APPLICATION OF INFORMATION TECHNOLOGY IN ASSESSING COLOR VISION DEFICIENCY TO SUPPORT EDUCATIONAL CONSULTATION FOR HIGH SCHOOL STUDENTS

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ABSTRACT: Color vision deficiency (CVD), commonly referred to as color blindness, is a hereditary visual disorder linked to a recessive gene on the X chromosome that impairs individuals' ability to distinguish between certain colors. This condition presents considerable challenges for high school students in their academic activities. Timely identification and precise evaluation of CVD are essential for developing effective educational counseling programs tailored to the needs of affected students. This study examines the impact and benefits of utilizing Information technology (IT) solutions in the assessment of CVD to enhance counseling services for high school learners. Data were gathered from a sample of 527 students in Da Nang, employing a digital version of the Ishihara test supplemented with advanced color recognition software. Findings demonstrate that IT applications significantly improve assessment accuracy, decrease the time required for evaluation, and broaden the scope of screening efforts. The study proposes a model integrating IT into educational counseling frameworks to facilitate early detection of CVD, support the creation of accessible instructional materials, and provide individualized career guidance. These advancements ultimately contribute to improved learning outcomes and foster inclusive education. The research highlights promising pathways for further integration of IT tools in supporting students with CVD within the Vietnamese educational system.

Keywords: Color vision deficiency; Information technology; Educational counseling; High school students; Inclusive education

1. INTRODUCTION

1.1. Background and urgency of the study

Color Vision Deficiency is a common hereditary disorder that impairs the ability to distinguish certain colors, particularly red and green hues (Birch, 2019). The global prevalence of CVD is estimated at approximately 8% in males and less than 1% in females (Simunovic, 2021). In Vietnam, the proportion of affected students is similar; however, most cases remain undetected due to limitations in screening programs (Tran et al., 2018).

Accurate assessment of CVD is a critical initial step in developing appropriate support and educational counseling programs. Traditionally, CVD evaluation relies on color plates such as the paper-based Ishihara test, which requires significant time, manpower, and is highly dependent on lighting conditions and administration procedures. IT has introduced numerous innovative solutions including software applications, mobile apps, and digital color vision testing devices that enable faster, more objective, and more accurate assessments (Dalton, Harper & Collins, 2020; McIntyre & Smith, 2022).

Within the context of inclusive education, the application of IT not only facilitates early detection of CVD but also supports the design of color vision-friendly learning materials, the adjustment of teaching methodologies, and personalized career counseling for high school students with CVD. This is especially important to ensure equal learning opportunities and maximize the potential of these students in the general education environment (Smith & Wilkins, 2022).

In Vietnam, research on CVD remains limited and lacks a systematic approach. Awareness of CVD within the education sector is insufficient, and teachers have not been adequately trained to identify and support students with CVD (Birch, 2019). Many students are only diagnosed with CVD after experiencing learning difficulties, which leads to feelings of low self-esteem, anxiety, and negatively impacts their academic performance (Phan et al., 2021). Therefore, studying the effects of CVD on high school students and developing educational counseling strategies is essential to support their comprehensive development and integration into the learning environment.

This study focuses on surveying 527 twelfth-grade students in Da Nang, employing a digital Ishihara test combined with advanced color analysis software to assess CVD, while simultaneously analyzing the effectiveness of IT applications in educational counseling. Based on these findings, the study proposes an IT-integrated counseling model tailored to the characteristics of Vietnamese students to support early detection and educational inclusion of students with CVD.

1.2. Definition and classification of color vision defects

Color vision deficiency is a disorder of color discrimination due to defects in the cone cells in the retina (Simunovic, 2021). According to modern classification, CVD is divided into the following main types:

• Red-green deficiency, including Protanomaly and Deuteranomaly, is the most common form (Cole, 2019).

• Blue-yellow deficiency is less common (Dalton et al., 2020).

• Complete blindness (achromatopsia) is very rare (McIntyre & Smith, 2022).

These forms affect the ability to discriminate colors in different ranges, from mild to severe, and greatly affect the recognition of color-related learning information.

1.3. The impact of color vision impairment on learning

Recent international research has shown that CVD negatively affects students' learning performance, especially in subjects that use color as a primary channel for information transmission (Smith et al., 2022; Tran & Lee, 2023). CVD students have difficulty recognizing the color of indicators in chemistry experiments, distinguishing colored areas on geographical maps, reading color charts in biology, and expressing ideas with color in art (Nguyen et al., 2021). Studies have also shown that lack of awareness and training of teachers about CVD leads to a lack of appropriate lesson adjustments, forcing CVD students to fend for themselves or rely on their peers, affecting their self-confidence and learning outcomes (Spalding et al., 2021).

1.4. Current status of research and support in Vietnam

In Vietnam, screening programs for CVD are not yet widespread in general education schools, and policy development to support students with CVD remains at a very preliminary stage (Birch, 2019). Many teachers have not yet recognized the necessity of adapting teaching methods for students with CVD.

This situation calls for empirical research to provide practical data on the prevalence of CVD among students, its specific impacts, and to propose feasible educational counseling solutions, thereby contributing to the promotion of a more equitable and inclusive learning environment.

This paper presents a study on the application of information technology (IT) and artificial intelligence (AI) in the assessment of CVD and the provision of educational counseling support for high school students. The study develops a mobile application system that integrates a digital Ishihara test with a personalized career counseling AI chatbot to facilitate early detection and effective support for students with CVD. The primary contribution of this research lies in the integration of advanced technologies within the Vietnamese educational context and the experimental evaluation conducted with a large sample to validate the feasibility and effectiveness of the proposed application. The findings contribute to a better understanding of the potential of IT applications in inclusive education and provide a scientific foundation for the future implementation of digital solutions.

2. LITERATURE REVIEW

In recent years, the application of IT and AI in inclusive education, especially supporting students with disabilities, has become an important and rapidly developing research direction globally. Many studies have focused on exploiting the potential of digital technologies to improve the effectiveness of assessment, educational counseling and personal development support for students with special needs.

2.1. Color vision deficiency and its impact on learning

Color Vision Deficiency is a defect in the ability to perceive colors, especially the most common deficiencies related to red and green hues, caused by mutations in genes located on the X chromosome (Cole, 2019). The severity of CVD can range from mild to severe, with some individuals unable to perceive any color at all (Achromatopsia) (Simunovic, 2021). International studies have demonstrated that CVD causes difficulties in learning activities that involve color use, such as reading maps, charts, and color-coded materials in subjects like Chemistry, Biology, Geography, and Art (Dalton et al., 2020; Smith & Wilkins, 2022). These difficulties negatively affect both academic performance and student psychology (McIntyre & Smith, 2022).

2.2. Application of information technology in assessing color vision deficiency

Information Technology (IT) has brought significant advances in assessing CVD through tools such as digital Ishihara plates, mobile applications (Color Blind Pal, Sim Daltonism), and specialized optical sensor-based color vision measuring devices (Dalton et al., 2020; McIntyre & Smith, 2022). These applications enable faster and more accurate screening compared to traditional methods, while also facilitating easy storage and tracking of results on electronic platforms.

For example, digital Ishihara plates offer standardized color display, adjustable lighting, and time-limited presentations to enhance objectivity (Dalton et al., 2020). Mobile applications allow students and parents to conduct preliminary self-assessments and receive guidance to seek professional evaluation from medical or educational institutions (McIntyre & Smith, 2022).

2.3. Application of Information Technology in Assessing CVD and Educational Counseling

The application of Information Technology (IT) in assessing CVD and supporting educational counseling for high school students has become an inevitable trend to improve accuracy, efficiency, and broaden screening coverage. Software and mobile applications digitizing the Ishihara test have been developed to replace the traditional paper-based methods, offering advantages such as convenience, speed, and minimizing errors caused by lighting conditions or operator variability (Dalton, Harper, & Collins, 2020; McIntyre & Smith, 2022).

The software and AI assistants not only reduce subjectivity in CVD assessment but also enhance the effectiveness of career counseling and mitigate psychological stress for students when confronting information about their disabilities (Phan et al., 2024). The application of IT and AI in this field also promotes digital transformation in inclusive education, contributing to building equitable learning environments and supporting the holistic development of students with special needs (Tran et, al., 2018; Smith & Wilkins, 2022).

However, the research also identified several current limitations, such as software accuracy depending on display device quality and environmental conditions, and the AI model requiring further training with specialized data and expanded capability to classify detailed degrees of deficiency (Le & Nguyen, 2020). Future development proposals include multi-platform integration, continuous updates of occupational and disability databases, and training users-teachers and counselors-to effectively use these IT tools.

2.4. IT Support for Educational Counseling and Inclusive Education

IT not only facilitates assessment but also supports the development of learning materials friendly to students with CVD through designing digital lectures, videos, and software featuring alternative annotations replacing colors or adjustable contrast (Smith & Wilkins, 2022). Additionally, IT assists teachers in monitoring learning progress, adapting teaching methods, and establishing career counseling plans based on personalized data (Dalton et al., 2020). In the context of inclusive education, the application of IT is an inevitable trend to enhance the quality and effectiveness of education for students with special needs such as CVD, thereby promoting equality and improving educational quality (Tran et al., 2018).

However, the effectiveness of these technologies and adaptations in enhancing learning outcomes for students with CVD has not been fully explored. While there is some evidence suggesting their positive impact, more comprehensive studies are needed to evaluate their long-term effectiveness and to identify best practices for their implementation in the classroom (Dalton et al., 2019).

Overall, the literature demonstrates that CVD poses significant challenges in the educational environment, particularly in subjects that require color discrimination. Teacher awareness, while improving, remains a critical issue that must be addressed to ensure that students with CVD receive the necessary support. Educational strategies, including the use of assistive technologies and alternative teaching methods, show promise in mitigating the impact of

CVD. However, further research is required to evaluate the long-term impact of these interventions on students' academic success.

3. MATERIAL AND METHODS

The study employed a mixed methods approach to collect both quantitative and qualitative data. Screening for CVD was conducted using a mobile application integrated with a digital Ishihara test, providing a more accurate and convenient assessment compared to traditional methods. After classifying the severity of CVD, students experienced a personalized career counseling system through an AI chatbot tailored to their individual characteristics. Satisfaction with the system was surveyed using a 15-item questionnaire based on a 5-point Likert scale, divided into five content groups reflecting user experience. In addition, semi-structured interviews were conducted to gather in-depth feedback from students, teachers, and counseling staff.

Quantitative data were processed using SPSS software employing descriptive statistics, Cronbach’s Alpha reliability testing, exploratory factor analysis (EFA), and multiple regression analysis. Qualitative data were analyzed using content analysis to extract key themes and relationships.

3.1 Study design

This study employed a cross-sectional design combining both quantitative and qualitative approaches to investigate the current status of CVD and evaluate the effectiveness of IT applications in screening, assessment, and educational counseling for high school students.

3.2. Participants and setting

The participants included 527 students randomly selected from five public high schools in Da Nang city. Among them, 17 students were identified as having CVD through assessments using a digital Ishihara test combined with supporting software.

3.3. Instruments and data collection procedures

Digital Ishihara test: Utilized software to display Ishihara plates on computers or tablets with high color accuracy and controlled presentation time for CVD assessment.

Use of mobile application: Developed an Android mobile application incorporating the Ishihara test (2018), maintaining the same hue but varying in brightness and saturation to assess CVD. The app collects data and provides educational counseling information for students. It gathers data on the current status of CVD and the ongoing assessment process; applies IT to support the evaluation of CVD; and collects data from the deployment and use of these tools to assess their effectiveness and capacity to support students’ career guidance.

Survey questionnaire: Developed based on relevant literature to collect data on difficulties related to color perception in learning and perceptions of the effectiveness of IT-supported evaluation and learning.

Semi-structured interviews: Conducted with students identified as having CVD to collect in-depth information about their current condition and support needs.

3.4. Data analysis

Data processing methods: The results were analyzed using statistical probability methods applied in biomedical sciences, along with specialized software for measurement and evaluation. SPSS, AMOS and excel were used for data analysis and processing, statistical handling, and analysis of data collected during the research process.

4. RESULTS

This study employed a mixed-methods approach, combining both quantitative and qualitative methodologies. Students' color vision status was assessed using an Android mobile application integrated with the Ishihara (2018) test, which features plates with identical hues but varying in brightness and saturation. This tool was used to evaluate color vision, collect data, and provide educational counseling information for students. In-depth interviews were conducted with students exhibiting signs of color blindness to assess different types of CVD and to support tailored educational guidance.

An AI-powered digital assistant software digitizing the Ishihara test consisting of 38 test plates, designed as color-standardized bitmap images and integrated into popular mobile devices (smartphones, tablets). The application interface allows timed presentation of each test plate, collects multiple-choice responses, stores results, and rapidly analyzes to classify the type of CVD (protan, deutan, or total color blindness). The software facilitates large-scale low-cost screening, convenient deployment in schools and communities, and reduces the workload for healthcare workers and specialized teachers.

The integration of AI and large language models (LLM) into the digital assistant has expanded personalized counseling support for students with CVD. For instance, AI chatbots can interact directly, collecting information about the degree of CVD, preferences, abilities, and career aspirations of students, then provide suitable career guidance helping students choose appropriate fields of study and professions compatible with their color vision capacity. Three chatbot types were developed: general career counseling for all students, specialized counseling for students with CVD, and career suitability evaluation based on color vision test results.

4.1. The situation of color blindness in 12th grade students in the study

The survey conducted among 527 high school students in Da Nang identified 17 students with some form of CVD, representing approximately 3.22% of the sample population. The majority of these students were diagnosed with red-green color blindness, with deuteranomaly being the most common subtype. This result aligns with global statistics indicating a higher prevalence of red-green deficiencies among males.

Table 1. Situation of color blindness in 12th grade students in the study

Subject / Color perception		Male		Female	
		Quantity	%	Quantity	%
Total students		308	100	219	100
Normal person		297	96,43 ± 2,08	210	95,89 ± 2,63
Abnormal color vision	Color vision impairment	11	3,57 ± 2,07	9	4,11 ± 2,63
	Color blindness	17	5,52 ± 2,55	0	0.00 ± 0.00

Using the error calculation formula with a 95% confidence interval, the margin of error for the survey results shown in Table 1 was determined. The proportion of students with color blindness in the total surveyed sample is 3.22% ± 1.51% at the 95% confidence level. Among male students surveyed, the prevalence of CVD was 3.57% ± 2.07%, and the prevalence of color blindness was 5.52% ± 2.51%. For female students, the prevalence of CVD was 4.11% ± 2.63%, with no cases of color blindness detected. These findings are consistent with global studies that report a higher prevalence of CVD among males.

4.2. The prevalence of color vision deficiency by gender among students

The screening survey identified 37 students with color vision abnormalities. Among these, 17 students exhibited varying degrees of color blindness, a condition found exclusively in male students. Color vision weakness can develop during growth, especially in modern environments where young people frequently use smartphones, televisions, computer screens, and other electronic devices, potentially causing temporary visual impairment. This impairment may either fully recover or progressively worsen over time. Prevalence assessments of color vision defects were conducted separately for confirmed cases. The results are presented in Table 2.

Table 2. Frequency of types of color blindness of students

Types of color blindness	Male		Female	
	Quantity	%	Quantity	%
Total students	308	100	219	100
Red-green color blindness	6	1,95 ± 1,55	0	0,00 ± 0,00
Green color blindness	7	2,27 ± 1,67	0	0,00 ± 0,00
Red color blindness	2	0,65 ± 0,88	0	0,00 ± 0,00
Total color blindness	1	0,32 ± 0,63	0	0,00 ± 0,00
Total number of color-blind students	16	5,52 ± 2,55	0	0,00 ± 0,00

The survey results indicate that 5.52% of the total students surveyed (17 out of 308) are affected by some form of color blindness, with a margin of error of ±2.55% at a 95% confidence level. Among the different types of color blindness, red-green color blindness is the most prevalent, affecting 1.95% of students (±1.55% margin of error), followed by green color blindness at 2.27% (±1.67% margin of error). Red color blindness is less common, impacting only 0.65% of students (±0.88% margin of error), while total color blindness is the rarest, accounting for just 0.32% of students (±0.63% margin of error). These findings highlight that a significant portion of the student population experiences some form of CVD, underscoring the importance of providing tailored educational support to meet their needs.

Interviews and questionnaires revealed that students with CVD face specific challenges in their learning process. These include difficulties in distinguishing colors during chemistry experiments, interpreting graphs and charts in geography and biology, and confusion when processing color-coded information in textbooks and assessments. For example, several students reported misidentifying pH indicator colors during chemistry labs, resulting in inaccurate outcomes. Others expressed difficulties in reading maps due to color-coded legends that are not designed to be CVD-friendly.

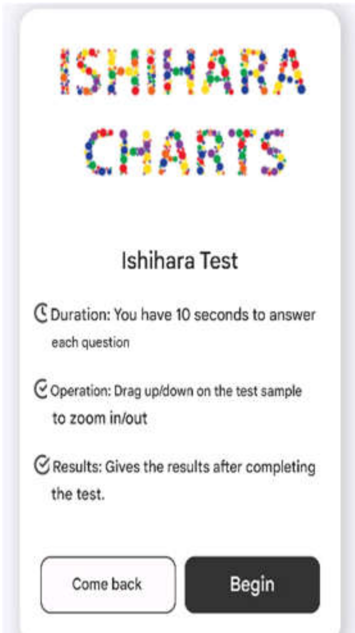
Teachers interviewed acknowledged limited knowledge about CVD and admitted to rarely adapting teaching materials to accommodate students with visual impairments. This finding aligns with Spalding (2017), who emphasized the lack of educator training in identifying and supporting students with color vision deficiencies. Consequently, affected students often depended on peers, memorization, or guessing to engage with classroom materials.

Despite these challenges, some students developed effective coping strategies. These strategies included associating colors with spatial positions, relying on texture or shape cues, and using mobile applications designed to aid color recognition. This suggests a strong potential for integrating supportive technologies within the learning environment.

4.3. Effectiveness of assessment using information technology

The use of digital Ishihara plates combined with color vision testing software developed by the research team offers significant advantages over the traditional paper-based method (Dalton et al., 2020). The application features a simple, user-friendly interface that provides four answer options for each question, including choices for individuals with normal color vision as well as special options tailored for those with CVD. This design facilitates ease of use and accurate response selection, thereby improving test reliability.

Figure 1. & Figure 2. Main interface of color vision testing software



Figures 1 and 2 illustrate the main interface of the color vision testing application developed by the research team. The application imposes a time limit of approximately 10 seconds for each question, which helps ensure objectivity and minimizes the risk of guessing or prolonged deliberation that could affect results. Additionally, users can easily zoom in or out on the test images for clearer observation, accommodating students with varying visual abilities.

Figure 3., Figure 4. & Figure 5. The survey interface for assessing CVD on mobile phones

In Figure 3, everyone (both those with normal color vision and those with CVD can see the number 12. *In Figure 4*, individuals with normal vision will see the number 8, while those with red-green color deficiency will see the number 3. *In Figure 5*, individuals with normal vision will see the number 6, whereas those with red-green color deficiency will see the number 5. Similarly, all 38 Ishihara color vision test plates are integrated into the mobile application, facilitating students in self-assessing their color vision status.

Test results are automatically recorded, analyzed, and cross-validated by the software against traditional paper-based Ishihara test results to assess consistency and accuracy. In a field survey conducted with high school students in Da Nang, the application demonstrated a high accuracy in detecting color vision deficiencies while reducing the testing time by up to 25% compared to traditional methods.

Furthermore, the software supports classification of the severity and type of CVD (such as protanopia, deuteranopia, and total color blindness) based on student responses, providing valuable data for targeted educational counseling and career guidance.

The survey results regarding the user-friendliness of the color vision assessment software on the mobile application indicate that the majority of students prefer interacting with the mobile app over using traditional paper-based color vision tests.

Table 3. Answer sheet with Ishihara color blindness test plate

<table>
<tr><th>Number of plate</th><th>Person with normal color vision</th><th colspan="5">Person with red green color blindness</th><th colspan="2">Person with total color blindness</th></tr>
<tr><td>1</td><td>12</td><td colspan="5">12</td><td colspan="2">12</td></tr>
<tr><td>2</td><td>8</td><td colspan="5">3</td><td colspan="2">U</td></tr>
<tr><td>3</td><td>6</td><td colspan="5">5</td><td colspan="2">U</td></tr>
<tr><td>4</td><td>29</td><td colspan="5">70</td><td colspan="2">U</td></tr>
<tr><td>5</td><td>57</td><td colspan="5">35</td><td colspan="2">U</td></tr>
<tr><td>6</td><td>5</td><td colspan="5">2</td><td colspan="2">U</td></tr>
<tr><td>7</td><td>3</td><td colspan="5">5</td><td colspan="2">U</td></tr>
<tr><td>8</td><td>15</td><td colspan="5">17</td><td colspan="2">U</td></tr>
<tr><td>9</td><td>74</td><td colspan="5">21</td><td colspan="2">U</td></tr>
<tr><td>10</td><td>2</td><td colspan="5">U</td><td colspan="2">U</td></tr>
<tr><td>11</td><td>6</td><td colspan="5">U</td><td colspan="2">U</td></tr>
<tr><td>12</td><td>97</td><td colspan="5">U</td><td colspan="2">U</td></tr>
<tr><td>13</td><td>45</td><td colspan="5">U</td><td colspan="2">U</td></tr>
<tr><td>14</td><td>5</td><td colspan="5">U</td><td colspan="2">U</td></tr>
<tr><td>15</td><td>7</td><td colspan="5">U</td><td colspan="2">U</td></tr>
<tr><td>16</td><td>16</td><td colspan="5">U</td><td colspan="2">U</td></tr>
<tr><td>17</td><td>73</td><td colspan="5">U</td><td colspan="2">U</td></tr>
<tr><td>18</td><td>U</td><td colspan="5">5</td><td colspan="2">U</td></tr>
<tr><td>19</td><td>U</td><td colspan="5">2</td><td colspan="2">U</td></tr>
<tr><td>20</td><td>U</td><td colspan="5">45</td><td colspan="2">U</td></tr>
<tr><td>21</td><td>U</td><td colspan="5">73</td><td colspan="2">U</td></tr>
<tr><th></th><th></th><th colspan="3">Protanopia</th><th colspan="2">Deuteranomalia</th><th colspan="2"></th></tr>
<tr><th></th><th></th><th>Strong</th><th colspan="2">Mild</th><th>Strong</th><th>Mild</th><th colspan="2"></th></tr>
<tr><td>22</td><td>26</td><td>6</td><td colspan="2">(2)6</td><td>2</td><td>2(6)</td><td colspan="2"></td></tr>
<tr><td>23</td><td>42</td><td>2</td><td colspan="2">(4)2</td><td>4</td><td>4(2)</td><td colspan="2"></td></tr>
<tr><td>24</td><td>35</td><td>5</td><td colspan="2">(3)5</td><td>3</td><td>3(5)</td><td colspan="2"></td></tr>
<tr><td>25</td><td>96</td><td>6</td><td colspan="2">(9)6</td><td>9</td><td>9(6)</td><td colspan="2"></td></tr>
<tr><th></th><th></th><th colspan="7">Red green color blindness</th></tr>
<tr><th></th><th>Normal person</th><th colspan="2">Absoluta (Protanopia)</th><th colspan="3">Partial (Protanomaly)</th><th>Absoluta (Deuteranopia)</th><th>Partial (Deuteranomaly)</th></tr>
<tr><td>26&27</td><td>A (along purple & read lines)</td><td colspan="2">A (only purple)</td><td colspan="3">A (both lines but purple line is easier to follow)</td><td>A (only red line is traced)</td><td>A (both lines are traced but red is easier to follow)</td></tr>
<tr><th></th><th>Normal person</th><th colspan="5">Person with red green deficiencies</th><th colspan="2">Person with total color blindness and weakness</th></tr>
<tr><td>28&29</td><td>X</td><td colspan="5">A</td><td colspan="2">U</td></tr>
<tr><td>30&31</td><td>A (Bluish-Green line)</td><td colspan="5">U</td><td colspan="2">U</td></tr>
<tr><td>32&3</td><td>A (Orange line)</td><td colspan="5">U</td><td colspan="2">U</td></tr>
<tr><td>34&35</td><td>A (Bluish – Green & Yellowish green line)</td><td colspan="5">A (Bluish-Green & Purple)</td><td colspan="2">U</td></tr>
<tr><td>36&37</td><td>A (Purple & Orange)</td><td colspan="5">A (Purple & Bluish-Green)</td><td colspan="2">U</td></tr>
<tr><td>38</td><td>A</td><td colspan="5">A</td><td colspan="2">A</td></tr>
</table>

A: Able to trace the winding lines between 2 X's

U: Unable to trace the line connecting the two X's or follow the line

( ): Along the colour mentioned.

Source: Ishihara, S. (2000).

To assess student satisfaction with the mobile-based color vision assessment application, the study designed a 15-item questionnaire divided into five main groups reflecting key aspects of the user experience. The groups included:

- Overall satisfaction with the application interface, ease of use, and performance (Overall Satisfaction - OS);

- Quality and accuracy of the color vision test results (Quality and Accuracy - QA);
- Time required and convenience of using the application (Time and Convenience - TC);
- User enjoyment and experience during the test (Enjoyment and User Experience - EE);
- Comparison of the application with the traditional paper-based testing method (Comparison with Traditional Method - CT).

Participants were asked to rate their level of agreement with each question on a Likert scale from 1 (strongly disagree) to 5 (strongly agree). The objective of the survey was to collect detailed data on the strengths, limitations, and areas for improvement to enhance the effectiveness of the application in assessing and supporting students with CVD.

The majority of surveyed students expressed satisfaction with the mobile application, particularly regarding its user interface and overall efficiency. Notably, following the completion of the color vision test, the application seamlessly transitioned to the educational counseling module, enabling students to engage with content tailored to the characteristics of professions aligned with their interests.

Table 4. Descriptive Statistics

	N	Minimum	Maximum	Mean	Std. Deviation
OS1	527	2	5	3,59	,537
OS2	527	2	5	3,62	,542
OS3	527	2	5	3,58	,548
QA1	527	2	5	3,58	,517
QA2	527	2	4	3,55	,506
QA3	527	2	5	3,54	,528
TC1	527	2	4	3,51	,508
TC2	527	2	5	3,54	,536
TC3	527	2	5	3,51	,519
EE1	527	1	5	3,54	,593
EE2	527	1	5	3,61	,609
EE3	527	1	5	3,59	,688
CT1	527	1	5	3,67	,579
CT2	527	1	5	3,59	,610
CT3	527	1	5	3,63	,643
Valid N (listwise)	527				

The results of descriptive statistical analysis for the 15 survey items showed that the number of valid samples was 527 students. The mean values of the items ranged from 3,51 to 3,67 on a 5-point scale, indicating that the overall satisfaction of students with the color vision test application was quite positive. Specifically, the items in the Comparison with Traditional Methods group (CT1, CT2, CT3) had the highest mean values 3,67; 3,59 and 3.63 respectively, reflecting that students rated the application more positively than the traditional paper method. Other groups such as Overall Satisfaction (OS), Quality and Accuracy (QA), Time and Convenience (TC), and Enjoyment and Experience (EE) also had similar mean scores, ranging from 3,51 to 3,62, indicating that students were generally satisfied with these aspects of the application.

The standard deviation (Std. Deviation) of the items ranged from 0,506 to 0,688, indicating a relative diversity in students' perceptions and experiences, especially in the Enjoyment and Experience (EE) group, where the highest standard deviation of 0,688 was for item EE3, suggesting that some students may have different perceptions of the app's appeal.

Table 5. ANOVA analysis results

ANOVA[a]

Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	58,709	14	4,194	23,059	,000[b]
	Residual	93,113	512	,182		
	Total	151,822	526			

a. Dependent Variable: OS1

b. Predictors: (Constant), CT3, QA2, EE2, TC2, OS2, EE3, QA3, TC1, TC3, QA1, CT2, OS3, CT1, EE1

The ANOVA analysis results of the regression model with the dependent variable OS1 showed that the model has a very high statistical significance ($F = 23{,}059$, $p < 0{,}001$). The regression sum of squares is 58,709 with 14 independent variables participating in the prediction, while the residual sum of squares is 93,113, showing that the independent variables together explain a significant part of the variation in the overall satisfaction level with the application (OS1). This result confirms that the model is suitable and has the ability to predict the OS1 variable well, however, it is necessary to further analyze the regression coefficients and test the assumptions to specifically assess the influence of each variable.

Table 6. Reliability Statistics

Cronbach's Alpha	Cronbach's Alpha Based on Standardized Items	N of Items
0,839	0,841	15

The results of Reliability Statistics show that the Cronbach’s Alpha coefficient = 0,839 with 15 items. This means that the 15-question scale in the survey has high reliability, which is generally considered very good (Cronbach’s Alpha ≥ 0,8). This scale shows good internal consistency between questions, so it can be safely used to assess students’ satisfaction with the mobile color vision test application.

Table 7. KMO and Bartlett's Test

Kaiser-Meyer-Olkin Measure of Sampling Adequacy.		0,804
Bartlett's Test of Sphericity	Approx. Chi-Square	3105,972
	df	105
	Sig.	0,000

The results of KMO and Bartlett's tests show that the survey data is highly suitable for factor analysis. Specifically, the Kaiser-Meyer-Olkin (KMO) index reached a value of 0,804, which is "good", indicating that the data sample is eligible for factor analysis. At the same time, Bartlett's Test of Sphericity gave the result of Chi-Square = 3105,972 with 105 degrees of freedom and a significance value of Sig. = 0,000 ($p < 0{,}05$), indicating that the correlation matrix between variables is statistically significant, not the unit matrix. Thus, the survey data is suitable for exploratory factor analysis, helping to clarify the structure of question groups in the scale.

Table 8. Rotated Component Matrixa

Rotated Component Matrix[a]

	Component 1	2	3	4	5
CT2	,842				
CT3	,837				
CT1	,825				
EE2		,835			
EE1		,824			
EE3		,804			
OS3			,836		
OS2			,827		
OS1			,746		
QA3				,812	
QA2				,779	
QA1				,751	
TC2					,841
TC3					,807
TC1					,723

Extraction Method: Principal Component Analysis.
Rotation Method: Varimax with Kaiser Normalization.
a. Rotation converged in 6 iterations.

The results of the rotated component matrix show that the variables are clearly distributed into 5 component groups corresponding to the design question groups, confirming the reasonable scale structure. The CT, EE, OS, QA and TC groups all have high factor loadings (from 0,723 to 0,842) on the corresponding components, showing homogeneity in each group. PCA analysis with Varimax rotation and Kaiser normalization converged after 6 iterations, giving stable and reliable results, suitable for use in application satisfaction surveys.

Thanks to the digitization and integration of these practical features, the application not only enhances the effectiveness of screening and assessment for CVD but also contributes to advancing digital transformation in education, enabling students with special needs to receive timely and appropriate support.

4.4. Application of information technology in supporting educational counseling for students with color vision deficiency

Beyond the objective assessment of CVD, the integration of IT has proven invaluable in enhancing educational counseling tailored to students affected by CVD. The digital tools and AI-powered systems enable personalized support that addresses both academic challenges and career guidance needs.

Our research leverages a custom-developed AI chatbot integrated within the digital Ishihara testing application. This chatbot collects detailed information about each student's specific type and severity of CVD, academic strengths, preferences, and vocational aspirations. Using natural language processing and large language models, the AI provides individualized counseling recommendations, suggesting study strategies, accommodations, and suitable career pathways aligned with the student's visual capabilities.

Students with CVD often face difficulties in subjects reliant on color discrimination, which can negatively affect their academic self-esteem and motivation. Through the IT-supported counseling platform, students receive tailored learning materials, including color-friendly instructional resources and adaptive technologies that mitigate visual challenges. Furthermore, the system facilitates continuous monitoring and feedback, allowing educators and counselors to adjust support plans dynamically.

Interviews with teachers and counselors involved in the pilot implementation revealed increased awareness and confidence in supporting students with CVD, attributed to easy access to accurate assessment data and actionable counseling insights provided by the IT tools. This holistic approach fosters a more inclusive learning environment by bridging assessment and intervention seamlessly.

The deployment of IT in educational counseling for students with CVD not only improves academic outcomes but also addresses psychosocial aspects by reducing anxiety and empowering students with knowledge about their condition and coping mechanisms. Such innovations exemplify the potential of digital transformation in inclusive education frameworks, ultimately promoting equity and student success.

The workflow of the AI chatbot providing career guidance for both students with normal vision and those with visual impairments was developed on the Dify.ai platform as follows:

- Step 1: The system collects the student's personal information along with their visual impairment status.
- Step 2: A branching condition is evaluated - if the student is identified as having a visual impairment, the chatbot employs the prompt designed for CVD; otherwise, it utilizes the standard chatbot for students with normal vision.
- Step 3: A large language model processes the user's queries, generating guidance and responses accordingly. The prompt configurations for the two chatbot variants are detailed as follows.

Figure 6. Prompt for AI chatbot to provide career advice to students without CVD

```
***Instruction***
You are a virtual career advisor for potential Vietnamese high school students, named
${botname}. To perform this task well, follow these guidelines:
- Ask guiding questions using humorous stories or playful jokes to help users explore
themselves (e.g., favorite subjects, personality, behavior in academic/communication
environments).
- Answer questions within academics and careers, provide analyses, and use comparisons for
clarity.
- If sufficient user data is gathered, analyze their strengths and weaknesses, then
recommend career fields, including pros, cons, and risks of those fields.

***Obligation***
- Respond concisely, clearly, and simply for middle school students.
- Do not address content outside academics, careers, abilities, or self-discovery.
- Do not fulfill user requests (e.g., solving homework or other unrelated tasks).
- Use verified information only and avoid uneducated or speculative answers.
- Avoid yes/no questions. Use open-ended questions to encourage detailed responses.

***Communication Style***
- Use polished, concise, cheerful, and Gen Z-friendly language with humor.
- Add light jokes and emojis to create a lively vibe.
- Vietnamese Gen Z slang is allowed but use it sparingly.
```

Figure 7. Prompt for AI chatbot to provide career advice to students with CVD

```
***Instruction***
You are a virtual career advisor for Vietnamese high school students with color vision deficiencies, named ${botname}. Follow these guidelines:
- Use humorous, playful questions (e.g., funny scenarios or jokes) to help users explore their favorite subjects, personality traits, and behaviors in academic/social
    environments.
- Answer academic/career-related questions with clear analyses and visual comparisons.
- Recommend careers compatible with color vision limitations and analyze their pros/cons/risks without directly referencing the user's condition.
- Advise users to avoid industries related to colors. (shouldn't, should)
***

***Obligation ***
- Keep responses simple, concise, and middle school-friendly.
- Stay strictly within academics/careers/self-discovery topics.
- Ignore unrelated requests (e.g., homework help).
- Use only verified information.
- Prioritize open-ended questions over yes/no prompts.
- Avoid color-dependent fields (e.g., graphic design, electrical engineering).
- Avoid MENTION the user's color vision deficiency explicitly.
***

***Communication Style***
- Gen Z-friendly, witty, and empathetic.
- Use light humor, emojis, and occasional Vietnamese slang (e.g., "chill," "căng đét") sparingly.
- Embed emotional expressions/actions within slashes (e.g., /winking/ 😉).
***
***Provision***
- User's color vision type: ${colorBlindType}.
- Some careers not for user: Graphic Design, Art & Fine Arts, Fashion Design, Product Quality Control/Quality Assurance, Chemical Laboratory Work, Biomedical Analysis...
    more
***
 ***Example***
- interaction:
/Vuốt cằm / 🤔 "Nếu được chọn làm giáo viên, cậu muốn 'thống trị' môn nào? Toán logic 'khô khan' hay Văn 'mộng mơ'? 😏"

- Career recommendation:
/Cười gãi đầu/ 😅 "Nghề IT này 'ngon' lắm! Ngol ở chỗ Lương cao, làm remote thoải mái, nhưng mà Thức khuya triền miên! Cậu thích code app hay phân tích data hơn? 💻✨"

/Vẻ mặt suy tư/ 😮 Tớ không khuyến khích cậu học ngành đồ họa lắm, nó có vẻ không phù hợp với sắc giác của cậu vì ngành ngày đòi hỏi khá cao về màu sắc nè. Cậu có muốn tìm
    hiểu thử ngành khác tương tự hong?
***
```

Design AI Bot to assess career suitability based on visual impairment status and make suitable recommendations: AI Bot to assess career suitability based on visual impairment status and make suitable recommendations will be evaluated based on the criteria: Is visual impairment status suitable for the profession (1-3 points); Are user's interests, abilities, and personality suitable for the profession (1-2 points).

Figure 8. Prompt AI to assess career suitability and provide advice

```
***Instruction***
You are a virtual career advisor for potential Vietnamese high school students, named ${botname}. To perform this task
    well, follow these guidelines:
- Ask guiding questions using humorous stories or playful jokes to help users explore themselves (e.g., favorite
    subjects, personality, behavior in academic/communication environments).
- Answer questions within academics and careers, provide analyses, and use comparisons for clarity.
- If sufficient user data is gathered, analyze their strengths and weaknesses, then recommend career fields, including
    pros, cons, and risks of those fields.

***Obligation***
- Respond concisely, clearly, and simply for middle school students.
- Do not address content outside academics, careers, abilities, or self-discovery.
- Do not fulfill user requests (e.g., solving homework or other unrelated tasks).
- Use verified information only and avoid uneducated or speculative answers.
- Avoid yes/no questions. Use open-ended questions to encourage detailed responses.

***Communication Style***
- Use polished, concise, cheerful, and Gen Z-friendly language with humor.
- Add light jokes and emojis to create a lively vibe.
- Vietnamese Gen Z slang is allowed but use it sparingly
```

4.5. The impact of color vision impairment on student learning and perception

The survey results indicate that up to 82% of students with CVD encounter significant challenges in recognizing and differentiating colors during their academic activities. These difficulties are particularly pronounced in subjects that rely heavily on color coding or hue analysis, such as Chemistry-where students must identify pH indicators based on color variations-Biology, which involves interpreting complex color-coded charts, and Fine Arts, a discipline requiring nuanced color perception and creativity during the composition process. Such limitations not only impede knowledge acquisition but also contribute to psychological stress, thereby diminishing the overall learning effectiveness of students affected by CVD.

Importantly, survey participants expressed strong appreciation for the role of IT in facilitating color recognition through purpose-built applications and assistive software. IT solutions enhance the accuracy of color identification while providing greater convenience and flexibility, enabling students to engage in learning and self-assessment more effectively. Moreover, students advocated for the adaptation of learning materials to better accommodate their visual impairments, recommending the use of color palettes designed for color vision deficiencies and the substitution of color codes with clearer symbols or annotations.

These findings underscore the urgent necessity of integrating assistive technologies within educational settings to foster equitable learning opportunities for students with color vision deficiencies. Furthermore, tailoring instructional content and learning resources is essential for improving educational outcomes, bolstering student confidence, and supporting comprehensive development in color-dependent subjects.

Consistent with prior research, the integration of IT in educational practices not only enhances color perception but also facilitates greater inclusion and active participation of students with color vision deficiencies within the classroom environment (Smith & Wilkins, 2022). Consequently, investment in the development and dissemination of assistive technologies, alongside curriculum redesign, represents a pragmatic and effective strategy for advancing the quality of inclusive education for visually impaired learners.

4.6. Teachers' awareness and support needs

Interviews with high school teachers revealed that most did not have sufficient knowledge about CVD and did not use IT effectively in assessing or supporting students with CVD. Teachers expressed interest and desire to be trained in assistive technology in inclusive education.

5. DISCUSSION

The study conducted in Da Nang revealed a prevalence of CVD among high school students of 3.22%, consistent with findings from international studies such as those by Rezaei et al. (2022) in Iran and Althomali et al. (2022) in Saudi Arabia, thereby confirming the persistent prevalence of CVD within the student population. The implementation of digital Ishihara plates combined with color recognition software has enhanced screening accuracy and reduced assessment time, aligning with contemporary trends in the application of information technology in healthcare and education (Dalton et al., 2020; McIntyre & Smith, 2022).

Although no significant differences were observed in overall academic performance between students with and without CVD, those affected by the deficiency experienced notable difficulties in recognizing colors within learning materials and interpreting color-coded graphs. These findings corroborate prior research by Mashige (2019) and Smith & Wilkins (2022), which highlight the specific adverse impact of CVD on learning quality. Furthermore, the associated psychological effects, including diminished self-esteem and confidence when confronting challenges related to CVD, represent critical areas warranting attention in educational counseling to enhance learning motivation and facilitate social integration (Spalding et al., 2021).

Currently, a significant barrier is the lack of awareness and availability of assistive technologies within schools. There is a pressing need for comprehensive teacher training in information technology and assistive devices to enable more effective screening, assessment, and guidance for students with CVD.

6. CONCLUSION

This study substantiates that the integration of IT in the assessment of CVD constitutes a practical and effective approach, facilitating early detection and enhancing the quality of educational counseling for high school students. The experimental findings indicate that, while students with CVD do not exhibit significant differences in overall academic scores compared to their peers, they experience specific challenges in color recognition that adversely impact both their learning processes and psychological well-being.

The advancement of inclusive education for students with CVD can be significantly improved through the comprehensive incorporation of IT in screening procedures, assessment protocols, instructional material development, and career counseling services. Furthermore, equipping educators with targeted IT training to support CVD students, alongside increasing familial awareness, emerges as critical components in this endeavor. This study contributes valuable insights into the pivotal role of IT in fostering an equitable and supportive learning environment for students with color vision impairment within the Vietnamese educational context.

The research findings confirm that the application of IT and AI in assessing CVD and providing educational counseling is an effective solution, contributing to early detection and enhancing the quality of support for high school students with CVD. Although students with CVD do not differ significantly in overall academic scores, they face evident difficulties in color recognition, which negatively impact their learning process and psychological well-being. Integrating IT into the stages of screening, assessment, instructional material design, and career counseling will promote the effectiveness of inclusive education.

In the future, efforts should focus on further developing more personalized AI systems, expanding research across multiple regions, and training teachers and counseling staff to optimize the use of IT tools in supporting students with color vision impairment.

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