METHOD ARTICLE

Immersive virtual classroom as an education tool for color barrier-free presentations: a pilot study [version 1; peer review: 3 not approved]

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Abstract

Background: This study aimed to develop an experiential approach for understanding color vision variations using virtual reality technology.

Methods: A virtual classroom was developed in a three-dimensional space, and 10 university students were tested to understand color vision variations.

Results: Most participants noted that the virtual classroom was an excellent educational tool, which could help teachers understand the problems associated with [visual analog scale (VAS): mean $\pm$ standard deviation (SD), 9.55 $\pm$ 1.57] and obtain a better understanding of (VAS: mean $\pm$ SD, 9.04 $\pm$ 1.0) color vision variations.

Conclusions: Our results show that this approach enhanced the participants' understanding of color vision variations; thus, it may assist children who suffer from this variation. It is necessary to evaluate the effectiveness of this approach for teachers.

Keywords

color vision variation, experiential education tool, virtual reality

Open Peer Review

Approval Status **XXX**

	1	2	3
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version 1 29 Sep 2021	view	view	view

1. **Alice Skelton** , University of Sussex, Brighton, UK
2. **Teresa M. Chan** , McMaster University, Hamilton, Canada
3. **Juan Luis Higuera-Trujillo** , Universitat Politècnica de València, València, Spain

Any reports and responses or comments on the article can be found at the end of the article.

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Author roles: **Fukuyama S:** Conceptualization, Data Curation, Formal Analysis, Software, Writing – Original Draft Preparation; **Saito T:** Software, Supervision, Visualization; **Ichikawa D:** Supervision, Validation; **Kohyama A:** Investigation, Supervision, Writing – Original Draft Preparation; **Oyama H:** Conceptualization, Funding Acquisition, Methodology, Project Administration, Resources, Validation, Writing – Original Draft Preparation, Writing – Review & Editing

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Introduction

Color vision variations affect approximately 6–10% of males and 0.4–0.7% of females, although most of them live without experiencing significant problems.¹ Such variations are classified into three grades: monochromatism, dichromatism, and trichromatism. They are also classified according to the disorder or lack of cone cells: protan deficiency, deutan deficiency, and tritan deficiency. It is difficult for patients with long or middle wave sensitive cones to distinguish red-green colors or for patients with short wave sensitive cones to distinguish blue-yellow colors. If two or more types of cone cells lack or have abnormal cones, it is classified as monochromatism; if the cone cells are normal, it is classified as normal trichromatism.²

Patients with color vision variations often have problems in daily life, including school life, admission to schools, and obtaining a job. There is currently no effective treatment for this disorder. It is, therefore, necessary to consider how to use colors based on universal designs; this approach involves products or environments that are perceptible to patients with any color vision variations.³

In Japan, color vision tests during primary school medical examinations were abolished in 2002. However, before the termination of such tests, some studies showed that approximately 70% of primary or junior high school teachers were unaware of color vision variation. Approximately 80% knew that color vision variations could be detected during a medical examination using a color vision test. Moreover, approximately 90% of teachers were unfamiliar with the “Teaching Guidelines for Problems with Color Vision.” Thus, many teachers lacked knowledge and an understanding of color vision variations. After the termination of color vision tests, “Japanese Teaching Guidelines for Color Vision” was published to help teachers better understand color vision variation. In addition, the Color Universal Design Organization (CUDO) appraises and approves textbooks for the universal design of colors.⁴

However, it can be difficult for teachers to become aware of students who have color vision variations, and most teachers have not used the publication “Japanese Teaching Guidelines for Color Vision.” Color vision variations can cause problems for students in three main areas: school life, admission to schools, and the ability to obtain a job.³ For example, students with color vision variations may be reprimanded by teachers who have limited knowledge of, or who are unable to detect, the disorder.

In 2014, the Ministry of Education, Culture, Sports, Science, and Technology in Japan instituted the “Partial Revision of Ordinance for Enforcement of School Health and Safety Act” for medical examinations to help teachers learn more about color vision variation and to better assist students with such a variation in learning and career guidance. However, this Act did not assist teachers in learning more about color vision variation.

There are some supporting tools for individuals with color vision variations that use color universal designs to assist them in recognizing colors.^{5,6} For example, designs have been developed so that affected individuals can perceive the colors in a design from a two-dimensional picture or on a website, but they are not designed to help educate teachers about color vision variations. Such designs involve a three-dimensional (3D) walking space without virtual reality (VR).⁷

It is well-known that virtual environments with a 3D space can assist in learning.^{8–10} However, few reports have applied this process to teaching the problems of students with color vision variations. This study aimed to develop an experimental learning approach for understanding color vision variations using a color vision variation simulator in a primary school classroom using VR technology.

Methods

Study design

VR was used to simulate and communicate the problems of students who have color vision variations. A primary school classroom and its teaching materials were constructed and projected in a VR space. Because approximately 70% of patients with a color vision variation are deutan deficient, this system simulated both deutan deficiency and normal trichromatism so that these two types of color vision could be compared.

The teaching materials constructed in the classroom were common to primary school classrooms; some were designed based on the publication “Japanese Teaching Guidelines for Color Vision,” which considers content about colors that are difficult for students with color vision variations to recognize or distinguish.

Previous studies used a head mount display (HMD) for experience-based simulation-enhanced learning,^{11–13} so in our system, an HMD was used for the VR experience. In addition, an analog stick was adapted as an operating device to enable users to operate and control their viewpoint manually and intuitively.

Experimental equipment

An iMac ME089J/A computer (Apple, Cupertino, CA) was used as hardware for the development of the execution environment, and Windows 7 Professional (Microsoft, Redmond, WA) was used as the operating system. Oculus Rift DK2 (Oculus VR, Irvine, CA) was used as the HMD for VR, and an Xbox360 controller for Windows (Microsoft) was used as an analog stick for controlling the viewpoint. **Unity3D** (Unity Technologies, San Francisco, CA), an integrated development environment, was used to construct the VR space with C# as the development language. “Japanese classroom set” (SbbUtutuya), a unity asset, was used as the 3D model for the virtual classroom and teaching materials. It is possible to develop this using an open-source software like **Godot**, but it is necessary to be certified by a professional organization that the software accurately displays color vision variations.

Based on existing guidelines for color vision variations, seven parameters were chosen, designed, and constructed in the virtual classroom as contents that are difficult for students with color vision variations to recognize or distinguish: 1) the color of chalk, 2) the color of a calendar, 3) the color of flowers, 4) the colors of paints, 5) a red pen, 6) the colors of figures or graphs, and 7) the color coding used in maps (**Figure 1**).

“Color vision variation Simulator for Unity” (Gulti, Tokyo, Japan), a unity asset, was used as a color vision simulator; it was developed based on the theory of color vision simulation by Brettel *et al.*,^{5,6} and was verified and approved by the CUDO.¹⁴ In this study, the “Deuteranope” mode was used to simulate a deutan deficiency. In addition, “dichromatism mode” and “trichromatism mode” were included; the former was applied to the “Simulate Intensity,” a parameter that showed the degree of simulation and was maximized, while the latter involved the state when the simulator was turned off.

Usability and utility tests

Objective

The test evaluated the usability and utility of the system for educational purposes.

Experimental set-up and tasks

The participants, who did not have color vision variations, were recruited by snow-ball sampling. The test took approximately 30 min and was performed in the authors’ study room with a single participant and a test navigator. The participants were seated when using the system (**Figure 2**).

Before the test started, the objectives of the test were explained, and the participant completed the pretest questionnaire.¹⁸ Then, the participant received additional explanations regarding the outlines of the system and items in the virtual

Figure 1. Seven parameters were selected, designed, and constructed in the classroom.

Figure 2. The participants followed the instructions of the navigator and experienced the differences between normal and abnormal color vision while moving through the virtual classroom.

classroom that must be watched, and he/she was given instructions on how to operate the controller. The participant was then connected to the Oculus Rift to start the test. The Oculus Rift was set up based on the participant's height.

First, the participant experienced the dichromatism mode. During this experience, the navigator in charge asked seven questions about how the participant saw colors. The participant answered the questions orally while operating the viewpoint. Second, the participant experienced the trichromatism mode and answered the same questions. Finally, the participant completed a questionnaire about usability and utility (10 cm visual analog scale [VAS]) and finished the test.

There were four items in the questionnaire: ease of operation with the controller, immersion with the HMD, clearness of the display, and VR sickness. There were two questions about whether the participant learned about problems with color vision and whether the system promoted a better understanding of color vision variations.

The test was consistent with the "Ethical Guidelines for Medical and Health Research Involving Human Subjects" (Ministry of Education, Culture, Sports, Science, and Technology, Ministry of Health, Labor, and Welfare, 2014) and was performed after written informed consent was obtained from the participants. The questionnaire was completed anonymously and was self-administered. Personal information was treated in accordance with the Act on the Protection of Personal Information and information security policy of the University of Tokyo, Tokyo, Japan. Ethics approval was obtained from the Research Ethics Committee of the University of Tokyo (1139).

Data analysis

R (R Development Core Team) was the statistical software used in this study. We calculated the average, standard deviation, and 95% confidence interval for the VAS scores after the participants' experiences.

Results

The participants were 10 university students (two males and eight females) at the Graduate School of Medicine; they were 21–47 years of age, with an average age of 26.6 years and a standard deviation (SD) of 7.3 years.¹⁸

Table 1. The results of the questionnaire on usability and utility (VAS, n = 10).

	Mean	SD	95% CI	
			Lower	Upper
Usefulness				
1) Whether the participants could learn the locations of color vision problems?	9.6	0.6	9.2	9.9
2) Whether the system promoted a better understanding of color vision variation?	9.0	1.0	8.4	9.7
Usability				
1) Controllability of the controller	7.3	1.7	6.3	8.4
2) Immersion by the head mount display	8.4	1.6	7.4	9.4
3) Is the virtual world clear?	5.8	2.2	4.4	7.1
4) The degree of VR sickness	6.6	2.5	5.0	8.2

Abbreviations: SD, standard deviation; CI, confidence interval.

All participants answered that they were familiar with the term “color vision variations,” but only four knew situations when students with color vision variations had difficulties. One participant answered that she had previously used a color vision variation simulation tool only to check the coloring of her website.

Table 1 shows the results of the questionnaire regarding utility and usability.

Regarding utility, whether they could learn the locations of color vision problems was 9.6 ± 0.6 (VAS average $\pm$ SD) and whether the system promoted a better understanding of color vision variation was 9.0 ± 1.0 .

Regarding usability, the ease of operation was 7.3 ± 1.7 , immersion with HMD was 8.4 ± 1.6 , clearness of the display was 5.8 ± 2.2 , and VR sickness was 6.6 ± 2.5 .

Some remarks were included in the free description field, including “to use things which contents we have to understand only by color should be avoided,” “although the colors are similar, if the tints of them are different, some people could not tell them apart,” and “we should be careful of how to show graphs: how to use colors, designs or patterns.”

Discussion

We developed an experience-based educational support system using VR technology to provide information about color vision variations and evaluated its usability and utility for participants without color vision variations.

Approximately 20% of the teachers in a previous report stated that they became aware of problems with the colors of chalk.¹⁴ The result of this study shows that a few participants had not noticed difficulties in students with a color vision variation, although they knew the term “color vision variations.” In addition, few participants had used color simulation tools. Although the participants were students, there was an apparent minimal interest in, or awareness of, the problems associated with color vision variations.

In the evaluation of the system’s utility, the average score was 9.6 for the question “How well do you understand what items are difficult for children with color vision variations to see or distinguish?” and the confidence interval was small. The other question item, whether the system promoted a better understanding of color vision variations, also received an average score of 9.0. This high evaluation is a result of the participants being presented with the world of the virtual classroom in both two-color and three-color modes, so that participants could experience the differences in color between the two modes alternately. Furthermore, for student participants with different color variations, only the problematic points as shown in Figure 1 were used, and the participants were operating the system while asking questions, which may have made it easier for them to focus on the target in the virtual classroom. It was suggested that additional educational effects could be achieved by organizing and expanding the content.

The usability evaluation results show that the average ease of operation with the controller was 7.3 (SD: 1.7). In this system, a video game controller was used as the operation device; therefore, whether the participants had experience

operating a game controller influenced the results. In addition, because the movement speed of the viewpoint during rotation was set to slow to avoid VR sickness, the usability evaluation might have decreased.

The average immersion of the HMD was 8.4, suggesting that the participants received a high degree of immersion using the HMD because their actual surroundings were eliminated by wearing the HMD, and the display followed the motion of the participant's head.

Regarding the clearness of the display, the average (5.8) was lower than that for the other parameters, and the confidence interval varied widely. It is assumed that the experience of wearing the HMD differed among the participants. Color noise was sometimes seen in the display because the HMD tilted due to head movement or looseness of the headband. In addition, a participant stated that the HMD display resolution was low, which caused a decline in immersion. The HMD resolution should therefore be improved.

Most participants experienced VR sickness. One participant experienced VR sickness during rotation movements with the controller. The VR sickness is consistent with many studies that reported that visual rotational motion could cause visually-induced motion sickness.^{15–17} An unfamiliar controller operation might have caused VR sickness. The user interface should therefore be improved, and the ability to rotate the controller should be restricted.

From the results of the free-response question regarding whether one's understanding of color vision variations increased, the reason for the better understanding of the changes in color vision was not only that the participants answered the questions while comparing the three-color vision modes with the two-color vision modes, but also that the navigator explained to the participants the specific things to think about during the experience. The system could be used to develop better graphs for PowerPoint presentations, not just by schoolteachers and staff but also by students and other occupational workers.

There are limitations to this study. First, the participants were students even though the system was developed for teachers. Second, the evaluations were subjective, and the teaching efficacy could not be measured quantitatively.

Conclusions

We have developed a VR system that allows children with color vision mutations to experience their color vision and demonstrate its properties. With this system, teachers will be able to increase their knowledge of color vision mutations and solve color vision problems in the classroom. In the future, it is necessary to evaluate the effectiveness of this approach for teachers.

Data availability

Underlying data

OSF: Immersive virtual classroom as an education tool for color barrier-free presentations: A pilot study data. <https://doi.org/10.17605/OSF.IO/3KJVR>.¹⁸

This project contains the following underlying data:

- manuscript72900RawData.xlsx (raw data)

Data are available under the terms of the [Creative Commons Zero “No rights reserved” data waiver](#) (CC0 1.0 Public domain dedication).

Extended data

OSF: Immersive virtual classroom as an education tool for color barrier-free presentations: A pilot study data. <https://doi.org/10.17605/OSF.IO/3KJVR>.¹⁸

This project contains the following extended data:

- manuscript72900_Extended_data.pdf (blank copy of the questionnaire)

Data are available under the terms of the [Creative Commons Zero “No rights reserved” data waiver](#) (CC0 1.0 Public domain dedication).

Acknowledgments

The authors are grateful to Drs. T. Sakamoto and S. Ino for useful discussions. We also thank the students at the University of Tokyo who participated in the evaluation.

References

- Birch J: *Diagnosis of defective colour vision*. Elsevier Health Sciences; 2001.
- Keene DR: **A Review of Color Blindness for Microscopists: Guidelines and Tools for Accommodating and Coping with Color vision variation**. *Microsc. Microanal.* 2015; **21**(2): 279–289.
[PubMed Abstract](#) | [Publisher Full Text](#)
- Cole BL: **The Handicap of Abnormal Colour Vision**. *Aust. J. Optom.* 1972; **55**(8): 304–310.
[PubMed Abstract](#) | [Publisher Full Text](#)
- Okabe M, Ito K: **Color Universal Design (CUD)-How to make figures and presentations that are friendly to Colorblind people**. *J* Fly Data Depos. Drosoph. Res.* 2008.
- Viénot F, Brettel H, Ott L, et al.: **What do colour-blind people see?** *Nature.* 1995; **376**(6536): 127–128.
[PubMed Abstract](#) | [Publisher Full Text](#)
- Brettel H, Viénot F, Mollon JD: **Computerized simulation of color appearance for dichromats**. *J. Opt. Soc. Am. A Opt. Image Sci. Vis.* 1997; **14**(10): 2647–2655.
[Publisher Full Text](#)
- Kubota S, Seki H, Kano T, et al.: **Development and Application of Color Universal Design Support System for Pedestrian Space**. *IPSJ J.* 2011; **52**(1): 140–152.
[Publisher Full Text](#)
- Mills S, De Araújo MMT: **Learning through virtual reality: a preliminary investigation**. *Interact. Comput.* 1999; **11**: 453–462.
[Publisher Full Text](#)
- Panagiotis KK, Konstantinos G, Stylianos M, et al.: **E-Learning through virtual reality applications: The case of career counseling**. *Int. J. Technol. Learn.* 2014; **21**(1): 57–68.
[Publisher Full Text](#)
- Shen C, Ho J, Kuo T-C, et al.: **Behavioral Intention of Using Virtual Reality in Learning**. *Proceedings of the 26th International Conference on World Wide Web Companion*. International World Wide Web Conferences Steering Committee; 2017, pp. 129–137.
- Freina L, Ott M: **A literature review on immersive virtual reality in education: State of the art and perspectives**. *Proc. eLearning Softw. Educ. (eLSE)* (Bucharest, Rom. April 23–24, 2015) 2015.
- Moro C, Štromberga Z, Raikos A, et al.: **The effectiveness of virtual and augmented reality in health sciences and medical anatomy**. *Anat. Sci. Educ.* 2017; **10**: 549–559.
[PubMed Abstract](#) | [Publisher Full Text](#)
- Peden RG, Mercer R, Tatham AJ: **The use of head-mounted display eyeglasses for teaching surgical skills: A prospective randomised study**. *Int. J. Surg.* 2016; **34**: 169–173.
[PubMed Abstract](#) | [Publisher Full Text](#)
- CUDO: **Color Universal Design Organization**. [Accessed: 31-Aug-2017].
[Reference Source](#)
- Golding JF, Gresty MA: **Motion sickness**. *Curr. Opin. Neurol.* 2005; **18**: 29–34.
[PubMed Abstract](#) | [Publisher Full Text](#)
- Golding JF: **Motion sickness susceptibility**. *Auton. Neurosci. Basic Clin.* 2006; **129**(1–2): 67–76.
[PubMed Abstract](#) | [Publisher Full Text](#)
- Palmisano S, Mursic R, Kim J: **Vection and cybersickness generated by head-and-display motion in the Oculus Rift**. *Displays.* 2017; **46**: 1–8.
[Publisher Full Text](#)
- Oyama H: **Immersive Virtual Classroom as an Education Tool for Color Barrier-Free Presentations: A Pilot Study Data**. *OSF*. September 15, 2021.
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Juan Luis Higuera-Trujillo

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The study contains the seeds of an interesting and very socially useful approach. In that sense, I should congratulate the authors. However, it has the major problem of presenting a very low sample size and, more critically, not fully aligning the objective with the methods employed. I understand that it is a pilot study. But a "pilot study" is not a concept that legitimises lack of depth in the paper. Such studies should try to express the methodology as justifiably and clearly as possible. However, the article (in its current version) fails to express this adequately. Other limitations of the article are a weak introduction, and discussion section. In the following review, I try to give my view on how the authors could improve the article.

Introduction

The introduction is easy to follow and well structured. However, it contains the following weaknesses:

- The first paragraph is illustrative. But it would require further explanation, as it introduces concepts such as "dichromatism" with which readers may not be familiar.
- A scholarly introduction should state the problem and put it in context with related literature. In this introduction the problem is stated, but it lacks academic rigour. It is a relatively short introduction, citing only 10 references. It reads more like a professional report than an academic introduction. I suggest the authors improve the scientific scope of this text.

Methods

- The comment about "Godot" doesn't really make sense. If it was not used, it should not appear.
- The choice of the seven parameters (the colour of chalk, etc.) should be justified.

- The general experimental methodology is explained textually, but it would be a significant support to elaborate a figure indicating the whole process. The aim of this section is to allow the replicability of the study; and in its current version this would not be possible.
- The questionnaires used by the authors should be listed in a table in this section. It is not enough to present the questions together with the results in the results section. The methods section should be self-explanatory.
- I understand that the questionnaires used are partly based on other questionnaires. They should be referenced.
- The description of the sample should not be included in the results section, but in the methods section. On the other hand, the following aspects of the sample are critical: (1) very low number of participants; (2) very different ages, especially considering the low number of participants; and (3) unbalanced gender.

Results

- Question 4 of the usability questionnaire could be confusing: do high scores refer to a high degree of sickness? I understand that it meant the opposite, and that the VAS corrects this problem. But for future studies I would recommend to the authors that, if they develop their own questionnaires, all questions should be equally oriented. For example, in this question, it would have been better: "4) The degree to which you are free of VR sickness", or something similar.
- It is confusing how it can be said "We have developed a VR system that allows children with colour vision mutations to experience their colour vision and demonstrate its properties", when the whole sequence has been aimed at testing the tool with university students without such problems.

Discussion

An academic discussion tries to put the results in context with the available literature. However, in this case it is essentially limited to explaining the results. The commentary on the results should be in the Results section, not in the Discussion one. The discussion should attempt to contextualise them. This does not occur in the current version of the study (or it occurs very briefly: only in the last and antepenultimate paragraphs of the discussion). I encourage authors to improve this section in order to follow the structure of a strong research article.

Is the rationale for developing the new method (or application) clearly explained?

Partly

Is the description of the method technically sound?

No

Are sufficient details provided to allow replication of the method development and its use by others?

No

If any results are presented, are all the source data underlying the results available to ensure full reproducibility?

Yes

Are the conclusions about the method and its performance adequately supported by the findings presented in the article?

Partly

Competing Interests: No competing interests were disclosed.

Reviewer Expertise: Virtual reality; neuroarchitecture

I confirm that I have read this submission and believe that I have an appropriate level of expertise to state that I do not consider it to be of an acceptable scientific standard, for reasons outlined above.

Author Response 03 Dec 2021

Hiroshi Oyama, University of Tokyo, 7-3-1, Hongo, Bunkyo-Ku, Tokyo, Japan

Dear Dr. Juan Luis Higuera-Trujillo,

We thank you for carefully reading our manuscript and for giving valuable comments. The ultimate goal of this research is to propose a first-person experiential education method using VR to help participants (especially new teachers) respond appropriately to children with color vision variations at the school. This paper is a report on the first stage of realizing this goal. It is positioned as a Phase 1 study of a clinical trial. Therefore, we mainly examined whether there would be any problems for healthy people and whether there would be any usability problems during the experience. The next step will be to examine the impact on new teachers.

We will revise the manuscript based on your feedback.

Sincerely

Hiroshi

Competing Interests: No competing interests were disclosed.

Reviewer Report 10 November 2021

<https://doi.org/10.5256/f1000research.76511.r99517>

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Teresa M. Chan

Continuing Professional Development Office and McMaster Education Research, Innovation, and Theory (MERIT) Program, McMaster University, Hamilton, ON, Canada

Thank you for inviting me to complete this peer review. Overall I see the merit in this paper and feel that it is worthy of indexing.

My suggested edits are to help you shift this article from a surface reporting of what you did towards a more scholarly report of the techniques used.

Major concerns:

1. Why did you chose a visual analogue scale for this study? There is very little in the literature around the selection of this particular VAS scale for the purposes of your study. More substantiation (and/or more details about pilot testing) of your measurement tool would be imperative prior to indexing. What is the interrater or intrarater reliability of the VAS?
2. I am perplexed about the study design - there seems to be only 1 arm of individuals. The layout of the introduction led me to believe you might compare groups of individuals with colour vision variations to those who are not.
3. Please add your sample size calculation for this study. It is unclear why you are even reporting standard deviations or 95% CI since there is no comparator group. Please more thoroughly discuss this in the Data Analysis section as currently they do not appear beyond the table. I would suggest it is important to highlight these in the text and also discuss them in your discussion.
4. Finally, your utility and usability framework are unclear to me. What prior literature informed your survey tool? Please cite supporting references that helped you design your study.

Is the rationale for developing the new method (or application) clearly explained?

Yes

Is the description of the method technically sound?

Yes

Are sufficient details provided to allow replication of the method development and its use by others?

Partly

If any results are presented, are all the source data underlying the results available to ensure full reproducibility?

Partly

Are the conclusions about the method and its performance adequately supported by the findings presented in the article?

Partly

Competing Interests: No competing interests were disclosed.

Reviewer Expertise: Medical education; Health professions education; Digital learning

I confirm that I have read this submission and believe that I have an appropriate level of expertise to state that I do not consider it to be of an acceptable scientific standard, for reasons outlined above.

Author Response 15 Nov 2021

Hiroshi Oyama, University of Tokyo, 7-3-1, Hongo, Bunkyo-Ku, Tokyo, Japan

Dear Dr. Teresa M. Chan,

We thank you for your fruitful suggestions, especially for suggesting a better study design and valuable comments.

(1) Why did you choose a visual analog scale for this study?

Res) Although there have been reports of VAS being used in usability evaluations of surgical VR systems, there have been no reports of evaluation scales measuring the impact of VR systems such as this one. We also considered using the Likert scale but did not use it because it has the disadvantage that different respondents give different reasons for their choices. The VAS is a scale that allows respondents to freely answer their rating results in a continuous band, the length of which is on a line. It is vital to motivate respondents to answer honestly. Therefore, motivating respondents to answer is a significant advantage of the VAS method, so we used it this time. In addition, the VAS method has the advantage of measuring minute differences in respondents' impressions and being able to relativize and quantify information that is difficult to relativize and quantify. Therefore, we believe that the VAS method can accurately measure users' perceptions of the VR system. As you suggested, it is necessary to evaluate the validity of this scale. We will add the verification of the validity of this scale in the limitation section of this study.

Ref) Jokinen, E., Mikkola, T. S., & Härkki, P. (2020). Simulator training and residents' first laparoscopic hysterectomy: a randomized controlled trial. *Surgical endoscopy*, 34(11), 4874-4882. DOI: [10.1007/s00464-019-07270-3](https://doi.org/10.1007/s00464-019-07270-3)

(2) I am perplexed about the study design - there seems to be only one arm of individuals.

Res) This VR system is intended to be an educational tool to assist teachers in making appropriate responses to children with color vision variations. As such, this study corresponds to Phase I of the clinical trial. As you suggested, the efficacy study (Phase II)

will be conducted on new teachers in elementary and middle schools.

(3) Please add your sample size calculation for this study. ...

Res) This study is a Phase I clinical trial in advancing the clinical application of VR systems. The incidence of adverse events in VR systems has ranged from 30% (Chen *et al.*, 2011) to over 80 % (Kim *et al.*, 2005). The median value of the VAS scale is 5. If it was a normal distribution, the sample size was calculated using a two-tailed t-test of the mean values of one group with a significance level of $\alpha = 5\%$ and a power of 80% with a mean difference of 1.5 and a standard deviation of 1. The calculation resulted in a sample size of 8.06. Since this is a Phase I study, standard deviations and confidence intervals are shown to determine the characteristics of the population. We will add this information to the data analysis and discussion as you suggested.

We think that a sample size of 30 or more is appropriate. We will add the sample size to the limit.

Ref) Chen, W., Chen, J. Z., & So, R. H. Y. (2011). Visually induced motion sickness: Effects of translational visual motion along different axes. *Contemporary ergonomics and human factors*, 2011, 281-287.

Kim YY, Kim HJ, Kim EN, Ko HD, Kim HT (2005) Characteristic Changes in the Physiological Components of Cybersickness. *Psychophysiology* 42(5):616–662. DOI: [10.1111/j.1469-8986.2005.00349.x](https://doi.org/10.1111/j.1469-8986.2005.00349.x)

Rebenitsch, L., & Owen, C. (2016). Review on cybersickness in applications and visual displays. *Virtual Reality*, 20(2), 101-125. DOI: [10.1007/s10055-016-0285-9](https://doi.org/10.1007/s10055-016-0285-9)

(4) Finally, your utility and usability framework are unclear to me.

Res) The evaluation framework and survey tools for this study were based on the following paper. We will add the following study in the Method section as a reference.

Pallavicini, F., Pepe, A., & Minissi, M. E. (2019). Gaming in virtual reality: What changes in terms of usability, emotional response and sense of presence compared to non-immersive video games? *Simulation & Gaming*, 50(2), 136-159. DOI: [10.1177/1046878119831420](https://doi.org/10.1177/1046878119831420)

Competing Interests: No competing interests were disclosed.

Reviewer Report 03 November 2021

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Alice Skelton

The Sussex Colour Group, School of Psychology, University of Sussex, Brighton, UK

The method suggested is using a VR classroom setting and applying the built in filters for modelling different types of colour vision deficiency (CVD) so that people without CVD can better understand the perceptual experience of people with CVD. 10 participants wear the VR headset and view a classroom environment under different examples of CVD before being asked to self-report if they have learnt about what people with CVD experience & if they think it's useful. They are also asked some basic questions about the usability of the set up. The majority of participants do report learning about CVD. It appears that showing people what colour vision deficiency might be like makes the majority of participants understand a bit better about what colour vision deficiency is like.

There are a lot of inaccuracies in the introduction in defining what variations in colour vision are: e.g. a reference to 'trichromatism' as being a colour vision variation affecting 6-10% of males, trichromacy is actually typical colour vision; "It is difficult for patients with long or middle wave sensitive cones to distinguish red-green colors" is also incorrect - having L and M cones means you *are* able to discriminate reds and greens. Many textbooks with a section on colour vision would be a better place to start to find out about the physiology of colour vision (e.g. a nice accessible version is: Snowden *et al.* 2012¹).

The method of demonstrating the perceptual experience of people with colour vision deficiencies (CVD) in order to help teachers and educators better understand the experience of children in their classrooms is a good idea. It is a little hard to see what this particular method offers over what can already be gained from CVD simulators however, and this method is not compared to any other method of educating people on the experience of living with CVD, so it's hard to know how effective it is in comparison to these other methods which would likely be more accessible in terms of equipment for the majority of educators.

It's important that interventions to teach people about individual differences are teaching people accurate information. The paper does not report how accurate the simulated versions of the classrooms are in matching the perceptual experience of people with CVD. There has been rigorous testing of the accuracy of simulations (e.g. Lillo *et al.* 2014²) which shows there is some variation in how accurate these simulations are.

Most CVD simulators do not use calibrated displays which can most accurately capture the perceptual experience of a student with CVD, and that technical aspect is also missing from the current method.

References

1. Snowden R, Snowden RJ, Thompson P, Troscianko T: Basic vision: an introduction to visual perception. *Oxford University Press, Oxford*. 2012.
2. Lillo J, Alvaro L, Moreira H: An experimental method for the assessment of color simulation tools. *J Vis*. 2014; **14** (8): 15 [PubMed Abstract](#) | [Publisher Full Text](#)

Is the rationale for developing the new method (or application) clearly explained?

No

Is the description of the method technically sound?

Partly

Are sufficient details provided to allow replication of the method development and its use by others?

Yes

If any results are presented, are all the source data underlying the results available to ensure full reproducibility?

Yes

Are the conclusions about the method and its performance adequately supported by the findings presented in the article?

No

Competing Interests: No competing interests were disclosed.

Reviewer Expertise: Colour vision, cognitive development

I confirm that I have read this submission and believe that I have an appropriate level of expertise to state that I do not consider it to be of an acceptable scientific standard, for reasons outlined above.

Author Response 06 Nov 2021

Hiroshi Oyama, University of Tokyo, 7-3-1, Hongo, Bunkyo-Ku, Tokyo, Japan

Dear Dr. Alice Skelton,

We thank you for careful reading our manuscript and for giving useful comments.

This research aims to propose a methodology on CVD using a simulation tool based on VR technology rather than a comparative study with existing color simulations. It is based on Situated Learning Theory to support education about CVD using VR technology.

>There are a lot of inaccuracies in the Introduction....

-> We will check our references and revise the first paragraph of the Introduction.

>The method of demonstrating the perceptual experience of people with colour vision

->The reason for choosing medical students as subjects were to reduce knowledge bias about CVD in the evaluation.

>It's important that interventions to teach people about individual differences....

->The "Color vision variation Simulator for Unity" used in this project is a simulation tool certified by CUDO (Color Universal Design Organization: <https://www2.cudo.jp/wp/>). The HMD resolution is 1,920 x 1,080, which enables full high definition-like display. However, following your suggestion, we will add "The Simulcheck method will be needed to be

evaluated." in the limitation paragraph.

Sincerely,

Competing Interests: No competing interests were disclosed.

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