EXPLORING THE EFFECTS OF COLOURS OF DIGITAL MATERIALS ON LEARNERS' COMPREHENSION IN HIGHER EDUCATION

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ABSTRACT

Recent studies demonstrate that colours could attract attention, improve concentration and readability, as well as enhance information recall. Although colour design is essential in education, more scientific research is needed to examine the optical colours for instructional materials. This project encompasses a focus group, pre-experiments, and main experiments to understand the effects of colours on human comprehension in digital learning environments. Forty participants completed a comprehension ability test with 16 questions displayed on eight different background colours: red, orange, yellow, green, blue, purple, grey, and black. Note that to ensure consistent contrast between foreground and background colour, grey fonts were used for the black background and black fonts for the other seven colours. It also assessed the different colour materials' preferences, readability, and legibility. The study found that native English speakers performed better in the tests with grey and red background colours, with higher correction rates and shorter response times for the two colour conditions. There were significant differences in the evaluation scores between grey and black backgrounds, which have black and grey foreground colours, respectively. On the other hand, the colours did not significantly affect non-native English speakers' comprehension ability. However, the two groups had no significant differences in the subjective preference assessment, legibility, and readability. This study suggests that people's cognitive performance may improve under light background and dark foreground colour combinations. Also, learners' preferred colours may not lead to a better understanding of text-based information. Educators, instructional designers, and developers of digital educational materials can benefit from these insights to enhance digital learning experiences by optimising the integration of colour and addressing the impact of language proficiency.

Keywords: Colour design, digital learning material, comprehension assessment, higher education.

INTRODUCTION

Studies have acknowledged the importance of using colours in designing learning materials in higher education; however, more empirical knowledge is needed. For example, Roberts stressed that *"Even though the use of colour in the production of instructional materials is widespread, its relative effectiveness as an aid in improving student achievement remains inconclusive and at best contradictory"* [1, p. 26]. Also, Diachenko et al. highlighted the potential of using colour in designing learning material in higher education that can enhance students' perceptions and memorisation [2]. Some studies have shown that colour or colour combinations can help people recall information and form colour coding [2, 3]. Therefore, the present study aims to explore the effects of colours of learning materials on students' comprehension ability in higher education settings. It addresses three questions: First, how do modern learners feel about the readability and legibility of different colour materials and their preferred colour choice for digital materials? Second, which colour setting enables learners to comprehend text-based information most effectively? Last, whether students' preferred colour of learning material leads to their better understanding of the textual information.

METHODOLOGY

Fonts

When it comes to fonts for the test learning materials, 'Verdana' and 'Microsoft's Times New Roman' were selected based on screen information design principles set by Pettersson [4]. The font size was set at the optimal size range with a body size of 24 points (typically 32px) for text and a body size of 30 points (typically 40px) for the headings in the Verdana typeface. In the footnote section below the learning material, in the serif font Time New Rome, with a body size of 18pt (typically 24px) [5].

Background Colours

This study carefully selected eight colours for the background of digital learning materials to ensure text-based information's effectiveness and maximise the digital materials' legibility and readability. The eight background colours include six chromatic colours (such as red, orange, yellow, green, blue, and purple) and two achromatic colours (such as black and grey). Especially the six chromatic background colours were systematically selected from the Adobe HSB colour system [6]. For example, hue is measured in degrees of the colour circle ranging from 0 to 360 (red = 0°,orange= 30°; yellow= 60°; green = 120°; blue = 240° and purple= 270°). From each degree, choose a colour and ensure that the contrast between these colours and black remains at the same level.

Foreground (Font) Colours

Grey was used as the foreground colour for the black background, and black was used as the foreground colour (font colour) for the other colours. The font colour of the learning materials is black, and the contrast with the background colour is guaranteed to reach a higher level to ensure the readability of the learning materials to the greatest extent [7]. Against different colour backgrounds, the black text will be more readable compared to other colours [8]. So, in the coloured background condition, all text colours are black, with an RGB value of C=0,0,0, while in the black background, reference grey will be used as the foreground colour.

Luminance Contrast between Background and Foreground (Font) Colours

The luminance contrast between the background and critical visual cues is essential to ensuring the readability of learning materials, and some researchers suggest that this contrast should be fixed in 3:1 OR 7:1 threshold set by the W3C specifications [9, 10, 11].

Using linear colour components C= [R, G, B], one may get the relative luminance by:

$$L = 0.2126R + 0.7152G + 0.0722B \tag{1}$$

Knowing the relative luminance, calculate the contrast ratio of a coloured text and background by the formula:

$$(L1 + 0.05) / (L2 + 0.05) \tag{2}$$

- L1 is the relative luminance of the lighter of the foreground or background colours, and
- L2 is the relative luminance of the darker of the foreground or background colours.

Relative luminance of text and background colour (L1>L2). The ANSI/HFS 100-1988 standard requires that the contribution from ambient light be considered when calculating L1 and L2. The value is based on the (IEC-4WD) Typical Viewing Flare [11]. After the calculation, please see Table 1 for the colour samples and values.

Table 1: The sRGB colour coordinates of the eight background colours (H_ Hue, S_ Saturation, B_ Brightness, R_ Red, G_ Green, B_ Black).

Colour name	Colour sample	H	S	B	R	G	B	Contrast ratio
Reference Grey		0	0%	60%	153	153	153	7.37
Red		0	60%	100%	255	102	102	7.34
Orange		30	100%	94%	240	120	0	7.39
Yellow		60	100%	62%	158	158	0	7.34
Green		120	100%	70%	0	178	0	7.37
Blue		240	45%	100%	140	140	255	7.31
Purple		270	52%	100%	189	122	255	7.39
Black		0	0%	0%	0	0	0	

Note: The colour names indicate the hue value of the colours and ensure that all combinations of foreground and background colours have their contrast controlled around 7.3. The saturation and brightness will need some tweaking, so some of these colours may not represent the name.

Participants and Demogrphic Distribution

In this experiment, participants were selected based on the following three criteria: (1) having normal vision, (2) currently having a higher education, and (3) having experience in online education learning education. Based on the above screening conditions, 44 participants were recruited for this experiment, half males and half females. After the first round of data counting and screening, valid data from 40 participants were adopted for the final data analysis, with an average age of 28.32 (19-42 years old). The specific experimental setting and cultural background, etc., are shown in the table below. After the first round of data counting and screening, valid data from 40 participants were adopted for the final data analysis, with an average age of 28.32 (19-42 years old). The 40 participants were carefully distributed based on the condition of the physical learning environment and gender. Table 2 shows the participant distribution.

Table 2: The distribution of the 40 participants (offline and online).

	Offline Condition			Online Condition			
Gender	Chinese	Mixed Culture	Native Speaker	Chinese	Mixed Culture	Native Speaker	Total
Female	5	2	3	5	2	3	20
Male	5	3	2	5	3	2	20
Total	10	5	5	10	5	5	40

Online Questionnaires

An online questionnaire evaluated participants' online learning experiences, colour preferences, and readability and legibility of digital learning materials. The questionnaire contains 29 questions (and takes about 7 minutes to complete.)

Comprehension Test Materials

Comprehension tests are designed to test verbal skills and understanding of written text with word change questions. These questions avoid the limitations of single- or multiple-choice questions, allowing participants to guess without understanding the text. Participants can make sentences comprehensible by changing the position of words, as shown in Figure 1.

Example:

Change the position of FOUR WORDS only in the sentence below in order for it to make complete sense.

The discovery of today's plastics materials begins with the semi-synthetic history of a series of thermoplastic in the mid-nineteenth century.

Answer:

The **history** of today's plastics begins with the **discovery** of a series of **semi-synthetic** thermoplastic **materials** in the mid-nineteenth century.

Notes:
1. Synthetic: produced by combining different artificial substances, rather than being naturally produced.
2. Thermoplastic: a plastic that is soft and bendable when heated but hard when cold.

Figure 1. An example of the comprehension test, the word-changing questions used in the main experiment.

Each participant was required to answer 16 questions throughout the experiment. Under each background colour, participants will answer two different questions. To ensure that the difficulty of the various questions does not affect the final experimental results, the combination of material content and colour needs to appear randomly, not in a fixed order.

Procedures

First, the experiment divided the 40 participants into two distinct environments. For half of them, a real-time connection was established through Microsoft Teams software, allowing them to engage with the researcher remotely. They undertook the experiments online, where the physical surroundings were beyond their control. In contrast, the remaining participants participated in the experiment in an offline lab environment equipped with a D65 standardised light source and a standard sRGB display setting. Upon entering the lab, these participants had 1-2 minutes to acclimate to the surrounding ambient light.

Second, prior to commencing the experiment, all participants needed to complete the online Ishihara Colour Blindness Test), ensuring their possession of normal Colour vision.

Third, following the colour blindness test, participants were directed to complete an online questionnaire, which typically required around 8-9 minutes.

Lastly, sixteen experimental questions were presented to the participants randomly. Once they felt prepared, they answered the questions while the researcher meticulously recorded the time to complete each inquiry.

RESULT AND DISCUSSION

Figure 2 shows the group comparison results of correction rates and response time from the comprehension test between the native and non-native English groups. Three outstanding findings were captured:

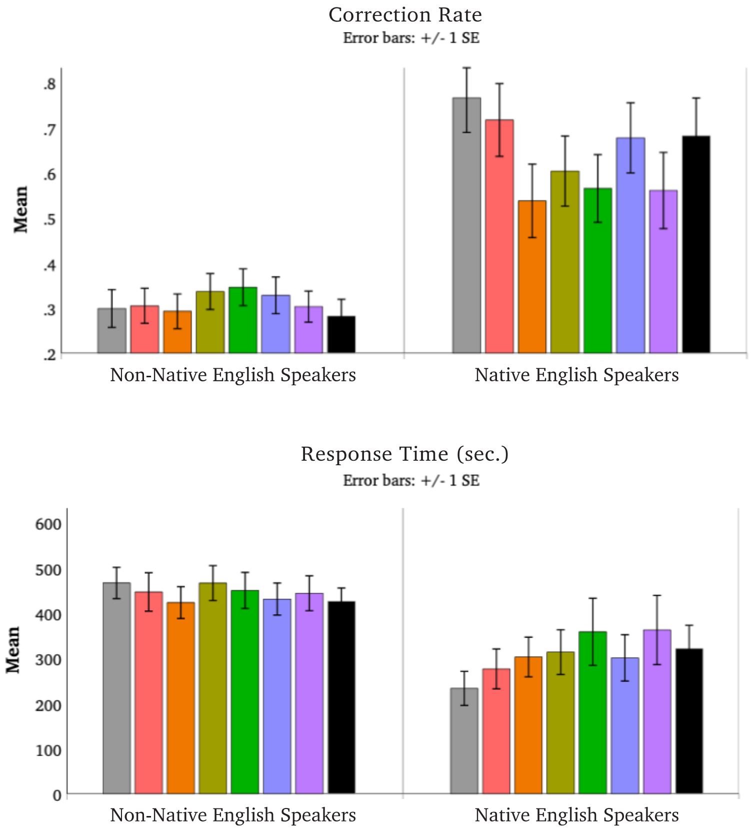

Figure 2. Correction Rate and Response Time Mean Comparison in the group of Native and Non-Native English Speakers

First, the average correction rates of the comprehension test for the native English group were slightly over twice as high as for the non-native English group across all eight colour conditions; for example, on average, the correctness mean for the group of non-native English speakers was 0.0315, while the overall correctness mean for native English speakers was 0.638.

Second, the average response time of the non-native English group was significantly higher than that of the non-native English speakers group. These results are not surprising since their natural English is different.

Third, most interestingly, the differences in either correction rate or response time across the eight different colour materials were significantly more prominent in the native English group than in the non-Native English group. For example, the native English speakers performed best on average in the grey condition (M: 0.77; SD: 0.34), which is followed by red (M: 0.72; SD: 0.36), blue (M: 0.68; SD: 0.35), and black (M: 0.68; SD: 0.37). They showed lower correction rates in the other four colours, which ranged between 0.50 and 0.60. Regarding response time, the data for the native English speakers' group demonstrated a wider range, with a difference of approximately 130 seconds between the maximum and minimum values. Analysing the data of the native English speakers' group, two colours, namely Grey (M: 232.98; SD: 168.72) and Red (M: 276.01, SD: 197.20), stood out as superior, with average completion times below 300 seconds. This indicates that participants took less time to complete the test under these two Colour conditions.

The different pattern between the two groups may be explained by more significant individual differences regarding English comprehension tests in the non-native English group. Although we assume their proficiency in English reasonably is similar, it should be disregarded that the English ability is complex and encompasses multiple dimensions of language or literacy ability. For example, non-native English speakers did not show a more significant data variation in the correction rates or response time among colours. The influence of colour on their comprehension of textual information was minimal.

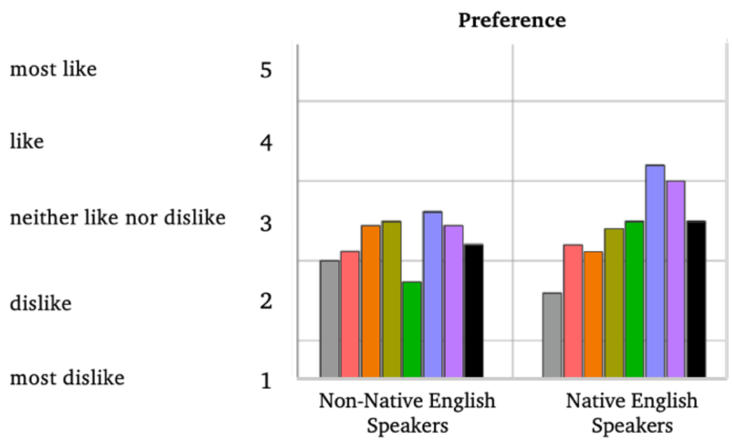

Figure 3. Preference results from the online questionnaire.

Figure 3 showed that regardless of the group, blue emerged as the participants' favourite colour, followed by purple. Similar trends regarding readability and legibility were observed when combining different colour backgrounds with text. This finding is consistent with Hall and Hannah's findings: "Variations in text-background readability findings emphasise the interconnected of readability vis- à-vis colour preference [12].” Even at different age stages, 8-9-year-old children's colour preferences show surprising similarities to those of adults [13]. In addition to colour preferences, Brooker and Franklin's study highlights a significant difference in cognitive performance based on colours. Performance is notably worse in the presence of red compared to grey [13]. The effect of colour remains consistent across different tasks. These findings prove that colour can influence children's cognitive performance, with red specifically having a detrimental effect.

In summary, although there was no significant difference in the comprehension test performance for non-native English speakers in the different colour conditions, there was a significant variation in the survey data, i.e., in the colour preference.

CONCLUSION

Individual colour preferences may affect digital materials' readability but do not significantly affect text-based comprehension tests. Whether or not a participant's native language was aligned with the language in which the test material was written considerably impacted the final results. After removing the barriers created by language, the conclusions of this study showed that participants performed best in the grey colour condition and far better than the other colour conditions.

Although the black background material had the same colour combination as the grey background material, regarding participant performance, combining the more delicate background condition (grey and red) and the darker foreground condition (black) is better than the black background, with the light foreground colour not even as good as the blue colour condition.

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REFERENCES

1. Roberts, W. E. (2009). *The Use of Cues in Multimedia Instructions in technology as a way to reduce Cognitive load.* North Carolina State University. Retrieved from http://repository.lib.ncsu.edu/ir/bitstream/1840.16/4434/1/etd.pdf.
2. Diachenko, I., Kalishchuk, S., Zhylin, M., Kyyko, A., & Volkova, Y. (2022). Color education: A study on methods of influence on memory. *Heliyon, 8*(11), e11607-e11607.
3. Zufic, J., & Kalpic, D. (2009). More efficient e-learning through design: color of text and background. I*n E-Learn: World Conference on E-Learning in Corporate, Government, Healthcare, and Higher Education*, 3314-3319.
4. Pettersson, R. (2010). Information design–principles and guidelines. *Journal of Visual Literacy*, *29*(2), 167-182.
5. Rambally, G. K. (1986). The influence of color on program readability and comprehensibility. In *Proceedings of the seventeenth SIGCSE technical symposium on Computer science education*, 173-181.
6. Camgöz, N., Yener, C., & Güvenç, D. (2002). Effects of hue, saturation, and brightness on preference. *Color Research & Application: Endorsed by Inter-Society Color Council, The Colour Group (Great Britain), Canadian Society for Color, Color Science Association of Japan, Dutch Society for the Study of Color, The Swedish Colour Centre Foundation, Colour Society of Australia, Centre Français de la Couleur, 27*(3), 199-207.
7. Williams, R. (2015). *The non-designer's design book: Design and typographic principles for the visual novice*. Pearson Education.
8. Richardson, R. T., Drexler, T. L., & Delparte, D. M. (2014). Color and contrast in E-Learning design: A review of the literature and recommendations for instructional designers and web developers. *MERLOT Journal of Online Learning and Teaching*, *10*(4), 657-670.
9. Lin, C. C. (2003). Effects of contrast ratio and text color on visual performance with TFT-LCD. *International journal of industrial ergonomics*, *31*(2), 65-72.
10. Roberts, W. (2017). The use of cues in multimedia instructions in technology as a way to reduce cognitive load. *Journal of Educational Multimedia and Hypermedia*, *26*(4), 373-412.
11. *Web Content Accessibility Guidelines (WCAG) 2.1*. (2018, 05 June 2018). Retrieved 19 Jan. from https://www.w3.org/TR/WCAG21/
12. Hall, R. H., & Hanna, P. (2004). The impact of web page text-background colour combinations on readability, retention, aesthetics and behavioural intention. *Behaviour & information technology*, *23*(3), 183-195.
13. Brooker, A., & Franklin, A. (2016). The effect of colour on children's cognitive performance. *British Journal of Educational Psychology*, *86*(2), 241-255.