Print-and-Play and Digital Games for a Playful Assessment of Colour Vision Deficiencies

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Abstract: The term *colour vision deficiency* (or CVD, for short) refers to a spectrum of conditions of genetic origin where one or more types of cone cells in the human retina do not function correctly, or do not function at all, leaving those affected unable to distinguish certain colours (Wright et al., 1946); this condition affects approximately 1 in 12 males and 1 in 200 females worldwide, but in Italy it is often identified only after a child has entered primary school, thus an early detection of this condition can help reduce colour-related learning challenges and social disadvantages. In order to address this issue, we designed a tile-placement and colour-matching board game which we named *ColorFit* as a playful tool for discovering potential colour perception issues. The game is meant for two players and provides a controlled environment where player behaviour – such as the choice of moves and the players' response times – can be observed and analysed to deduce possible colour vision difficulties. ColorFit is available in print-and-play format, complete with game rules, components, and a user guide. To broaden its accessibility and analytical capabilities, a digital version was also created, with a higher degree of customization, adjustable colour palettes and game conditions, and a more precise tracking of player actions, such as timing, move accuracy, and error patterns. By integrating game-based interaction with observational analysis, ColorFit offers a non-invasive, engaging, and scalable method to support the early identification of colour vision deficiencies in children.

Keywords: board games, colour vision, colour blindness, detection, colour, diagnosis

1. Introduction

Colour vision deficiency (CVD), a genetic condition caused by at least one type of photoreceptor in the human retina functioning abnormally, affects the way individuals perceive and distinguish colours, especially reds and greens (Birch, 2012). The effects of CVD are typically not considered a disability in the traditional sense, but they can create subtle though significant barriers in many aspects of everyday life, especially in school or other educational settings where colour is frequently used for learning and communication.

CVD is relatively common, especially among males, affecting approximately 8% of boys (1 in 12) and 0.5% of girls (1 in 200) globally. In Italy, as in many other countries, this condition often goes undetected until a child encounters colour-based tasks in primary school. By this point, undiagnosed CVD may already have caused challenges in classroom engagement, self-esteem and school performance, especially in subjects that rely on colour-coded information, such as geography, math, science and art.

Identifying this colour vision deficiency in the early stages of life could help mitigate the disadvantages associated to this condition and would make it possible for educators and parents to adapt learning environments to individual needs. Conventional diagnostic tools such as the Ishihara test are typically administered in clinical settings, and may not be readily available in schools. In addition to this, young children could feel intimidated by the tests, a fact which could potentially affect their reliability and acceptance.

To address these challenges, the Game4CED group ("Gamification for Colour-blindness Early Detection") created *ColorFit* (Iocco, Rizzi, 2024), a colour-matching and tile-placement board game designed as an accessible, engaging tool for the early indication of colour vision deficiencies. By embedding observational cues into a playful environment, ColorFit aims to create a low-pressure context in which children's interactions with colour can be monitored and analysed. This paper describes the conceptual design of ColorFit, its physical and digital implementations, and its potential to support non-invasive, scalable early detection for colour vision challenges in early education settings.

2. Background and Related Work

Colour vision deficiency (CVD) has been studied in clinical research for over a century. The type and severity of the condition is commonly assessed by means of standardized tests, such as the *Ishihara Colour Test*, a series of coloured dot patterns that form numbers or shapes visible only to observers with normal colour vision. These tools are effective in clinical settings (Birch, 1997) such as medical environments, but they are often ill-suited for early detection, especially in schools, where time, resources, and professional oversight may be limited.

Many alternative diagnostic methods exist, such as the *Hardy-Rand-Rittler (HRR) plates* or the *Farnsworth D-15* arrangement test. These tests offer a broader assessment of specific CVD types, but they also require controlled lighting conditions and trained supervision, constraints that make them impractical in many non-specialized settings. Digital adaptations of these tools have recently emerged, exploiting mobile and web platforms to improve accessibility. The reliability of these tests could however be of concern, since they are often administered across multiple electronic devices because of inconsistent colour calibration and display quality.

In the last few years, interest in game-based health tools has considerably grown, with a particularly sharp rise regarding educational interventions for children. Behavioural data can be collected passively by exploiting the engagement and interactivity brought forth by the game, often without the user realizing that an assessment is underway. In the context of CVD, a handful of mobile games and apps – such as *Chromatic Vision Simulator* – aim to raise awareness or simulate colour vision differences, but these tools are primarily educational or diagnostic in nature, and they often lack structured environments suitable for early detection.

Games that integrate perceptual challenges into familiar mechanics can enable subtle assessments of sensory or cognitive traits. However, for such tools to be effective in detecting CVD, they must balance diagnostic value with accessibility, enjoyment, and developmental appropriateness.

ColorFit builds on these grounds by embedding colour-based decision-making into the core gameplay mechanics of a simple, two-player board game. Unlike explicit testing tools, it encourages natural interaction with colour elements in a structured yet playful format. By observing gameplay choices – such as difficulty in distinguishing tile colours or longer response times under certain conditions – researchers and educators can infer the presence of potential colour vision difficulties. We stress that while ColorFit's strict color-dependant rules cause players with impaired color vision to perform strikingly worse than standard-vision players, which in our experience make this comparable to a clinical test, the board game can be used for early detection, and not for a full-fledged diagnosis. This section sets the stage for the following chapters, which describe how ColorFit was designed to fill this gap in the early identification landscape.

3. Design of ColorFit

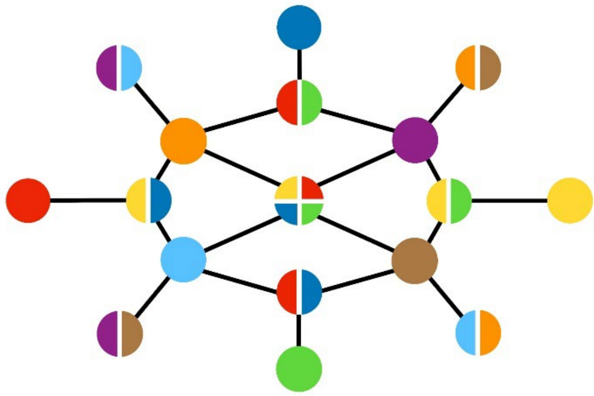
We designed the *ColorFit* board game with a clear set of constraints in mind: primarily, we wanted ColorFit to be unmistakably a game, and not a test or a diagnostic tool. This means, as with most games, that players take turns, follow a set of rules, compete in order to win and share an enjoyable experience. At the same time, the game had to remain extremely simple: the rules should be easy to understand, and anyone – without needing special training – should be able to observe a session and detect whether players are struggling with colour recognition.

Accessibility was another key requirement: ColorFit needed to be completely free to use and composed of materials that are easy to print or assemble at home. It also had to come with clear documentation explaining both how to play and how to supervise its use in more controlled settings. Last, but not least, the game needed to support multiple colour palettes, so that it could test a variety of colour vision deficiencies.

To meet these requirements, several design challenges had to be addressed. To start with, a session of ColorFit must be short and involve only a small number of participants, so that observers can closely monitor each move and easily spot colour recognition issues. This also allows researchers to run multiple sessions with the same group, each using a different colour palette, so that a broader range of diagnostic insights can be collected. By analysing aspects like the time players take on each turn and the types of mistakes they make, supervisors can gather objective indicators of potential difficulties in colour perception.

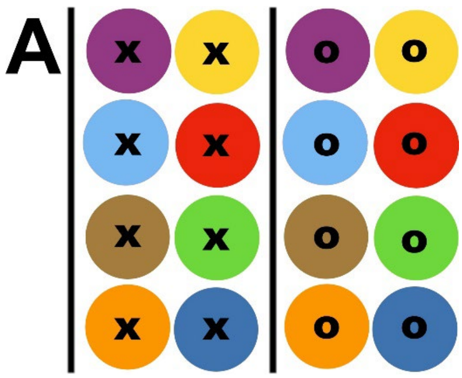
Initial testing highlighted another important consideration: we deliberately excluded references to real-world objects or storytelling elements. This was done to focus players' attention solely on colour – avoiding distractions, expectations or potential(ly misleading) associations that could influence their choices. While most board games are designed to engage a variety of cognitive skills, in our case this would have been counterproductive. ColorFit must still feel like a game, but it should not involve complex strategies or multiple layers of difficulty. The aim is to keep the experience straightforward and centred entirely on colour recognition.

In order to play ColorFit, a game board has to be chosen among 4 different variants.



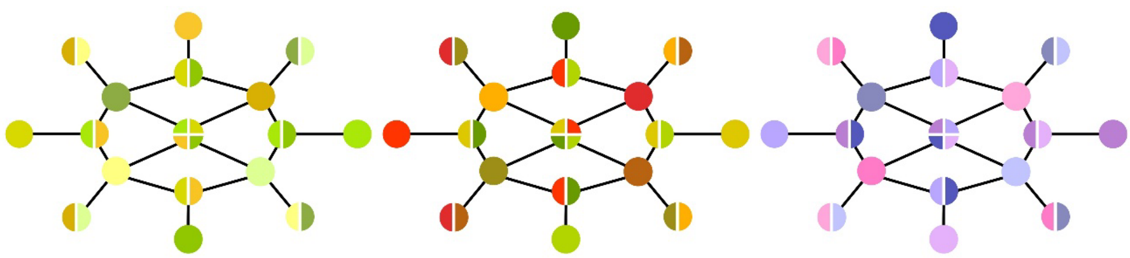
Picture n. 1 - The standard board for ColorFit.

The correspondingly coloured tiles are to be distributed between the two players, with one player receiving the tiles marked with the symbol "o" and the other those marked with "x".



Picture n. 2 - The corresponding "A" tokens

The variants only differ in terms of colour palette, while the connectivity of the underlying graph remains unchanged. The variants were baptised as "*spring*", "*autumn*" and "*winter*" boards, with reference to the palettes involved.



Picture n. 3 - The "spring", "autumn" and "winter" ColorFit boards.

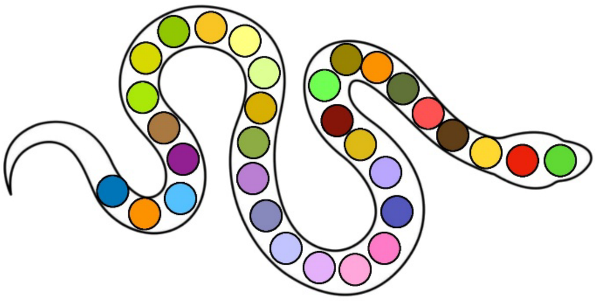
The first player is randomly selected, and he or she have to place one of their tiles on any node on the graph that matches the tile's colour. Players then take turns placing one tile at a time on the board, making sure that each tile is placed on a node that is directly connected to one already occupied and that shares the same colour as the tile being placed. If a player has no valid move – i.e., no available nodes that match their tile's colour, they must skip their turn. The first player to place all their tiles is declared the winner.

The predictivity of ColorFit was tested in our laboratory at the University of Milan with a group of colorblind players, who confirmed that the colors in the standard board (Picture n. 1) were indeed quite easy to distinguish, but were however useful to test whether the rules of the game had been picked up correctly by the players. On the contrary, the "seasonal" palettes (Picture n. 3) showed promising predictivity, highlighting differences in the performances of colorblind and standard-vision players.

A full ColorFit set consists of a series of printed documents and game components, which specifically include:

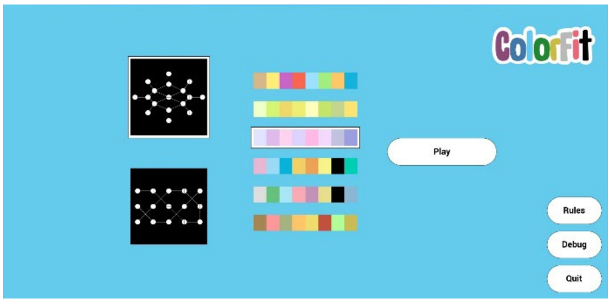
- An introduction to the Game4CED project
- Guidelines for using ColorFit in the classroom
- The complete game rules
- A variety of game boards, each featuring different colour palettes
- Colour-coded game tiles corresponding to the different boards

A single-player version of the game was also developed. In this case, the board consists of a snake-shaped path divided into coloured tiles, but the overall gameplay proceeds as usual: the player must place the coloured tiles in the precise order in which they appear on the snake-shaped guide.



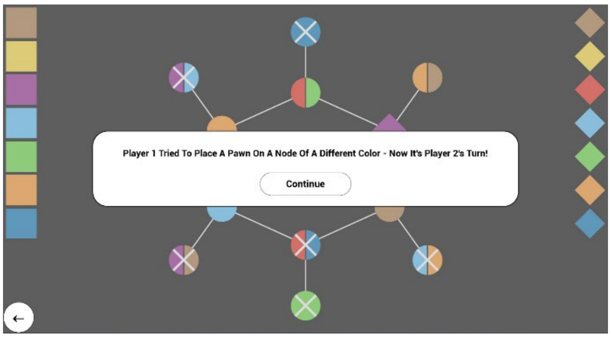
Picture n. 4 - The "solitaire" version of ColorFit.

A digital version of ColorFit was also developed as part of a master thesis program. With respect to its analogue version, some of the features of ColorFit are enhanced in the digital version: beside customizable colour palettes and graph connectivities, the program enforces the game rules, and therefore it does not allow the player to make illegal moves; when he or she tries to place a coloured token in the wrong section of the board, it informs the player and waits for a correct move to be sent to the game.



Picture n. 5 - The interface of the digital version of ColorFit.

In addition to this, the game also records latency times, an important parameter given by the time between the start of a turn and the moment in which a player places a coloured token; these values are shown to each player together with the pair of wrongly associated colours.



Picture n. 6 - With respect to the analog version, digital ColorFit enforces the game rules, and therefore it does not allow the players to place tiles incorrectly.

4. Methods for observational analysis

ColorFit represents an unusual application of game-based learning (GBL) where the actual learners are the people who administer the game-based test as a means to assess the player's ability in color discrimination without resorting to labelling or naming conventions. ColorFit was introduced to pre-school and to elementary school classes, each consisting of approximately twenty students. The students were divided into groups of four, with two playing at a time while the other two waited for their turn. Each student received a personalized player card marked with a unique identification code, along with a score sheet to keep track of the number of games played, as well as their wins and losses.

During the activity, students had the opportunity to play on different versions of the game board, starting from the standard board as to check if the rules had been understood correctly, and later on moving to those featuring "spring", "autumn", and "winter" colour palettes. Each student played at least three matches for each board, with at least one of those games supervised by a member of the Game4CED project team. The supervised match was also recorded on a video camera: during this match the players received no direct feedback, so that any bias or mistake could be determined by rewatching the video. In a typical session, students with specials needs or having difficulties with game rules were invited to try the solitaire version of ColorFit presented above.

During the systematic observation phase, specific observation protocols were designed in the form of structured coding grids. In the first trial phase, data collection was conducted in two formats: paper-based grids (completed manually) and a digital version that could be completed online. In addition to direct observation, video recordings were also used in selected classrooms (Baldacci, Frabboni, 2013).

During the trial phase, it became apparent that completing the observation grids in real time was a major challenge due to the large number of variables that had to be taken into account simultaneously. It became apparent that this complexity impaired both the accuracy and the completeness of the recorded data. Therefore, video recording was systematically introduced to enable retrospective coding. This approach not only improved the precision and reliability of the observation process, but also enabled the involvement of external coders, increasing the objectivity and validity of the data collected.

5. Pilot testing and discussion

The pilot testing phase of the game was conducted with the primary aim of assessing the clarity of the rules, the children's understanding of the game mechanics (Nesti, 2017), the variability in the duration of the game sessions and the role of the mediator or observer during these sessions. The test included a sample of seven school districts, which comprised ten school sites, in various locations in Northern Italy, mainly in the Emilia Romagna, Lombardia and Veneto regions. Following preliminary contacts, the testing was authorised by each school board, and school officials were given forms in advance to hand out to the parents, for them to know the types of observations that would be carried out, including an ethics declaration. Parents uninterested in the proposed activity could prevent their children from participating by not authorising or by not signing the form. No interactions with the school pupils took place following the tests. A total of 52 classes took part, including 7 pre-school and 45 primary school classes. The sample consisted of 1009 students (558 boys and 516 girls), including only those present at the time of screening; absent students were excluded from the dataset.Within this cohort, 36 students were identified as potentially colourblind, representing a prevalence rate of 3.6%. It is important to emphasize that this was an early detection and not a definitive diagnostic procedure. The purpose was to identify suspect cases and to communicate them to school and families. The observed prevalence is lower than the national average, which is estimated to be around 8.5% for males (Maffia *et all*. 2022). The group of observers included members of the Game4CED project, previously authorised by each school; no specific training was required for the observers, as their role was merely to relate the game rules and record game sessions. Observers kept from providing feedback to the players, in order not to influence their observed performance. Observers highlighted an active participation of the children, this allowed to observe children's behaviour more carefully, especially those who consistently made mistakes when placing the pieces on the board, mistakes that were related to colour matching rather than adherence to the actual rules.

Students who made a higher number of mistakes during the game often perceived the game as "difficult" and began to spontaneously develop compensatory strategies, for example: imitating the peer's moves, mirroring the game's progress on the board, asking for support from a peer, repeatedly asking peers or adults, verbalizing the colours to gauge reactions, or in more difficult cases, deciding to give up the game altogether. The children who made the most mistakes associated a single tile with multiple colours on the board.

In these cases, a second phase of individual play was introduced to rule out possible causes such as colour vision deficits, environmental factors such as lighting or print quality, or social factors such as interaction with peers, competitiveness, or contamination by the opponent's behaviour. This second phase included an individual game session with the snake-shaped path, designed to more accurately assess children's colour perception.

Among the critical issues identified during the pilot project, one of the most common concerned the understanding of the rules of the game, in particular the use of the "X" and "O" symbols on the tiles. Many children attributed functional meanings to these symbols, such as "X = block" and "O = permission to play", or interpreted them as conditions for a move, such as only playing where their tile "opened the way", or trying to form a winning line (similar to tic-tac-toe). This misunderstanding was counteracted by formulating the purpose of the symbols more clearly in the rules.

In addition, many children pointed out that it was unclear whether they should be played face up or face down, as the rules did not provide for this. Children aged 3 to 5 tended to lay the tiles flat on the table rather than holding them, as the latter presented a challenge. Those who tried to hold all the tiles in their hands often lost concentration while looking for certain colours or catching dropped tiles, so the teacher often intervened and suggested placing the tiles on the table instead.

In contrast, primary school children, unless instructed otherwise by their teacher, usually held all their pieces in their hands. This limited the strategic game considerably. In the first round, many children pointed out to the game masters that whoever starts first is likely to win. These comments showed that the strategy was primarily based on managing one's own colours without considering the opponent's resources.

An important observation concerned the reasons why the children preferred to hold the tiles in their hands. During the initial presentation of the activity, students were asked if they were familiar with board games. Among the most common answers were "Briscola", "Rubamazzo", "Scarta la carta" and the modern "UNO". In all these games, the cards are usually held in the hand and hidden from the opponent. This suggests that the confusion is due to the fact that the game tested consists of tiles that resemble cards, inadvertently leading children to play in a similar style. It is expected that this issue will be resolved in the final version of the game, where the distinction between cards and tiles will be more clearly defined.

Interestingly, some children who initially held the tiles in hand later asked to see their opponent's colours during subsequent rounds. When asked why, they explained that revealing the opponent's colours allowed for more strategic play: *"If I can see what my opponent has, I can decide what to play to block them and stop them from getting the colour they need to finish."*

Other children, playing with face-up tiles randomly placed on the table, tended to play with the tiles in the order they were laid out, significantly limiting their colours options.

In preschool, greater flexibility was allowed regarding the rules for tile placement so that children could focus more on the perception of colour.

From a data collection perspective, the snake-shaped path game proved to be particularly valuable for assessing the youngest participants. It was conducted in two different modalities: in the first modality, all the coloured tiles were randomly placed on the table and the children were asked to arrange them in the correct order in the body of the snake. In the second modality, which was introduced to address difficulties related to visual scanning between too many tiles and keeping children focused on perception, children were given one tile at a time, taking care to avoid similar colours in the sequence— to ensure that selection was based on colour recognition rather than order of placement. The snake-shaped path modality also proved particularly useful in cases where competitive dynamics interfered with children's ability to make accurate colour-based decisions. Several children intentionally placed tiles on similar but incorrect colours in their desire to win, even though they were aware of the difference. This tendency showed how peer interaction can influence performance, and how important individualized and non-competitive play environments are in order to avoid false positives when colour discrimination skills are being assessed.

One of Colorfit's greatest strengths is its remarkable flexibility of play, making it accessible to a wide range of age groups and catering to the various special educational needs in schools.

6. Future Work

While many results have already been reached (Iocco et al., 2024), many goals are still within reach.

The Game4CED project is structured around four interrelated work packages (WPs), each addressing a key dimension of research, development, education, and dissemination related to accessibility in board games, with a particular focus on supporting individuals with CVDs. WP1 focuses on the development of evaluation tools and inclusive game design; WP2 addresses the topic of teacher training and educational resource development; WP3 ensures broad dissemination of results; and WP4 oversees project coordination and implementation. The following is a summary of the main objectives and activities within each work package. As to WP1, devoted to scientific research, criteria are being developed to evaluate the accessibility of a variety of board games, with an emphasis on colour vision deficiencies. While a framework has already taken shape, its application on the most voted board games according to the popular BoardGameGeek website is still ongoing. In WP2, devoted to education, the project aims to raise awareness and build teacher capacity around colour blindness and inclusive education through a structured toolkit and professional development. The toolkit will by the end of the project include videos, booklets, an online evaluation tool, a colorblind-friendly palette and various screening materials. As to WP3 and WP4, devoted to disseminating and managing the project, both activities are proceeding at full pace, with our group participating in various international symposia and conferences to present the early results of our research.

7. Conclusion

Using board games as tools for the early detection of colour blindness represents a meaningful step forward in preventing the challenges often associated with this condition. We believe that ColorFit offers a fast and effective way to identify individuals who may have difficulty perceiving colours.

The dissemination of the ColorFit documentation serves two main purposes: first, to raise awareness about colour vision deficiencies – particularly in educational settings – and second, to help identify and support students affected by these conditions from an early age. In this context, ColorFit could become one of the first board games of its kind to be used in schools independently, without the need for external experts.

We want to conclude by emphasizing that while board games like ColorFit can be useful as preliminary screening tools, they are not a substitute for medical diagnosis. Rather, they serve as a helpful starting point – providing early indications that may warrant further medical evaluation for colour vision deficiencies.

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References

Armellin, L., A. Plutino, and A. Rizzi. (2022) ‘Online games for colour deficiency data collection.’, RESEARCH CULTURE AND SCIENCE BOOKS, 6, 79-86, Vol. XX, ISSN: 2785-115X.

Baldacci, M., & Frabboni, F. (2013). Manuale della ricerca educativa. Utet.

Birch, J. (2012) ‘Worldwide prevalence of red-green colour deficiency.’ JOSA A: 313-320. Colour and Colorimetry. Multidisciplinary contributions. Vol. XVIII B ISBN 978-88-99513-24-5.

Birch J. Efficiency of the Ishihara test for identifying red-green colour deficiency. Ophthalmic Physiol Opt. 1997 Sep;17(5):403-8. PMID: 9390366.

Iocco, C.A., Aurelio, D., Rizzi, A., Silva, L. (2024) ‘ColorFit, un gioco “print and play” per la rilevazione del daltonismo in classe’, Colore e Colorimetria - Contributi Multidisciplinari, Vol. XIX B, ISBN 978-88-99513-26-9.

Maffia, A., Silva, L., Rizzi, A. (2022). Problemi aperti relativi all’uso dei colori nella didattica della matematica. XVII CdC – Conferenza del colore – Associazione Italiana del Colore – Firenze, 12-13 September 2022.

Nesti, R. (2017). Game-Based Learning. Gioco e progettazione ludica in educazione. Pisa, Edizioni ETS.

Wright, W. D., e L. C. Martin. (1946) ‘Researches on normal and defective colour vision.’ Optometry and Vision Science, 24(6), 311-312.