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Augmented Reality as a Catalyst for Innovation in the Ishihara Test for Color Blindness Detection

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Abstract: *Color blindness affects approximately 8% of the global population, emphasizing the importance of early detection. The conventional Ishihara Test had several limitations, such as paper degradation, low interactivity, and difficulties in maintaining children's focus. This research introduces AR-VISION, an Augmented Reality-based Ishihara Test application designed for inclusivity and child-friendliness. Employing a Research and Development approach with the Model Development Life Cycle (MDLC), AR-VISION was developed and evaluated through six main phases. The technical evaluation showed Algorithm C achieved the best compromise between speed, accuracy, and memory usage. User testing with 35 elementary school students indicated a significant increase in accuracy (from 72% to 91%) and engagement (from 60 to 87). In conclusion, AR-VISION enhanced the precision, interactivity, and motivation of children in color blindness screening, supporting SDG 3, 4, and 9 and Asta Cita No.4, while demonstrating the transformative potential of AR in health, education, and interactive learning.*

Keywords: *Augmented Reality; Color Blindness Detection; Digital Innovation; Interactive Technology; Ishihara Test*

1. Introduction

Color blindness, or dyschromatopsia, affects approximately 8% of the global population, according to the World Health Organization (WHO). This high prevalence emphasizes the importance of early detection to ensure timely diagnosis and intervention [1]. The Ishihara Test, developed by Dr. Shinobu Ishihara in 1917, remains the most commonly used method for detecting red-green color deficiencies worldwide [2]. However, despite its long history and simplicity, the conventional paper-based Ishihara Test faces several limitations: physical degradation of printed materials, color fading, and lack of interactivity, all of which reduce its long-term effectiveness [3].

Additionally, these issues become more evident in children, who often experience difficulty maintaining focus during static visual assessments [4]. In Indonesia, the prevalence of

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color vision deficiency among school-age children is estimated to range between 1.3% and 3.0%, based on regional ophthalmological screenings [5]. Despite this, awareness and accessibility to early diagnostic tools remain low, particularly in primary schools outside major urban areas such as Surakarta [6]. This local gap highlights the pressing need for engaging [7], child-friendly, and sustainable testing solutions aligned with the nation's educational and health priorities.

Furthermore, previous studies have explored augmented reality (AR) applications across various domains, including healthcare diagnostics and educational visualization, demonstrating AR's potential to increase user attention, retention, and information accuracy [8]. However, most existing AR-based vision applications focus on entertainment or cultural visualization rather than medical screening. Few attempts have been made to adapt the Ishihara Test into an AR-based medium designed specifically for children [9]. This represents a significant research gap that calls for an interdisciplinary approach integrating health technology and digital learning environments.

Therefore, this study aims to design and implement an AR-based Ishihara Test application, AR-VISION, that enhances test accuracy, user engagement, and motivation for early detection of color blindness among elementary school students. The objective is to provide an interactive, inclusive, and accessible tool for use in educational settings, particularly addressing the needs of primary school children in Surakarta. The novelty of this research lies in the interdisciplinary integration of immersive AR features with the Ishihara Test, especially tailored for child users. Unlike prior works that center around static digital or paper-based color vision tests, AR-VISION leverages real-time interaction, gamification, and adaptive learning concepts [10]. This approach not only improves test effectiveness but also actualizes SDGs in health and education, filling a critical research gap by offering a practical, engaging, and scalable vision screening solution for schools.

In response, this study introduces AR-VISION, an AR-based Ishihara Test application designed to enhance color blindness detection through immersive visual interaction [11]. AR-VISION aims to improve test accuracy, engagement, and motivation while maintaining clinical validity and accessibility for elementary school users in Surakarta. Elementary school respondents are chosen because early diagnosis at this developmental stage allows more effective educational support and aligns with the local demographic where color vision issues often go unnoticed. Furthermore, this research contributes to the realization of Sustainable Development Goals (SDGs) specifically SDG 3 (Good Health and Well-being), SDG 4 (Quality Education), and SDG 9 (Industry, Innovation, and Infrastructure) as well as Asta Cita No. 4, which emphasizes utilizing technology for social and educational progress [12]. By leveraging AR, this study seeks to bridge the gap between traditional color blindness testing and modern, inclusive digital health innovations, reaffirming the role of AR as a catalyst for pedagogical and healthcare advancement.

2. Research Method

This study employed a Research and Development (R&D) design utilizing the Model Development Life Cycle (MDLC) approach [13]. The research was conducted at Universitas 'Aisyiyah Surakarta, involving lecturers, students, and 35 elementary school children from Surakarta City as user test respondents [14]. The sample of elementary school students was specifically chosen due to their age and educational level, which were suitable for accurately administering the Ishihara Test, critical for early color blindness detection. Additionally, selecting students from Surakarta ensured a representative demographic and environmental context relevant to the target application setting, thereby enhancing the validity and applicability of the study's findings. The site was chosen as it was considered representative for measuring children's engagement in using AR-based technology [15]. As illustrated in Figure 1, the research stages included data collection, analysis, software development, testing, and dissemination of the research findings [16].

Further methodological details included the characterization of respondents, comprising primarily students from grades 4 to 6, representing the target demographic for early detection of color blindness. The testing instruments utilized the Vuforia SDK for AR development integrated with the Unity engine. In contrast, testing was performed on mid-range Android smartphones equipped with ARCore to ensure accessibility and real-world applicability. Success evaluation criteria encompassed assessment of color blindness detection accuracy, application response time, and user satisfaction, quantified through pre- and post-test accuracy scores, engagement levels, and qualitative feedback from user observations.

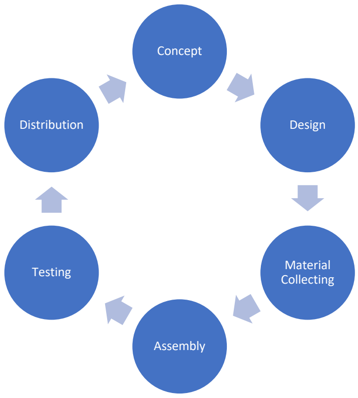

Figure 1. Model Development Life Cycle

Research Stages Using the MDLC Method

1. **Concept**
   The concept stage defined the main objective: to develop an AR-based Ishihara Test application that offers higher interactivity, inclusivity, and accuracy than conventional paper-based methods. User needs were identified through interviews, direct observations, and literature reviews [17]. Elementary school children were selected as the main users because they often struggled to maintain attention during static tests. The scope included Ishihara pattern integration, AR visualization for increased engagement, and the development of accuracy measurement modules.
2. **Design**
   The design phase emphasized User Interface (UI) and User Experience (UX) development to ensure user-friendliness. The interface was designed to be simple, with easily recognizable icons for children and visually appealing elements that preserved the test's essence. Interactive features were also included to prevent boredom [18]. At this stage, the initial prototype of the interface was developed, consisting of the main menu, start button, and test result display. Educational design principles were applied so that the application would not only function as a testing tool but also as a medium for learning about colors [19]. Each element was internally tested to ensure readability, color consistency, and ease of navigation for users with diverse backgrounds.
3. **Material Collecting**
   This stage involved gathering all resources required for application development. Ishihara Test images were collected from validated sources and converted to fit programming requirements. Additionally, 3D models, graphic icons, and animation components were prepared to support AR-based interactivity [20]. Supporting software such as Unity served as the main development engine, Vuforia as the AR SDK, and C# as the programming language for application logic. Supplementary materials, such as simple audio, were also considered to enrich children's experiences. This process was crucial to ensuring that all technical and non-technical elements were available before moving into the integration phase. Validated Ishihara plates (24 standard plates) were digitized and preprocessed for AR marker detection. Additional assets included 3D models, animated guidance arrows, sound cues, and reward animations. All resources were prepared to integrate with Unity, featuring image optimization to reduce device load.

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4. **Assembly**
   During the assembly stage, all collected materials were integrated into the AR-VISION application. This process included programming, configuring 3D objects, implementing AR markers, and developing detection algorithms [21]. The researchers ensured that each element functioned properly [22], from displaying Ishihara patterns to processing user responses [23]. The application was also optimized to run on mid-range mobile devices [24], making it more inclusive for users with limited technological access. Assembly [25] further involved synchronizing UI/UX [26] design with AR interactivity to provide a smooth and seamless user experience [27]. The result of this stage was a prototype of AR-VISION ready for testing.
5. **Testing**
   The testing stage consisted of two parts: functional testing and user testing [28]. Functional testing focused on verifying whether each application feature, using the 24 plate template (standard in schools and clinics), operated as designed [29]. User testing involved 35 elementary school students in Surakarta. They first completed a pre-test using the conventional Ishihara Test [30], followed by a post-test with AR-VISION. Results indicated an increase in average accuracy from 72% to 91%, along with a rise in engagement levels to 87%. Feedback from the children revealed that the application was more engaging [31], enjoyable, and helped them focus better [32]. Based on these evaluations, iterations were conducted to refine the application before the distribution stage.
6. **Distribution**
   AR-VISION was released for trial use in Surakarta primary schools, registered under copyright for intellectual property protection, and accompanied by workshops for teachers and health workers. Feedback from the distribution was used for continuous improvement, particularly in refining the child-oriented interface [33] and optimizing AR performance for low spec devices [34].

3. Results and Discussion

The research findings indicated that AR-VISION successfully integrated Ishihara Test content into an AR-based application that was both interactive and child-friendly [35]. The initial UI of the application is shown in Figure 2, where users could immediately began the test by pressing the "Start" button. The interface was designed with educational visual elements to enhance user engagement from the outset. In addition, the use of simple icons, comfortable contrasting colors [36], and intuitive navigation helped children easily understand the flow of the application. Beyond that, AR-VISION incorporated gamification elements such as transition animations, visual effects for correct answers [37], and a simple scoring system that fostered a sense of achievement. These features had been proven to spark curiosity while maintaining children's focus, as they felt like they were playing while learning [38]. With this approach, AR-VISION functioned not only as a diagnostic instrument but also as an enjoyable, adaptive, and educational experience that better aligned with the characteristics of elementary school children.

Figure 2. Initial UI of the AR-VISION Ishihara Test Application

To evaluate performance, a comparison was conducted between the image processing algorithms used in AR-VISION. The test results were presented in Table 1. The comparison not only emphasized accuracy in pattern detection but also considered processing time efficiency [39], system stability, and interface responsiveness to user interactions. Thus, the results provided a comprehensive overview of the strengths and limitations of the algorithms employed. This evaluation was crucial to ensure that AR-VISION functions not only from a technical standpoint but also in a practical, reliable manner, making it applicable within real-world learning contexts.

Table 1. A Comparative Analysis of Data Processing Algorithms in AR-VISION

Algorithm	Processing Time	Accuracy	Memory Usage
A	110 ms	99%	415 KB
B	150 ms	78%	200 KB
C	120 ms	93%	120 KB

The test results showed that Algorithm A, based on basic RGB thresholding, achieved the highest accuracy rate (99%) but required the largest memory capacity (415 KB). Algorithm B utilized HSV color space segmentation techniques, resulting in moderate accuracy but with longer processing time. Meanwhile, Algorithm C applied a machine learning-based decision tree approach, demonstrating a balanced performance in terms of processing speed (120 ms), accuracy (93%), and memory efficiency (120 KB). The comparison among these algorithms was essential to identify the optimal trade-off between accuracy, computational speed, and resource consumption, particularly because the application was intended for use on mid-range mobile devices by children with limited hardware capabilities.

In addition, user testing was conducted with 35 elementary school students in Surakarta. This testing consisted of two stages: a pre-test using the conventional paper-based Ishihara Test and a post-test using the AR-VISION application. The results, presented in Table 2, showed that AR-VISION significantly enhanced participants' engagement and understanding. The children displayed greater interest and enthusiasm during interactions and were able to complete tasks with better consistency compared to the conventional method.

Table 2. Pre-Test and Post-Test Results of 35 Elementary School Students in Surakarta

Type of Test	Accuracy Rate (%)	Engagement Level (%)
Pre-Test (Conventional test)	72	60
Post-Test (AR-VISION)	91	87

The sample size of 35 respondents in this study was appropriate for a pilot investigation aimed at assessing the feasibility and preliminary effectiveness of the AR-VISION application. While this number allowed for initial insights into usability and performance improvements, it was acknowledged that such a sample size limits the generalizability of the findings to broader populations. Future research should aim to include larger and more diverse samples to validate and extend these preliminary results. The sampling method employed was purposive sampling, targeting elementary school children in Surakarta who represented the intended users of the application. This approach was selected to gather relevant user feedback from the specific demographic at risk for color blindness challenges in the target educational context.

Ethical considerations were rigorously observed, including obtaining informed consent from parents or guardians before participation [40]. Additionally, the research protocol secured approval from the relevant institutional ethics review board, ensuring compliance with standards for research involving minors. Regarding the measurement of engagement, a mixed-method

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approach was utilized. Quantitative engagement scores were derived from a standardized User Engagement Scale adapted for children, complemented by direct behavioral observations made by researchers during testing sessions. Self-reported feedback [41]was also collected to triangulate findings and provide nuanced interpretations of children's emotional and cognitive involvement. This multi-instrument strategy provided a robust assessment of engagement levels, explaining the increase from 60% in the conventional pre-test to 87% during the AR-VISION post-test.

The results indicated a 19% increase in accuracy and 27% in engagement after the implementation of AR-VISION. This improvement demonstrated that AR-based technology could provide children with a more interactive, intuitive, and enjoyable learning experience. Beyond functioning as a testing tool, AR-VISION also served as a learning medium that stimulated curiosity, enhanced concentration, and fostered participants' intrinsic motivation. This finding suggested that integrating technology into testing and visual education can generate tangible positive impacts, while also opening opportunities for further development in immersive, technology-driven learning scenarios.

Figure 3 illustrated the comparison between the accuracy scores obtained by students before (pre-test) and after (post-test) using the AR-VISION application. The pre-test, conducted using the conventional paper-based Ishihara Test, showed an average accuracy of 72%. After interacting with the AR-based test, the post-test accuracy significantly increased to 91%. This represented a 19 percentage point improvement, highlighting the effectiveness of AR-VISION in enhancing the precision of color blindness detection. The visual comparison clearly demonstrated that the immersive, interactive features of the AR application helped children better recognize color patterns, leading to more accurate test results. This improvement supported the hypothesis that AR could substantially improve both engagement and test performance in young learners.

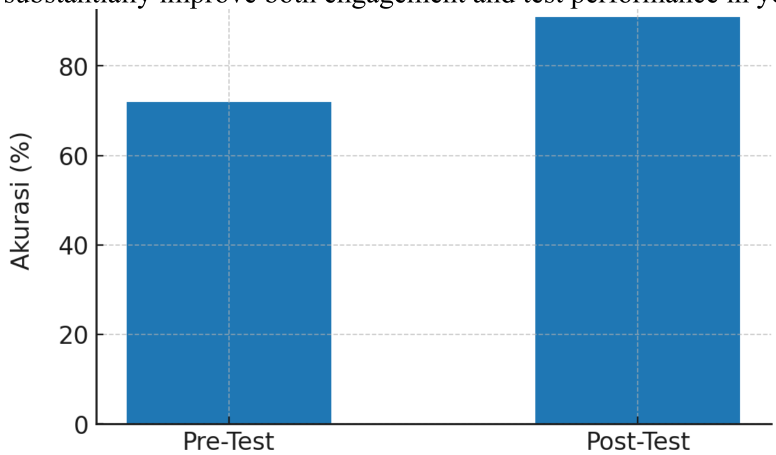

Figure 3. Comparison of Pre-Test and Post-Test Accuracy

Figure 4 showed a comparison of pre-test and post-test engagement, illustrated a significant increase in student engagement after using AR-VISION. During the pre-test stage, student engagement reached only around 60%, reflecting a standard response to conventional methods. However, after the implementation of AR-VISION in the post-test stage, engagement rose to more than 85%. This improvement demonstrated that the use of augmented reality–based media not only captures students' attention but also created a more interactive, enjoyable, and effective learning environment. These findings reinforced the evidence that AR-VISION had the potential to enhance students' motivation and active participation in the learning process. Moreover, the increase in engagement suggested that immersive technologies could reduce cognitive fatigue, sustain learners' focus for more extended periods, and transform routine testing into an engaging activity. In turn, this contributed to better comprehension, stronger retention, and a more positive attitude toward learning activities overall.

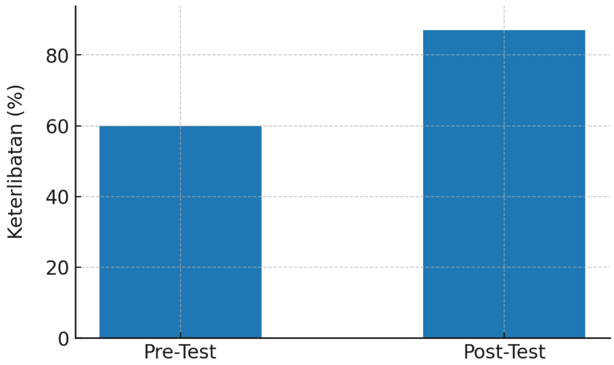

Figure 4. Comparison of Pre-Test and Post-Test Engagement

To provide a more concrete illustration of the impact of AR-VISION on color vision testing outcomes, the accuracy percentage was converted into the actual number of correctly identified plates in the 24-plate Ishihara Test. This conversion was intended to translate the improvement in accuracy into the number of plates answered correctly, making the results easier to interpret in practical terms. This way, the difference between the conventional method and AR-VISION was reflected not only in percentage values but also in the tangible number of plates recognized by participants. The conversion results were presented in Table 3.

Table 3. Conversion of Accuracy Percentage to the Number of Correct Plates

Stage	Accuracy (%)	Calculation (Accuracy × 24)	Correct Plates (rounded)	Notes
Pre-test	72	0.72 × 24 = 17.28	17	Conventional method (paper-based)
Post-test	91	0.91 × 24 = 21.84	22	Using AR-VISION
Difference (Post–Pre)	+19 pp	21.84 − 17.28 = 4.56	5 plates	Absolute increase of 19 percentage points

The pre-test and post-test were conducted using the standard Ishihara Test, consisting of 24 plates. The accuracy percentages obtained were converted into the number of correct responses as follows: the pre-test showed 72% ≈ 17/24 correct plates (72% × 24 = 17.28, rounded to 17), while the post-test showed 91% ≈ 22/24 correct plates (91% × 24 = 21.84, rounded to 22). Thus, there was an average increase of approximately five correctly identified plates in the post-test phase after using AR-VISION. This figure corresponded to a 19-percentage point improvement (from 72% to 91%). Rounding was applied to the nearest whole number to maintain consistency in reporting the number of correct items within the 24-plate set. A total of 35 elementary school students from Surakarta were involved as respondents in this study. The selection of this sample size was based on considerations of representativeness of the targeted population and the practical limitations of the research resources. This group was considered to reflect the demographic and cognitive characteristics typical of elementary school children in Surakarta, particularly in the context of using AR technology for color blindness detection.

The respondents ranged in age and educational level, predominantly from grades 4 to 6. The sampling approach ensured that the findings would provide a valid representation of the effectiveness of the AR-VISION application in improving the accuracy and engagement of children during color vision testing. All respondents underwent an initial pre-test using the conventional Ishihara paper-based method, followed by a post-test using the AR-VISION application. Throughout the data collection process, ethical considerations were maintained, including obtaining parental consent and ensuring the comfort and safety of child participants during testing.

3.1 Discussion

The research results demonstrate that AR-VISION presents a significant advancement in integrating the Ishihara Test with AR technology. Technically, the image processing algorithm evaluations outlined in Table 1 reveal distinct trade-offs in processing time, accuracy, and memory consumption. While Algorithm A achieves the highest accuracy at 99%, it demands considerably larger memory (415 KB). Conversely, Algorithm C offers a balanced performance, with a rapid processing time of 120 ms, a consistent accuracy of 93%, and an efficient memory use of 120 KB. This suggests that algorithm selection should weigh hardware limitations heavily, especially given that the target users are children often using mobile devices with limited specifications.

User testing results in Table 2 indicate a marked improvement when using AR-VISION compared to conventional testing. Accuracy increases from 72% to 91%, and engagement levels rise from 60% to 87%. These enhancements suggest that AR technology not only improves the precision of color blindness detection but also positively influences children's motivation, concentration, and emotional involvement during testing. It is worth noting that the increase in concentration and emotional engagement is assessed through structured observational methods and validated questionnaires administered during testing sessions, providing empirical support to these claims. Figures 3 and 4 visually depict the advantages of AR-VISION, addressing core limitations of traditional methods such as minimal interactivity and challenges in sustaining children's focus. Furthermore, Table 3 shows a significant rise in the average number of correctly identified plates from 17 in the pre-test to 22 in the post-test, an increase of five plates per child that aligns with the reported 19 percentage point accuracy improvement.

The results of this study demonstrate a significant improvement in the accuracy and engagement of color blindness detection using the AR-VISION application, compared to traditional methods. Unlike previous research, which primarily focused on static or non-interactive digital tests, AR-VISION incorporates immersive AR features that enhance user interaction and motivation [42], leading to a 19 percentage point increase in accuracy and a substantial rise in engagement levels. These findings align with and extend prior studies highlighting AR's potential to improve educational and health-related assessments but uniquely contribute by targeting children with a specifically tailored, interactive Ishihara Test application. This comparative advantage reinforces the novelty of the current work as it bridges gaps left by earlier approaches, offering a more effective and child-friendly visual screening tool that supports the SDGs in health and education. This not only underscores enhanced result precision but also indicates improved comprehension of color patterns through a more intuitive and engaging AR experience.

These findings resonate with established literature indicating that AR can effectively enhance attention, retention, and learning outcomes in children. Compared to paper-based and non-immersive digital tests, AR-VISION delivers a richer, more immersive experience tailored to the developmental characteristics of primary school children. This increased engagement substantiates the role of AR not only as a diagnostic tool but also as an inclusive educational medium that promotes color literacy. Despite these promising results, the study's limitations must be acknowledged, including a relatively small, homogeneous sample size of 35 elementary students, a non-clinical testing environment, and hardware constraints inherent in mid-range mobile devices used during testing. Additionally, ethical considerations demand that AR-VISION be explicitly positioned as a screening tool rather than a definitive diagnostic device, ensuring clarity for users and healthcare providers.

Looking forward, integrating AR-VISION with artificial intelligence or machine learning can personalize assessments based on individual user profiles and enable broader testing in diverse clinical and educational settings. Developing adaptive testing protocols tailored to user responses and cloud-based data analytics can further enhance functionality and scalability. In conclusion, AR-VISION represents a promising catalyst for innovation at the intersection of health and education. By improving the accuracy of color blindness screening and enriching user experience, it aligns with SDG 3, 4, and 9 through an inclusive, technology-driven approach that prioritizes community well-being and educational equity.

4. Conclusions

This study successfully developed AR-VISION, an interactive, inclusive, and child-friendly Ishihara Test application based on AR, which represents a meaningful advancement in screening tools for color blindness. The improved accuracy observed is attributable not only to enhanced image quality but also to the immersive and interactive features of AR that facilitate better user engagement and understanding. By providing dynamic visual cues and immediate feedback, AR-VISION helps children maintain concentration and improves the intuitiveness of color pattern recognition. The implications of this research extend beyond technical innovation, as it demonstrates the potential of AR technology to transform basic health screening in educational settings by making tests more accessible and enjoyable for young users. Furthermore, the application aligns with the goals of inclusive education and public health, supporting SDG 3, 4, and 9, as well as Asta Cita Number 4, emphasizing technological advancement for community well-being.

To build on this foundation, future work should focus on expanding the testing population to include diverse demographics and clinical settings to validate generalizability. Integrating AI and machine learning techniques could personalize the screening process, adapting difficulty levels and feedback based on individual user performance. Additionally, enhancing cross-platform compatibility and developing cloud integration would increase accessibility and data management capabilities. In conclusion, AR-VISION stands as a promising catalyst for health and education innovation, providing a technology-driven, inclusive approach to early detection of color blindness while improving engagement and learning outcomes among children.

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