approximately 5% of men and 0.2% of women have some form of color-vision deficiency, indicating that color-vision diversity is not a marginal issue but one that affects a significant portion of the population. Consequently, perceptual differences in color vision influence safety, usability, and accessibility in everyday contexts, including public signage, transportation systems, consumer products, and digital interfaces.

Color Universal Design (CUD) has been proposed as a systematic approach to mitigate communication failures caused by color differences and to ensure that visual information is understandable to a broad range

of users. In Japan, the CUD has been actively promoted through guidelines, certification systems, and educational materials, particularly in the design of public infrastructure and information displays. Although these initiatives have contributed to increased awareness and institutional adoption, many designers and non-experts still lack an experiential understanding of how color-vision diversity manifests in real-world tasks.

It is often difficult for individuals with typical color vision to clearly imagine how visual information appears to people with different color-vision characteristics. This gap between conceptual knowledge and perceptual experience can hinder the effective application of CUD principles in everyday design practice. Designers may understand the recommended rules in theory but fail to anticipate how specific design choices—such as subtle hue differences or insufficient luminance contrast—can affect information recognition and task performance.

From an applied human-factor perspective, presenting human characteristics merely as abstract knowledge is insufficient. Instead, these characteristics should be operationalized as design constraints and interaction scenarios that support understanding, empathy, and informed decision-making through human–system interactions.



Figure 1: Paper vision town.

RELATED WORK AND POSITIONING

Research on color-vision diversity has accumulated over the years, focusing on the physiological mechanisms of vision, classification of color-vision types, and perceptual effects on color discrimination and visibility. These findings have provided practical design strategies, such as maximizing the luminance contrast, avoiding problematic color pairings, and incorporating redundant non-color cues.

Color-vision simulation tools are useful for previewing how designs appear under specific conditions. Still, they often present static representations removed from task contexts, making it difficult to understand their behavioral impacts. Therefore, experiential and interaction-driven learning approaches are required.

CONCEPT AND DESIGN RATIONALE

The design of Paper Vision Town is grounded in three applied human factors principles: operationalizing perceptual differences as design constraints, situating learning in a familiar context, and enabling active task-driven interaction.



Figure 2: Learn about color-vision diversity and color universal design (CUD).

First, perceptual differences were operationalized by embedding color-vision characteristics directly into visual representations of the environment. Instead of abstractly describing color-vision diversity, the system allows participants to observe how specific design choices affect visibility and information recognition.



Figure 3: Intentionally non-inclusive design element.



Figure 4: Example of hatching represented using paper media.

Second, an urban streetscape was selected as the learning context because it contains numerous familiar color-based elements, such as signage, wayfinding, and public notices. This everyday context reduces cognitive load and facilitates the transfer of insights into real design situations.



Figure 5: Urban streetscape.

Third, the system employs task-driven interactions using theme cards that present concrete scenarios, such as locating a destination or identifying key information. These tasks encouraged participants to explore, compare, and make judgments, allowing them to discover perceptual differences through actions rather than explanations.



Figure 6: Designed theme cards.



Figure 7: Overview of the theme card design.

A paper-based physical system was adopted to support embodied interactions. Tangible artifacts enable participants to manipulate objects, change viewing distances, and experience perspective effects. Paper models are inexpensive, portable, and easy to deploy in educational and workshop settings.

SYSTEM DESIGN

Paper Vision Town consists of two paper-based city models placed side by side, a set of theme cards, and supporting materials. Both city models share identical spatial layouts, including building placements and road structures, ensuring that perceived differences arise primarily from visual representations rather than structural variations. One city was designed using color schemes optimized for typical color vision, whereas the other applied visual representations simulating deuteranopia based on established color-transformation methods. Some elements intentionally omit CUD considerations to highlight the contrast between inclusive and non-inclusive designs. The key CUD techniques implemented in the system include luminance contrast adjustment, redundant encoding using shapes and icons, the use of patterns and outlines, and explicit textual labeling. Theme cards guide experiences by framing tasks and scenarios. Participants completed the same tasks in both cities and then compared their experiences, supported by facilitator-led reflection.

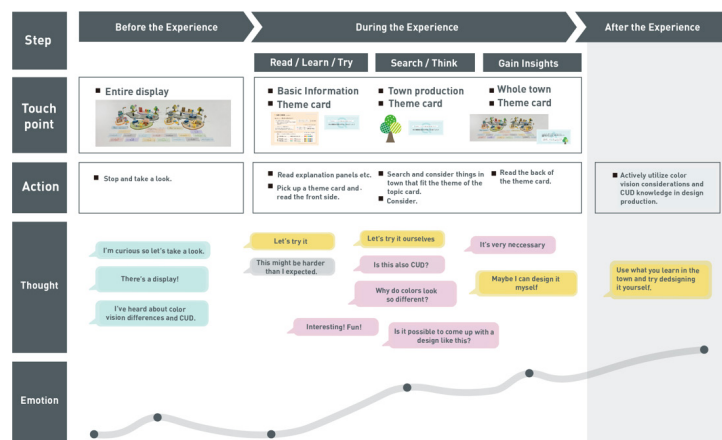


Figure 8: Customer journey.

EXPERIENCE PROCESS AND APPLICABILITY

Paper Vision Town supports both short workshop sessions and longer instructional activities. Informal pilot implementations with design students and mixed professional audiences showed consistent qualitative outcomes: participants became more aware of their reliance on color, identified concrete design improvements, and expressed greater motivation to apply CUD strategies. This system can be applied to design human factors education, professional training workshops, and public exhibitions to raise awareness of perceptual diversity. Its paper-based nature allows flexible scaling, cultural adaptation, and easy transportation.

DISCUSSION AND CONCLUSION

Paper Vision Town operationalizes color-vision diversity as an embodied, comparative learning experience that bridges the gap between theoretical

knowledge and practical design decisions. Its contributions include translating perceptual diversity into observable interaction outcomes, providing a low-cost, deployable educational system, and demonstrating the effectiveness of comparative experiential learning in promoting awareness of inclusive design.

The limitations include the current focus on a single simulated color-vision type and sensitivity to environmental factors such as lighting. Future work should expand the range of simulated conditions, integrate complementary digital technologies, and introduce controlled evaluation methods to quantitatively assess learning outcomes.

In conclusion, Paper Vision Town demonstrated that low-tech, task-oriented comparative experiences can effectively support applied human-factor objectives. The system contributes to the field of **Human Factors and Systems Interaction** by offering a practical approach for fostering an experiential understanding of color-vision diversity and universal color design.

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