Contrast Computation for Improved Visibility and User Experience in Educational Interfaces

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Abstract. The effectiveness of digital learning environments depends largely on the usability and accessibility of their visual components. Contrast levels in graphical interfaces play a key role in ensuring visibility, engagement, and a positive learning experience. However, not all educational details are equally noticeable to all users. A lower contrast, if strategically applied and visually striking, can still draw attention and enhance the perception of critical information. This technique is often used in video games, where selective emphasis on certain elements directs the player's focus and improves information processing. This study examines whether high contrast alone guarantees visibility and user-friendliness in digital learning environments. Specifically, we analyze the extent to which WCAG guidelines align with educational needs and whether alternative contrast configurations can maintain readability while reducing visual fatigue. By applying these insights, educators and developers of computational science training materials can refine digital tools, enhance user engagement and improving knowledge retention among learners.

Keywords: Digital learning · User experience · Contrast colors

1 Introduction

As of 2023, digital transformation has significantly influenced multiple sectors, including education. The integration of e-learning platforms, computational tools, and digital resources has heightened the importance of usability and accessibility in digital learning environments. This shift mirrors the trends observed in e-commerce, where technological advancements and internet accessibility have driven rapid expansion. Just as online sales redefine traditional shopping, digital learning is transforming educational methodologies, requiring effective, engaging, and accessible user interfaces.

The e-science market in the US was valued at nearly $400 billion in 2022 and is projected to reach $1 trillion by 2032 [3], driven by increased internet penetration, widespread use of mobile devices, and advancements in cloud-based

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learning systems and interactive simulations. However, accessibility remains a major challenge: According to the WebAIM annual accessibility report, only 3% of the 1.3 million analyzed websites meet the essential usability and readability standards [2].

In computational science education, the design of graphical components, including data visualizations, interactive models, and simulation tools, plays a crucial role in knowledge delivery. However, balancing engagement and cognitive load remains a challenge. Studies indicate that overly intense visuals can cause cognitive overload, reduced retention, and decreased user experience, while low-contrast designs may fail to effectively communicate key concepts [29].

The impact of visual intensity on user experience is particularly relevant in digital education, where interface design directly affects student engagement and knowledge retention. If critical content lacks sufficient emphasis, learners can overlook essential information, reducing the effectiveness of digital platforms. In contrast, excessive visual stimulation can lead to cognitive stress, making it harder for students to focus and process information efficiently [27, 28]. Overly complex visuals can hinder comprehension, induce frustration, and negatively impact learning [5], while insufficient visual emphasis can cause key content to be ignored [4, 11]. To optimize digital learning environments, developers must balance contrast, layout, and interactivity to ensure that visual elements enhance rather than obstruct comprehension and accessibility [36].

Although the WCAG [19] guidelines provide a framework for improving content visibility and accessibility, their adoption remains voluntary. As Figure 1 illustrates, Case 1 represents overly intense contrast, causing irritation and cognitive strain, while Case 2 demonstrates low contrast, leading to reduced visibility and engagement. The goal is to establish Case 3, where contrast is both engaging and comfortable, optimizing learning efficiency without inducing negative cognitive effects.

This study examines whether high contrast alone is sufficient to ensure visibility and user-friendliness in digital learning environments. Specifically, we investigate whether WCAG [19] guidelines align with educational needs or if lower contrast ratios could offer comparable visibility while reducing visual fatigue. This article is a continuation of our previous work [21, 22], in which we used eye-tracking technology to analyze various types of user interfaces. Our main contributions:

- Critical analysis of the applicability of WCAG [19] guidelines in educational interface design.
- Discussion on the role of visual intrusiveness, emphasizing that contrast alone does not determine usability.
- Empirical evidence showing that high contrast may improve visibility but reduce user comfort, while lower contrast can enhance readability and cognitive ease.
- Recommendations for color combinations that optimize both visibility and user-friendliness, improving the effectiveness of digital learning materials.

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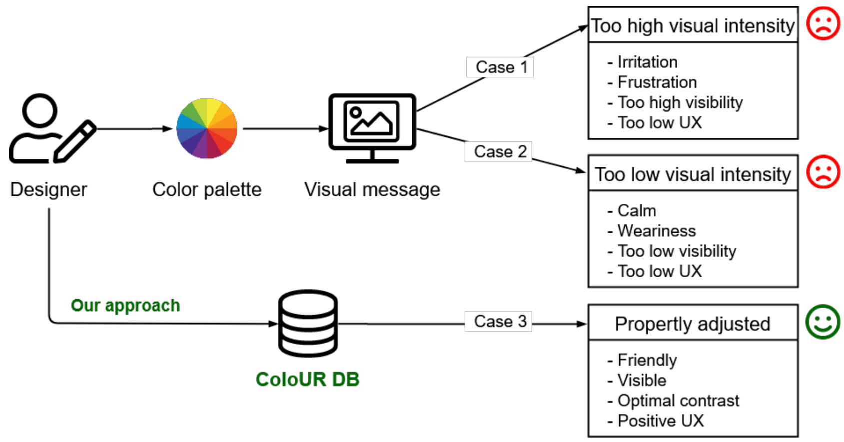

Fig. 1. A designer without support may choose colors that are either too high (Case 1) or too low (Case 2). Case 1 leads to overstimulation and irritation, while Case 2 results in reduced visibility and emotional impact. Our research aimed to develop Case 3 - a balanced approach ensuring user-friendliness, visibility, and contrast colors.

The paper is organized as follows. First, we introduce the state-of-the-art in the Related Work section. The conceptual framework and subjective experiment (which explains the subjective experimental procedure in detail) are presented in the Methods section. The results and analyses can be found in the Results section. A description of potential development directions concerning the state-of-the-art can be found in the Discussion section.

2 Related Work

Most accessibility guidelines recommend a minimum contrast ratio to enhance visibility, yet little attention is given to the potential drawbacks of excessive contrast. Research indicates that extremely high contrast can negatively impact reading experiences [20], causing visual discomfort and cognitive strain, particularly in educational contexts where students process large volumes of text and visual information over extended periods. Experimental studies have shown that a maximal contrast ratio of 21:1 is often perceived as intrusive and unfavorable. At the same time, prolonged exposure to high-contrast interfaces can reduce concentration, increase fatigue, and even lead to cybersickness [8, 7]. In contrast, insufficient contrast diminishes content visibility, hindering information retention and accessibility. Both extremes—overly intense and insufficient contrast—negatively affect user engagement, as illustrated in Figure 1. To enhance the effectiveness of graphical content in digital education, non-invasive attention-guiding techniques can help direct learners' focus toward key instructional elements [35]. Identifying entry points within an educational platform and highlighting salient areas improve user engagement and comprehension [24],

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while adapting the type, intensity, or frequency of visual stimuli mitigates habituation effects [16]. A key strategy for optimizing educational visual content involves using contrast-based color combinations that enhance readability and learning outcomes [31], as contrast significantly influences cognitive processing and information retention—critical factors in digital learning environments [30].

The importance of contrast in the perception of educational content. Contrast plays a crucial role in the visibility and clarity of educational materials, directly impacting readability and comprehension [15]. Various contrast models, such as Weber contrast [32], Michelson contrast [26], and RMS contrast [33], are applied in different contexts, posing a challenge for instructional designers. To ensure accessibility, this study follows the WCAG standard [19], which defines contrast using "relative luminance," a measure of brightness on a normalized scale from 0 (black) to 1 (white). Evaluating different contrast configurations helps identify combinations that enhance readability without causing strain. Poor contrast selection can either lead to excessive visual fatigue or reduced content visibility, hindering learning.

The problem of invasiveness in educational graphical content. A significant challenge in designing educational graphics is avoiding excessive invasiveness, which can disrupt the learning process. Inadequate color choices may distract students, interrupt cognitive flow, and reduce focus, leading to frustration and disengagement. According to [5, 36], the overuse of highly intrusive visual elements intended to capture attention is linked to declining learning efficiency and student satisfaction. Previous research that has examined the effects of intrusive elements on knowledge retention and cognitive load was investigated in [9]. Metrics have been developed to assess the level of intrusiveness [12] and have been applied in different educational contexts [25, 36]. Beyond perceived intrusiveness, frequent exposure to intense visual stimuli can lead to habituation effects [18], where learners become desensitized to critical instructional graphics. This outcome is counterproductive, as it reduces engagement and prevents students from focusing on essential content. To foster an effective learning experience, designers must strike a balance between engaging graphical elements and maintaining an optimal level of cognitive load, ensuring that visual materials enhance rather than hinder comprehension.

Role of color in human perception Color plays a key role in human perception, significantly influencing our emotions, decisions, and how we perceive the world around us. Colors have the inherent ability to evoke a range of emotions and psychological states. For instance, certain colors can increase heart rate, elevate adrenaline levels, induce feelings of excitement or tranquility, stimulate concentration, or improve mood [13]. The physiological and psychological impacts of color are well-documented, illustrating how specific hues can affect human behavior and emotional responses[10].

Colors also play a crucial role in our ability to process information and understand our surroundings. Bright and contrasting colors help in the faster identification of objects, thereby improving readability and information retention. Studies have shown that using appropriate color contrasts can significantly en-

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hance the legibility of text and the efficiency of learning materials [14, 34]. This is particularly important in educational settings, where the effective use of color can facilitate better learning outcomes and comprehension.

Taking the above, there arise the research questions regarding what level of contrast in digital educational content elements attracts user attention without negatively affecting user experience. How can the lowest possible contrast be maintained while ensuring acceptable readability and user-friendliness? The motivation for this study was the significant challenge of selecting appropriate colors in educational environments, such as e-learning platforms and interactive learning materials. Improper color choices can reduce the effectiveness of information transfer and hinder the process of knowledge acquisition over time.

Therefore, we propose an approach that detects the optimal visual intensity, ensuring user-friendly and well-visible messages. It is based on selecting contrast between primary and secondary colors, where the primary color remains a fixed element of the visual message, and the secondary color serves as its complementary counterpart. Primary and secondary colors may appear in the background, images, pictograms, text, etc. The proposed approach allows for balancing user experience and visual intensity, which can support learning efficiency. Proper color selection in educational interfaces can reduce cognitive fatigue and enhance learning efficiency by optimally adjusting visual intensity to the user's level of engagement. The study results, presented in detail in the *Results* section, demonstrate that it is possible to maintain low contrast while effectively delivering content in a user-friendly manner that supports the learning process.

3 Approach and Methodology

The authors confirm that all experiments followed the relevant guidelines and regulations. All analyzed data were fully anonymized. Before the experiment, the participants provided informed written consent to have data from the perceptual experiment used in the investigation. Informed consent was obtained from all participants.

Screening Observers. The observers may have reported implausible impression scores because they misunderstood the experiment instructions or did not engage in the task and gave random answers. If the number of participants is low, it is easy to spot unreliable observers by inspecting the plots. However, when the number of observers is very high or it is difficult to examine the plots, the ITU-R.REC.BT.500 [17] standard, Annex 2.3.1, provides a numerical screening procedure. We performed this procedure on our data and found that four participants needed to be removed.

Choice of colors for the experiment. Color theory provides essential principles for design, including the color wheel, harmony, contrast, and contextual application. In selecting colors for our experiment, we adhered to key guidelines:

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– Limited color set (maximum of 10) to maintain user focus and experimental consistency.
– Inclusion of neutral colors (white, black, gray) to balance saturated hues and provide a stable background.
– Use of highly saturated colors to enhance visual attention, based on prior research [6].
– Combination of warm and cool colors to explore their psychological impact.

Brightness and saturation variations were excluded, with all colors (except neutrals) set to 100% saturation, aligning with findings that users respond most strongly to highly saturated colors in graphical user interfaces [6].

Analysis of digital educational design trends on platforms like awwwards.com and colormatters.com highlights the increasing use of "Vibrant Colors Modulated by Neutral"—bold, saturated colors for interactive elements balanced by neutral tones for readability and engagement.

Our approach is based on the traditional color wheel, introduced by Newton (1666), which defines three primary colors (red, yellow, blue) and their secondary mixtures (orange, green, purple). This principle guided our selection of nine colors for digital learning content: red, yellow, blue, orange, green, purple, black, gray, and white. To ensure compatibility with digital displays and optimize the educational experience, colors were defined in the RGB color space—Red (255,0,0), Yellow (255,255,0), Blue (0,0,255), Orange (255,125,0), Green (0,255,0), Violet (125,0,255), Black (0,0,0), Gray (145,145,145), and White (255,255,255). These selections support contrast optimization, enhance visual hierarchy, and improve readability, ultimately reducing cognitive load and increasing accessibility in digital learning environments.

Contrast calculation. WCAG 2.1 standard [19] defines two success criteria for contrast levels in Guideline 1.4: Minimum contrast (AA level): At least 4.5:1 (or 3:1 for large text). Increased contrast (AAA level): At least 7:1 (or 4.5:1 for large text).

Contrast is calculated numerically as a luminance ratio between two colors, based on their RGB components. The process follows these steps: (Step 1) Measure the relative luminance of each letter (unless they are all uniform) using the formula $L = 0.2126 \cdot R + 0.7152 \cdot G + 0.0722 \cdot B$ where R, G and B are defined as: if $R_{sRGB} \leq 0.03928$ then $R = R_{sRGB} \div 12.92$ else $R = ((R_{sRGB} + 0.055) \div 1.055)^{2.4}$, if $G_{sRGB} \leq 0.03928$ then $G = G_{sRGB} \div 12.92$ else $G = ((G_{sRGB} + 0.055) \div 1.055)^{2.4}$, if $B_{sRGB} \leq 0.03928$ then $B = B + sRGB \div 12.92$ else $B = ((B_{sRGB} + 0.055) \div 1.055)^{2.4}$, and R_{sRGB}, G_{sRGB}, and B_{sRGB} are defined as: $R_{sRGB} = R_{8bit} \div 255$, $G_{sRGB} = G_{8bit} \div 255$, $B_{sRGB} = B_{8bit} \div 255$. (Step 2) Measure the relative luminance of background pixels immediately next to the letter using the same formula. (Step 3) Calculate the contrast ratio using the following formula: $(L1 + 0.05) \div (L2 + 0.05)$ where L1 is the relative luminance of the lighter of the foreground or background colors, and L2 is the relative luminance of the darker of the foreground or background colors. (Step 4) Check that the contrast ratio is equal to or greater than 7:1 It is also possible to use the Color Contrast Analyser software recommended by the WCAG

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(https://www.tpgi.com/color-contrast-checker).

To be able to compare results obtained for individual color pairs, data were standardized and normalized to the whole space.

Experimental method. Our approach is based on perceptual experiments. We introduced forced-choice metrics to identify colors that match in the most noticeable way. In the following, we explain the procedure we used. In order by the *forced-choice pairwise comparison* procedure, the observers are shown a pair of images (of the same scene) corresponding to different conditions and are asked to indicate the more eye-catching image. The question that was verified through consultation with a psychologist was as follows: *Choose the color composition that you think attracts the people's attention to the poster concerning the thing you lost.* It is easier for people to answer a natural question that does not require additional knowledge. Observers are always forced to choose one image, even if they see no difference between them (hence the name "forced choice"). There is no time constraint within which one must make their decision. The method is popular, but it is highly tedious if a large number of conditions need to be compared. However, as reported in [23], it results in the smallest measurement variance and thus produces the most accurate results.

Experimental procedure. The observers were asked to read a written instruction before every experiment. Following the recommendation ITU-R.REC.BT.500 [17], the experiment started with a training session in which observers familiarized themselves with the task, the interface, and the images displayed. To ensure that observers fully attended the experiment, three random trials were shown at the beginning of the main session without recording the results. The images were displayed in random order and with different randomizations for each session. Two consecutive trials showing the same test image were avoided if possible. If possible, two consecutive trials showing a different pair of pictograms with the same background were avoided. The experiment was carried out with the use of an eye tracker; therefore, each experiment was preceded by the calibration of the eye tracker, after which the user could start the experimental procedure.

4 Results and Analysis

The following section discusses the results of a perceptual experiment with the main goal of analyzing human preferences more related to the contrast between colors than the color itself. We want to identify the color connections that humans pay the most attention to in a positive manner. The selected colors should bring awareness to the content but without irritation or weariness. To avoid ambiguities, we created a consistent naming convention for all subsequent sections, described below.

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Characteristics of the stimulus and experiment conditions. To find the most eye-catching but user-friendly pairs of colors, 72 images were prepared as follows: for each of the analyzed colors (black, gray, green, blue, violet, red, orange, yellow, and white), one color was fixed as primary (and set as a background or a pictogram), and the second color for each generated pictogram was chosen from the set of remaining colors and called the secondary color. We used it as opposed to the primary color as a pictogram or a background, respectively. Example images with a black primary color are shown in Figure 2. The images had a rectangle shape in 1:2 proportions, allowing them to better fit the display resolution. They took up 40% of the full-screen surface. The object shapes were picked such that they did not distract the user. Hence, we chose a regular rectangle shape and the widely known e-mail icon. However, colors, not shapes, were our primary focus. The choice of colors for the experiment is presented in the Methods section.

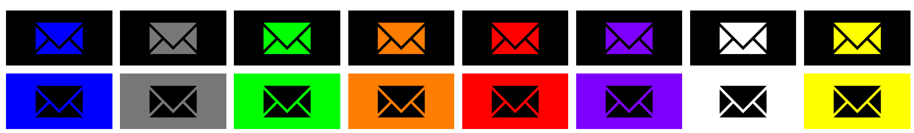

Fig. 2. The example test images used in the experiment. In the figure, the images were composed of a 'black' color set as primary for the background (top row) and for the pictogram (bottom row), and the remaining colors (blue, grey, green, orange, red, violet, white, and yellow) were set as secondary colors. We assume that the effect of contrast between two colors does not depend on whether they are used as the background or pictogram.

The experiment was carried out by 35 naive observers who were confirmed to have normal or corrected-to-normal vision. The age of the observers ranged between 20 and 68 years. For additional reliability, each observer repeated each experiment three times, but no two repetitions took place on the same day in order to reduce the learning effect. According to [23], collecting 30–60 repetitions per condition is sufficient. By condition, we understand that two matched colors (pictogram and background) are represented by a pair of objects.

The images are shown on a 50% gray background, which has been recommended by the International Color Consortium (www.color.org) as a background for comparing colors. The same background was used for the intervals between displayed pairs of images. The mouse cursor was reset to a neutral position after each trial. The experiment was conducted on an EIZO ColorEdge CG220 22.2-inch display, calibrated using X-Rite i1 Publish Pro 2. For optimal eye tracking, the distance from the participant's eyes to the eye tracker was set at 60 cm, as recommended by Tobii [1]. In the room, constant and uniform lighting conditions were ensured by using lamps with color temperature 5000 K (D50 standard). According to the International Color Consortium, the color observation angle was

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2^o. Additionally, the surrounding light in the room was regularly controlled using a Sekonic L-478DR light meter.

For comparison, only images with the same primary color were taken. This enables reliable user comparisons, as introducing more than three colors (one primary and two secondary) would make the experiment difficult to conduct or even lead to inconsistent results.

User-friendliness and visibility evaluation with rankings. To stabilize the results between images given for the same primary color, the analysis was performed on the scores that were computed for every primary color separately. The votes received per image were first standarized. The higher the score value, the more eye-catching and user-friendly the image. After standardization, the data was normalized, allowing easier comparison of the results. The results for every primary color are depicted in Figure 3. Every plot contains the color ranking arranged according to the four user-friendliness and visibility ranges: $< 0; 0.25)$, $< 0.25; 0.5)$, $< 0.5; 0.75)$, and $< 0.75; 1 >$. To compare the results with the typical approach given by the WCAG standard [19], contrast values were normalized as well and are displayed for the same color pairs.

During the experiment, users evaluated the colors within nine primary colors: black, gray, green, blue, violet, red, orange, yellow, and white. Each primary color was fixed as a background or pictogram, as shown in Figure 2. The goal was to investigate whether a change (negative) in the primary color influences the user assessment of user-friendliness and visibility. The analysis of the experiment results showed that the users did not see much difference between the primary color as a background and the primary color as a pictogram (the average difference between the user responses was 0.11). Therefore, the values can be averaged. It can be assumed that we have primary and secondary colors, where the primary color can be either a background or a pictogram.

The research procedure consisted of five steps. The first step was to carry out the experiment with users according to the procedure described at the beginning of this section. The experiment was carried out under controlled laboratory conditions in a group of 41 users. Users were tasked with selecting color pairs that, according to their perception, were more user-friendly and allowed them to easily read messages. The experiment was repeated three times for each user. The collected data were subjected to statistical analysis, including standardization and normalization. This enabled their comparison and drawing objective conclusions. Afterward, ColoUR DB was created. ColoUR DB contains data on user preferences for user friendliness and visibility of primary and secondary colors. In addition, the color contrast was calculated for each pair of colors according to the WCAG [19] recommendation. The procedure for calculating the color contrast is described in the Methods section. ColoUR DB allows for grouping colors regarding user-friendliness, visibility, and color contrast, creating a color ranking within each primary color. The color ranking shows the user-friendliness, visibility, and contrast values that each color pair has achieved. Finally, we divided the scores obtained from the experiment into 4 quartiles and performed statistical analysis between them.

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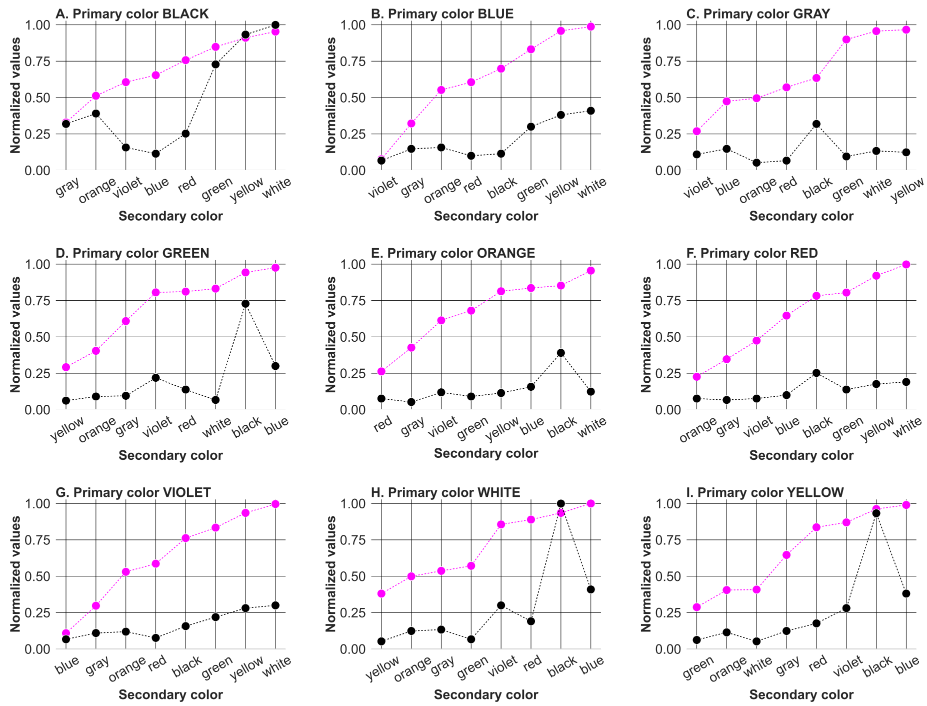

Fig. 3. Color rankings for primary and secondary colors were based on ColoUR DB. The figure presents results for nine tested colors: Black, Blue, Gray, Green, Orange, Red, Violet, White, and Yellow, ranked by user-friendliness and visibility. Each graph represents a single primary color, with secondary colors on the X-axis and normalized experimental values on the Y-axis. Two plots are shown: (1) user-perceived friendliness and visibility (pink) based on experiment data from the Results section, and (2) contrast values (black) calculated according to WCAG [19] as detailed in the Methods section.

The color ranking (see Figure 3) is ordered by user-friendliness and visibility based on user response. Results are presented for primary colors A through I, linked to a set of secondary colors (X-axis). All data have been normalized and divided into four ranges with division values 0, 0.25, 0.75, and 1 (Y axis). In the range <0; 0.25), users rated pairs of primary and secondary colors as the least user-friendly and visible. In the range <0.75; 1), users rated pairs of primary and secondary colors as the most user-friendly and visible. Each pair of primary and secondary colors has two values: user-friendliness and visibility (pink plot) and contrast (black plot). Discrete values are connected by a line for better data visualization. The ranking of user-friendly and visible colors does not always match that of color contrast. Primary and secondary color pairs having the highest contrast coefficients were not rated highest by users in terms of user-friendliness and visibility: see Cases C, D, E, F, H, or I in Fig. 3. On the other

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hand, primary and secondary color pairs with the lowest contrast coefficient reached a high level of user-friendliness and visibility, e.g., D: Green–White; A: Black–Blue.

ColoUR Picker Tool and ColoUR DB. The research results were implemented as a tool for designers—the ColoUR Picker Tool, an application that runs in a web browser environment. The Chrome browser is recommended. The ColoUR Picker Tool allows you to select primary and secondary colors from the color wheel, set the primary color as a background or a pictogram, and visualize the remaining colors as pictograms, background, or text. Figure 4 shows example screens and the sample selection process. The results are displayed to the designer in the form of a color ranking and a user-friendliness, visibility, and contrast index. The ColoUR Picker Tool retrieves data from ColoUR DB acquired earlier during the perceptual experiment. ColoUR DB contains 72 combinations of primary and secondary colors. There are two metrics for each color pair: the contrast calculation and the user-friendliness with visibility from user responses. Normalized data is displayed on a scale from 0 to 100% for each metric. The ColoUR Picker Tool is available on Github—*https://visual-communication.github.io/ColoUR-Picker.*

5 Discussion

The research confirms that it is possible to find color combinations that do not necessarily have high contrast but still provide visibility and enhance the user experience in digital educational content. The conducted experiment allowed us to derive meaningful insights regarding color perception in learning environments.

Among the best combinations in terms of user-friendliness and visibility, a large number contain neutral colors. Surprisingly, user ratings were lower when the secondary color was gray. In most cases, combinations featuring gray were perceived as less user-friendly and less visible. Combinations of warm and cool colors were deemed user-friendly and visible. For user-friendliness and visibility ranges, primary and secondary color pairs, along with their reversed versions, were identified. These findings suggest that these color pairs may be universally applicable across different contexts of digital learning design.

The results indicate that visibility goals can be achieved along with user-friendliness, even when using elements with moderate contrast. For selected color pairs, even low to medium contrast resulted in a positive experience alongside effective visual performance. Avoiding excessively high contrast is justified, as previous research suggests that excessively strong contrasts may be perceived as intrusive [20]. High contrast, particularly in prolonged reading or extended interaction with content, may negatively impact the learning experience. User interface elements should be highlighted to maintain visibility for interactions lasting longer than 15 minutes, as excessive contrast may lead to discomfort [8]. Additionally, reducing contrast while preserving informational clarity is crucial in preventing cybersickness caused by extreme contrast levels [7].

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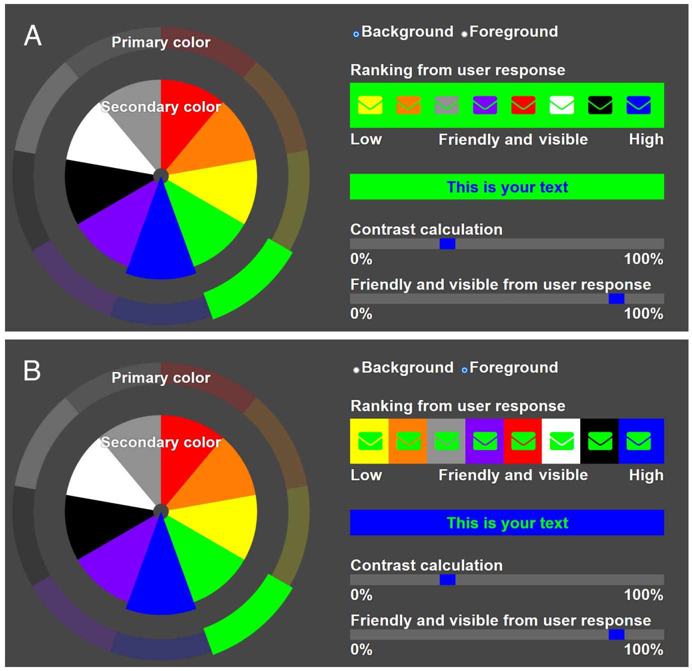

Fig. 4. The research findings are presented through the ColoUR Picker Tool. Users select primary and secondary colors via a color wheel, with a graphical analysis shown alongside. Rankings reflect user-friendliness and visibility, with pairs ordered accordingly. The tool allows toggling the primary color between background and foreground. Contrast (based on WCAG), user-friendliness, and visibility indices are displayed. Case Study: (A) Choosing green as the primary color shows compatible pairs ranked by user ratings, along with previews and metrics. The green–blue pair, for example, received higher visibility ratings than contrast values alone suggest. (B) Switching the view places green in the foreground, enabling comparison of how color roles affect perception.

Despite the practical applications of this study, certain limitations exist. The primary constraint is that an extensive set of colors may lead to cognitive overload, making it difficult for users to objectively assess differences. The experiment used a selection of 10 colors, which does not encompass the full spectrum of colors used in digital educational design. However, the findings can be applied to specific components that designers aim to highlight, such as icons, call-to-action buttons, alerts, and visual cues in educational platforms. Future studies could expand on this research by incorporating colors with varying saturation and brightness levels, broadening the scope of applicable design principles. Additionally, this experiment used images and pictograms, which prevented testing of text readability. Future research should consider text-based assessments to further refine these findings.

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Research application. The findings of this research can be applied to a wide range of digital educational materials, including graphical user interfaces for web-based learning, desktop and mobile applications, printed and digital instructional materials, and visual communication elements in e-learning environments. Designers working on digital education projects often face the challenge of choosing color schemes that both attract attention to key content areas and ensure user-friendliness, visibility, and aesthetic coherence. Use cases in digital learning environments include:

- A learning platform's design constraints may require the use of a specific accent color, such as blue. When designing text and menu icons, a designer can set blue as the primary color and use this research to select an optimal secondary color that enhances readability and user experience.
- Instructional banners and visual messages often use high-contrast colors, such as red, which may be overwhelming. Designers can select red as a primary color and pair it with a secondary color that enhances visibility while reducing contrast intensity, making the message more readable and user-friendly.
- In brand guidelines for e-learning content, logos, and graphical elements are often presented in multiple color variations. Designers can use these findings to select background colors that complement a primary logo color, such as choosing suitable secondary colors for a violet primary logo. Additionally, they can analyze how logo colors appear in negative versions and assess their visibility and user-friendliness.
- The insights from this study can also be applied to designing progress indicators in educational platforms. Color-coded feedback can enhance motivation by visually representing achievements, such as progress bars, skill levels, or reward systems. In gamification elements, selecting user-friendly yet engaging color combinations can improve user engagement, guiding learners through tasks and fostering a sense of accomplishment.

6 Conclusions and Future Work

The study confirmed that effective visibility and user-friendliness in digital educational materials can be achieved even with moderate contrast. Designers may deliberately avoid excessively high contrast, as it can negatively impact user comfort during prolonged learning sessions. Future research should encompass a broader color spectrum, including varying levels of saturation and brightness, as well as a more nuanced analysis of contrast in relation to specific content types - particularly text-heavy interfaces. This includes evaluating contrast in terms of text readability and prolonged exposure to textual content. Further experiments should also consider diverse usage contexts, including the needs of users with color vision deficiencies, and environments such as mobile applications, augmented reality, and interactive e-learning modules.

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