



School of Information Technology and
Engineering at the ADA University



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ACCESSIBILITY EVALUATION: UEQ PRINCIPLES IN USER INTERFACE DESIGN FOR
PERSONS WITH DYSLEXIA AND COLOR BLINDNESS

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ABSTRACT

This paper aims to analyze the challenges encountered by dyslexic and color blind individuals in their use of mobile applications by developing evaluation metrics based on the UEQ principles to ensure accessibility. The study involved testing a mobile application called “HNK Bank” with people from three different groups: those that are dyslexic, those with color blindness, and those who don’t have either condition. The application was designed for persons with dyslexia and color blindness in terms of appropriate fonts and color choices. During the evaluation process, each user was instructed to perform four scenarios with no intervention from our side, and we measured the time of testing each scenario individually. Following the testing, a brief interview was done with each, involving a wide range of questions about the application. Overall, the participants found the application easy to use and did not encounter much difficulty regarding reading and understanding. This indicates that choosing the right color and font options leads to good accessibility. However, the dyslexic group took longer to complete the scenarios compared to the other two groups, mainly because they need more time to process the information. Participants also shared a few ideas for future improvement of the application. The most common suggestion was the addition of the Azerbaijani language. This suggestion was primarily influenced by the fact that for some individuals, learning a second language can be quite challenging, especially those with dyslexia. We also observed an obvious pattern in likes and suggestions and the users’ corresponding conditions. Meaning, the users with dyslexia mostly mentioned font-related features, while color blind people focused on color-related features. The study demonstrated that by implementing suitable design considerations, technology can provide accessibility to any users regardless of their conditions. However, considering the current simplicity of the application, it is possible that when the application is further enhanced, accessibility might diminish. Therefore, it is utmost important that when the application equips more functionalities based on user suggestions, it should still maintain accessibility features.

Keywords: UEQ, dyslexia, color blindness, application testing, statistical analysis

Table of Contents

LIST OF FIGURES	v
LIST OF TABLES	vi
LIST OF ABBREVIATIONS	vii
1. INTRODUCTION	1
2. LITERATURE REVIEW	3
3. METHODOLOGY AND TECHNICAL APPROACH	6
3.1 User Experience Questionnaire	7
3.2 Application Interface	9
3.3 Evaluation Metrics and Methodology	15
3.4 Statistical Analysis	16
4. EVALUATION PROCESS	18
4.1 Test Scenarios.....	18
4.1.1 Create a New Account and Review Cards	18
4.1.2 User Dashboard Orientation	19
4.1.3 User Preference Settings.....	20
4.1.4 Transferring Money.....	21
4.2 Test Conditions.....	23
4.3 User Interview Questions	23
5. EVALUATION RESULTS.....	25
6. CONCLUSION AND FUTURE WORK.....	36

LIST OF FIGURES

No	Figure Caption	Page
1	Assumed scale structure of the UEQ	8
2	User Sign-up Screen	10
3	User Sign-in Screen	11
4	User Dashboard Screen	12
5	User Profile Screen	13
6	Edit Profile Screen	13
7	Money Transfer Screen	14
8	Help Screen	15
9	Total Time Spent by Each User	30
10	Scatter Plot of Scenarios, Users, and Time	31
11	Heatmap of Total Completion Times for Different Scenarios	32
12	Ratings Distribution by User Groups	34

LIST OF TABLES

No	Table Caption	Page
1	Evaluation Protocol	23
2	Interview Questions	24
3	Scenarios Data	26
4	Post-testing Interview Data	27
5	Post-testing Interview Comments Grouped by Users	35

LIST OF ABBREVIATIONS

Abbreviation	Explanation
UEQ	User Experience Questionnaire
BDA	British Dyslexia Association
IDA	International Dyslexia Association
UX	User Experience

1. INTRODUCTION

This paper focuses on creating evaluation metrics to test whether the created Mobile Banking Application is accessible for people with color blindness or dyslexia (Hasanguliyeva, 2024). In today's world, technology is deeply integrated into our day-to-day lives, enabling us to perform various tasks. One such technological advancement is the use of mobile banking applications, which allow us to perform numerous banking activities solely using our mobile devices. It is essential to recognize that the benefits of technology should be accessible to everyone. Therefore, some individuals require specially designed applications to achieve this goal.

The conditions of color blindness and dyslexia are quite common among people and necessitate specific design considerations when developing accessible applications. Before delving into the accessibility evaluation, it is crucial to understand those conditions better.

Color blindness (also called color vision deficiency) refers to an inherited condition affecting certain individuals whose perception of color varies significantly from the majority (Martin, Keller, Rogers, & Kabrinsky, 2000). While it is relatively rare in women (approximately 0.5%), it affects around 8% of men (About Colour Blindness, n.d.).

Color blindness occurs when there is a problem with the pigments in certain eye nerve cells that sense color. People could find it difficult to distinguish between red and green if only one pigment is absent which is the most common type of color blindness. They may have trouble seeing blue-yellow colors if a different pigment is missing. People with blue-yellow color blindness often have problems seeing reds and greens, too (Mediline Plus, n.d.).

According to the article written by the National Eye Institute (National Eye Institute, 2023), the main symptoms of color blindness include trouble seeing the difference between colors, as mentioned above, as well as difficulties identifying color brightness and different shades of certain colors.

In the same article, the primary cause of this condition is mentioned to be mostly genetics, but it can also occur due to an injury to the retina (the light-sensitive layer of tissue in the back of the eye), the optic nerve (which connects the eye to the brain), or the brain itself.

As of now, there is no effective treatment for inherited color blindness. However, there are some colored lenses or glasses available for those individuals. Some people find them effective in helping with the condition, while others find them confusing (Colour Blind Awareness, n.d.).

While color blindness is often difficult to recognize in individuals, dyslexia is typically identified during early childhood, particularly when individuals begin school.

The British Dyslexia Association (BDA) defines dyslexia as a learning difficulty that primarily affects the skills involved in accurate and fluent word reading and spelling. Characteristic features of dyslexia are difficulties in phonological awareness, verbal memory, and verbal processing speed (British Dyslexia Association, n.d.). According to the International Dyslexia Association (IDA), approximately 15-20% of the world's population exhibits some symptoms of dyslexia (International Dyslexia Association, 2020).

According to an article written in Harvard Medicine magazine about brain development and dyslexia (McDonough, 2023), finding the clues of dyslexia in a brain is not an easy task mainly because there is not a single region of the brain devoted to reading. If scientists wanted to pinpoint the basis of dyslexia, they would need to explore the many brain regions involved in reading and the neural pathways connecting them.

The same article also discusses a study conducted on children with dyslexia. The study concentrated on one white matter tract known as the arcuate fasciculus (“the arc”), which connects crucial brain regions involved in reading: those associated with vision and sound processing at the back of the brain, and the inferior frontal gyrus, responsible for comprehension and meaning. They subsequently discovered that children with lower phonological processing skills, a risk factor for dyslexia, also had smaller arcs.

Dyslexia is not a disease; therefore, there is no cure for it. However, it is a well-researched condition, and certain rules and regulations have been proven helpful for people with dyslexia. When designing an application accessible for dyslexic individuals, it is recommended to eliminate features that could cause unnecessary stress and to reduce software complexity by limiting the number of features available at any given time (Darejeh & Singh, 2013).

Considering the challenges associated with each condition, our application should to specific design patterns. According to (Aliyeva, 2024), those design patterns include:

- **Efficiency:** A website or application should have clear, legible fonts and sufficient line spacing to make the content accessible to all, including people with dyslexia.
- **Predictability:** It reduces uncertainty and frustration when interacting with a digital interface, especially for users with dyslexia.
- **Attractiveness/Originality:** Special fonts, such as OpenDyslexic or Dyslexie, are designed to be more visually appealing and readable for individuals with dyslexia. They have distinct characteristics from standard fonts.
- **Efficiency:** In the context of web design and accessibility, efficiency refers to how quickly and effectively users can accomplish their tasks and access information on a website or application, achieved by the use of visual cues, patterns, and text labels.
- **Transparency:** In web design and accessibility, transparency relates to how clearly and easily users can perceive and interact with the content on a website or application. By using high-contrast color combinations, a website or application enhances transparency by ensuring that content is more easily perceivable and distinguishable.
- **Stimulation:** Stimulation refers to how the design elements, such as color choices, shapes, and patterns, can engage and stimulate the user's visual and cognitive senses. The emphasis on avoiding red-green combinations and utilizing alternative differentiators is a way to stimulate an inclusive and user-friendly design, especially for individuals with color blindness.

The role of evaluation metrics is to assess the acceptability of the applied rules by the target audience.

The subsequent chapters provide comprehensive details on our approach to achieving that goal. The following chapter includes similar applications that were designed for individuals with dyslexia and color blindness in mind in various countries.

2. LITERATURE REVIEW

Considering the special requirements of each condition, designing applications that provide accessibility for those target audiences should be done with proper research so that the users would

not feel excluded. This chapter sheds light on the works that have been done on creating applications specifically for persons with dyslexia and color blindness.

For dyslexia, the mobile applications' main purpose was usually screening or intervention. The related works that will be mentioned in this chapter belong to the screening group since they are more related to our work.

In Sri Lanka, a group of researchers developed a mobile application (Martins, Lima, Sampaio, & de Paiva, 2016) to support people with dyslexia and dysgraphia called “the CURE”, which was developed using various machine learning algorithms for speech recognition tasks. The application was tested by approximately 100 individuals with these conditions, and overall, it was considered a success.

In Italy, an Android application was developed (Francese, Monaco, & Nicoletti, 2018) to help detect dyslexia in school children, primarily targeting students aged 7-8. The application consisted of reading exercises structured in levels and based on purposefully created sentences. After the application was fully developed, 46 second-class students tested it twice under supervision and were required to fill out a form regarding their experience with the application. Overall, the researchers arrived at an optimistic conclusion that their application could assist in the early detection of dyslexia among children.

Another mobile application designed to assist children with reading disorders, particularly dyslexia, was developed by Brazilian researchers (Martins, Lima, Sampaio, & de Paiva, 2016). The application underwent testing with two distinct groups: one comprising children with dyslexia and the other consisting of children without any reading disorders. Employing speech recognition technology, the application assessed users' reading abilities and compared the results to identify words that presented challenges for the majority. Additionally, the duration of the experiments was measured. Following the tests, users were asked to complete a questionnaire regarding their experience with the application. Overall, the responses indicated that the application successfully differentiated between children with dyslexia and those without it.

In another study, researchers from Quito, Ecuador, implemented Augmented Reality (AR) in a mobile application called “TEDE,” which aimed to help school children with dyslexia in the reading and writing process (Tenemaza, Navarrete, Jaramillo, & Rodriguez, 2019). The

application had two forms: digital (AR) and paper-printed forms. In this experiment, 11 kids aged 8-11 years old with dyslexia were asked to take the test, engaging in items focused on the reversion of complete words and confusing letters by sound at the beginning of the word. The test was completed by users supervised by authorities, teachers, and psychologists. As a result, the students found the digital format more appealing in terms of icons, colors, and sounds. The researchers concluded that applying AR in dyslexia detection yielded satisfactory results.

In the mobile application “Pubudu”, researchers from Sri Lanka utilized deep learning methods to address reading disabilities such as dyslexia, dysgraphia, and dyscalculia in children (Kariyawasam, et al., 2019). They developed a Convolutional Neural Network (CNN) model specifically for speech recognition tasks. The models were trained in both Sinhala and English languages, achieving high screening accuracies for the mentioned disabilities. For dyslexia, the application demonstrated 85% training accuracy and 65% test accuracy in Sinhala, with an average precision of 58%, while in English, the accuracy reached around 94%. The experiment involved 50 students, among whom 20 were pre-diagnosed with dyslexia. Through the application, an additional 13 of these students were correctly identified with dyslexia, resulting in a screening accuracy level of 65%.

In the literature, the number of studies on mobile application design for color-blind individuals is considerably less compared to dyslexia. That being said, we have included some related studies that also consider persons with color blindness in an application design.

This work (Iqbal, Shahzad, Ahmad, Amelio, & Brodic, 2018) adopted a comprehensive examination of research studies on the usability evaluation of adaptive user interfaces (AUIs) for color-blind individuals in mobile applications. Evaluations were conducted on usability effectiveness, efficiency, and user satisfaction by individuals with color blindness through three different activities, namely Color Switch, Bubble Shooter, and Baby Xylophone. The 30 participants were required to experiment with the activities in both adaptive and non-adaptive environments. As a result, the AUIs exhibited superior usability within the user groups. However, the researchers concluded that while an adaptive environment increased overall user satisfaction, it did not significantly improve effectiveness and efficiency.

In another study, a group of researchers from Russia developed a mobile application named “Vision of Color” to assist individuals with color blindness (Krasnova, Romanova, & Susanov, 2023). The application, developed in Java, provides real-time color identification for the target group by enhancing their ability to distinguish colors. The authors of the application believe that their product can be used across various industries to improve users' quality of life and assist them in their careers. Some potential applications include: in the classroom at school for tasks requiring work with illustrative materials such as maps and atlases; in the work of graphic designers for developing website graphics or programs; in the work of chemists for mixing various substances; when obtaining a driver's license; in the work of electricians; in robotics for creating robots using parts and wires of various colors that have semantic meaning on diagrams; and in other areas.

In another research paper with a focus on color blindness, researchers propose two methods for adapting the colors of mobile websites to improve accessibility for users with color vision deficiencies (Zhou, Bansal, & Zhang, 2014). The research aims to adapt colors in mobile web pages that are non-distinguishable to users with color blindness while preserving some properties of original colors. One method focuses on identifying foreground and background color combinations to determine which colors require adaptation. The other one aims to lower the computational costs of assessing a set of replacement colors by introducing differential naturalness and differentiability. Both methods proved effective, as demonstrated by the experiment results.

The following chapter describes the User Experience Questionnaire (UEQ) which provides an evaluation mechanism for user interfaces along with the application design.

3. METHODOLOGY AND TECHNICAL APPROACH

This chapter of the work provides details on what the User Experience Questionnaire is, as well as more detailed information on its application (Hasanguliyeva, 2024), how it works, and the features it provides. Additionally, we have included information about evaluation metrics that were defined based on the collected data, along with some possible statistics that will be applied to those metrics.

3.1 User Experience Questionnaire

The User Experience Questionnaire (UEQ) is a widely used method to measure the subjective impression of users towards the user experience (UX) of products. Its purpose is to allow the users to express feelings, impressions, and attitudes that arise when experiencing the product under investigation in a straightforward and immediate way (usually within 3-5 minutes) (Schrepp, Hinderks, & Thomaschewski, Design and evaluation of a short version of the user experience questionnaire (UEQ-S), 2017).

It is usually used as a part of usability testing to collect quantitative data about how the users felt about the product. Each UEQ item consists of pairs of opposite-meaning terms, for instance, understandable or not understandable, where participants rate them on a 7-point Likert scale (Schrepp, User Experience Questionnaire Handbook, 2015).

The original UEQ was first created in the German language in 2005. In that version, a data analytical approach was used to ensure the practical relevance of the constructed scales. Specifically, the scales were derived from data concerning a larger pool of items, with each scale describing a distinct quality aspect of an interactive product (Schrepp, User Experience Questionnaire Handbook, 2015).

Currently, it is available in 19 languages (German, English, French, Italian, Russian, Spanish, Portuguese, Turkish, Chinese, Japanese, Indonesian, Dutch, Estonian, Slovene, Swedish, Greek, Polish, Hindi, and Bulgarian) (Schrepp, Hinderks, & Thomaschewski, Design and evaluation of a short version of the user experience questionnaire (UEQ-S), 2017).

As mentioned in the mentioned handbook, the UEQ contains 6 scales with 26 items. The figure below illustrates that scale structure:

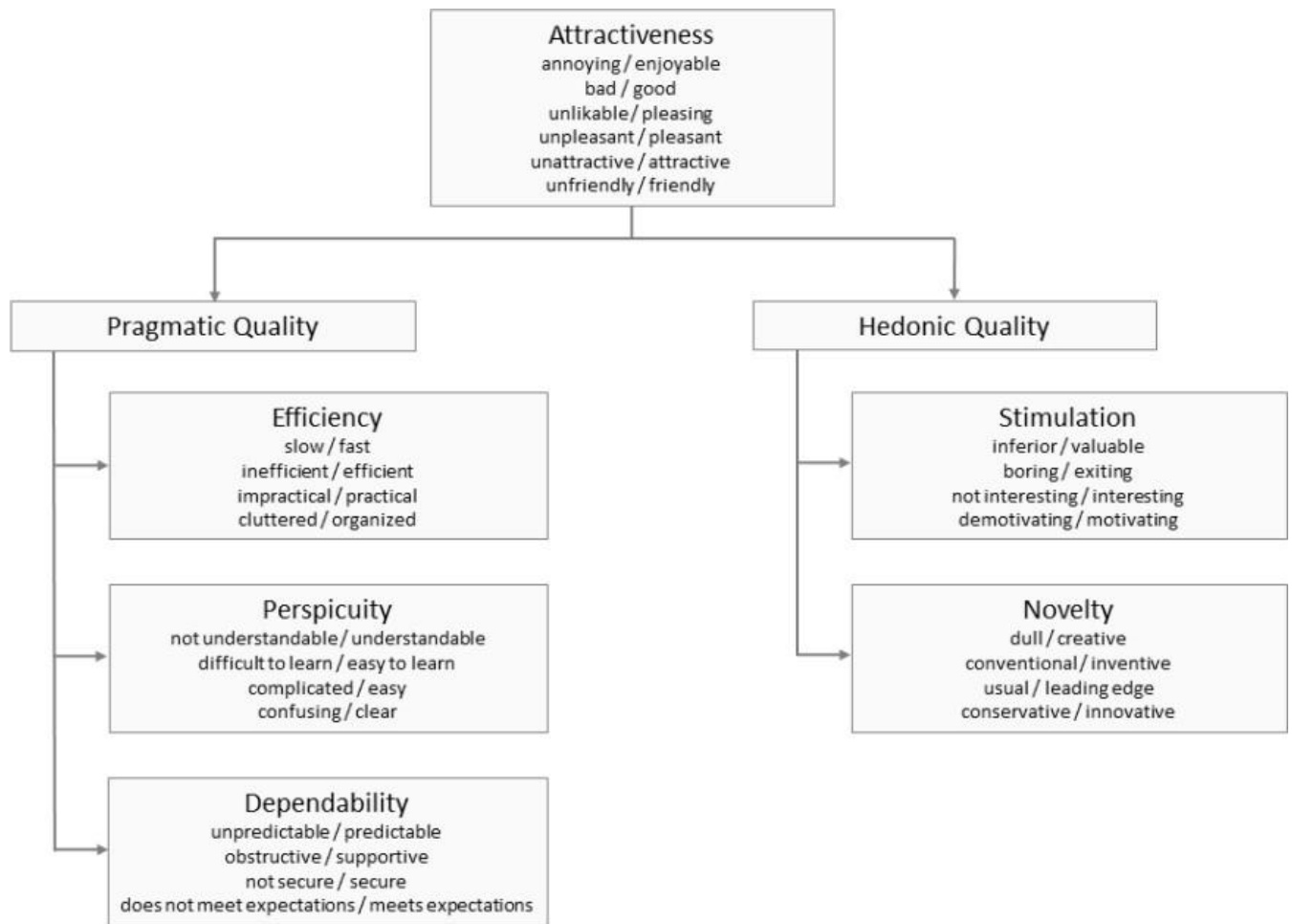


Figure 1. Assumed scale structure of the UEQ . Source: (Schrepp, Hinderks, & Thomaschewski, Design and evaluation of a short version of the user experience questionnaire (UEQ-S), 2017).

When it comes to the number of participants, the more people involved, the more accurate the results tend to be. According to Schrepp, for typical products, evaluations from 20-30 individuals usually yield suitable results. However, in our case, as the application is primarily intended for a very specific target group, we recruited a total of 9 participants. These participants were categorized into three groups: dyslectic individuals, color-blind individuals, and people with no disabilities.

3.2 Application Interface

The application, named “HNK Bank” is a mobile banking application, developed in Kotlin, that was designed to provide accessibility for persons with dyslexia and color blindness (Hasanguliyeva, 2024). Its design prioritizes accessibility features, such as appropriate font options for dyslexic people, as well as carefully chosen color schemes for color-blind people to ensure a seamless user experience for the target audiences. For every button and text input field, an additional text-to-speech option is provided to assist the users who might struggle with reading texts.

The application consists of the following screens:

1. **User Sign-up:** Allows new users to create an account by providing necessary information such as full name, phone number, and password.

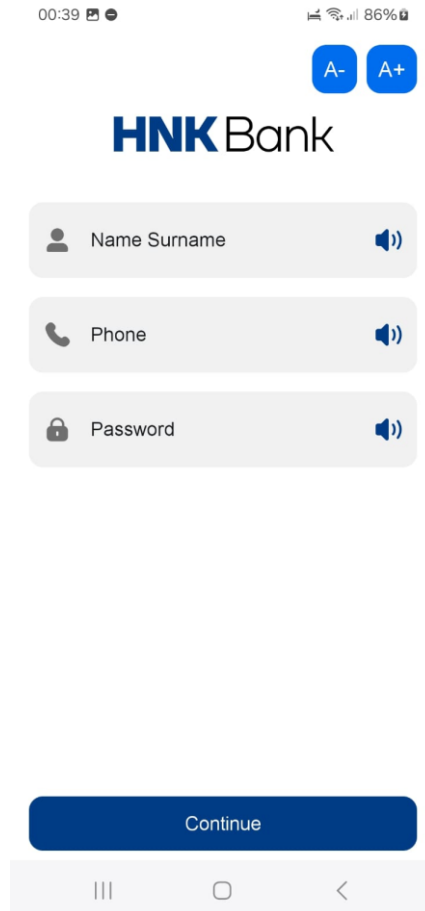


Figure 2. User Sign-up Screen

- 2. **User Sign-in:** Enables existing users to access their accounts by entering their credentials.

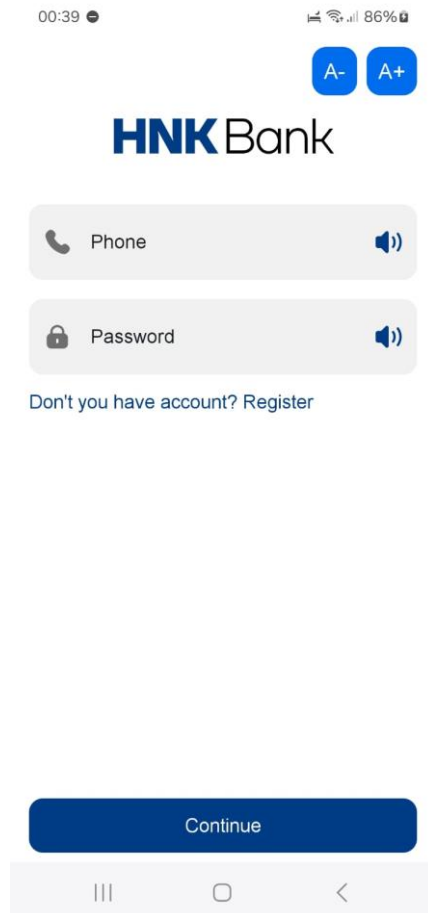


Figure 3. User Sign-in Screen

3. **User Dashboard:** The main screen displays essential user information, including cards associated with the account, transaction history, and transfer button.

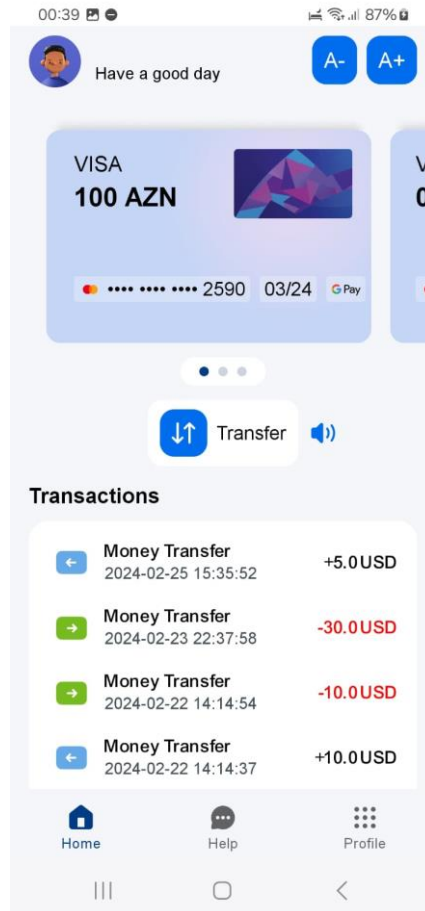


Figure 4. User Dashboard Screen

4. **User Profile:** Presents detailed information about the user as well as a button to edit existing information and sign out profile.

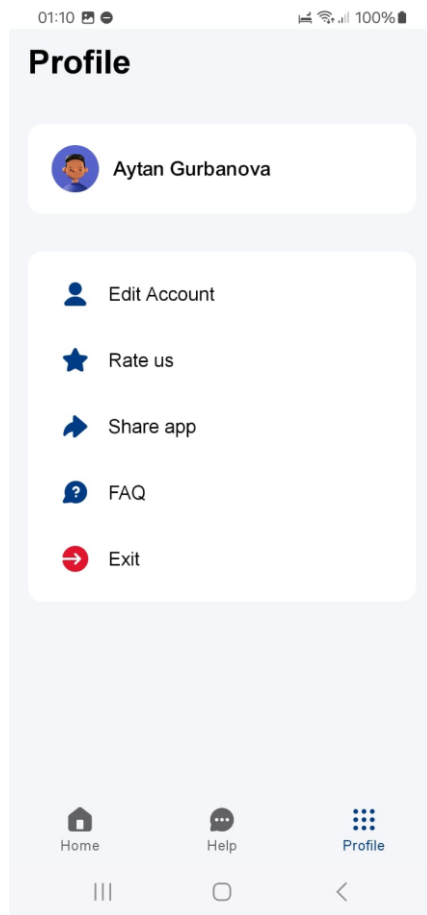


Figure 5. User Profile Screen

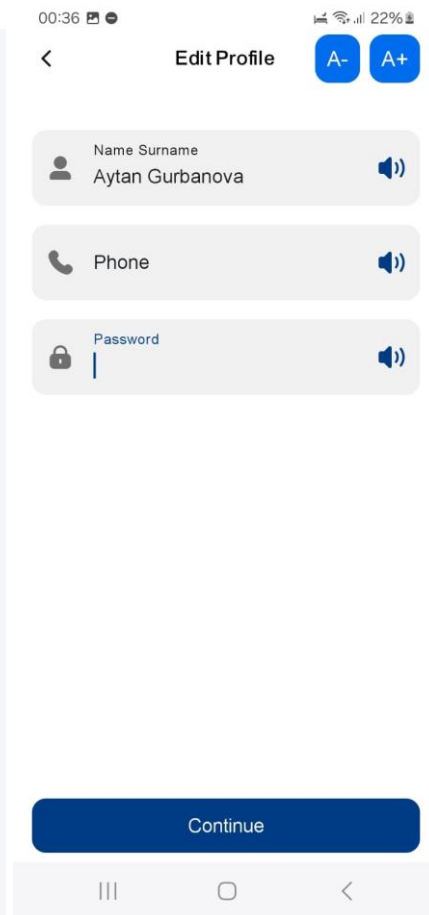


Figure 6. Edit Profile Screen

5. Money Transfer: Facilitates the money transfer to another card.

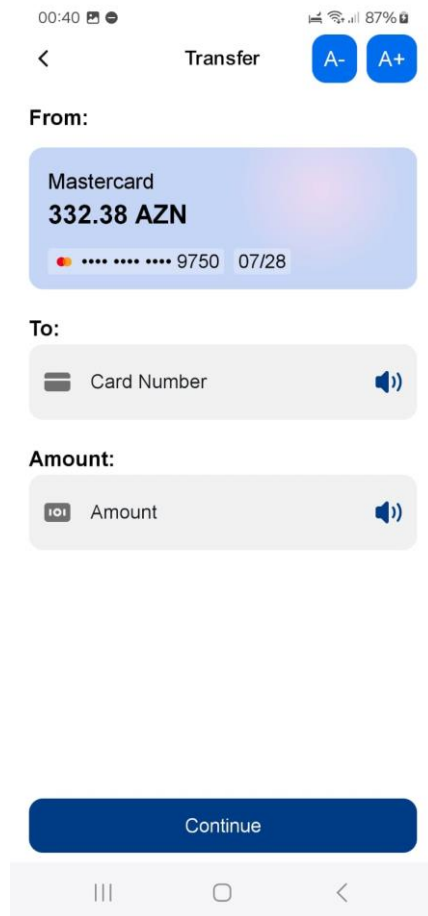


Figure 7. Money Transfer Screen

6. **Help Screen:** Assists the user with necessary information on how to perform different actions in case they have difficulty locating them.

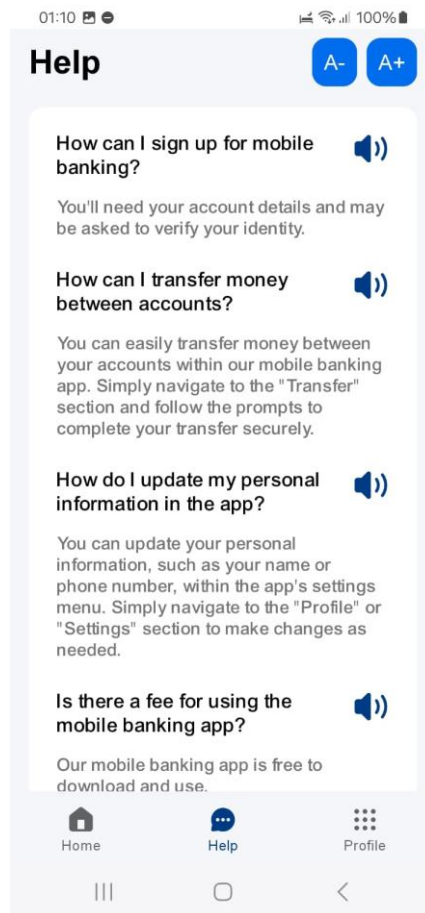


Figure 8. Help Screen

3.3 Evaluation Metrics and Methodology

To better understand accessibility, the following metrics will be collected from the target audience. Each measurement must be collected separately for people with color blindness and dyslexia, and people without these conditions highlight the differences between the groups.

The following metrics are planned to be generated:

- **Task Completion Rate:** The percentage of completed tasks out of the total tasks assigned during the evaluation. Ideally, the figures should be identical for all target groups so that the application does not distinguish between individuals.
- **Error Rate:** The percentage of errors made by users out of the total tasks assigned during usability testing. This measurement helps us identify areas that need improvement so that we can focus on them in the future.
- **Identifying User Struggles:** Analyze and document specific features where users faced challenges during the evaluation. This helps us understand whether the issue is in the lack of accessibility for specific individuals or a general design flaw that any user might struggle with.
- **Frequently Used Features:** Analyze and document which features were frequently used by users during testing. The results of this metric might be used in optimizing those features further, as their popularity indicates they would likely be used frequently.
- **Total Time Spent by Each User Group:** Measure and document the time spent on each scenario per user. These figures help us understand which user group requires how much time in total, and also to identify whether there are any obvious behavior patterns among the user groups.

3.4 Statistical Analysis

After the metrics mentioned above are collected, various statistics will be applied to the data. The primary objective of applying statistics to raw data is to help us in a better understanding of whether the application met its primary goal of accessibility or not. The insights gained from these figures also assist us in improving the application for further use in the future.

The statistics are specifically selected for each metric to provide what we believe are suitable insights. The list below contains the data along with the corresponding rationale.

- **Bar Plots for Task Completion Rate and Error Rate**

Bar plots are useful tools for visualizing data with multiple categories. Given that we have three target groups, these plots will help us analyze task completion rates and error rates for each group. By examining these figures, we can gain insights into tasks where users experienced more success and encountered the most difficulty.

Ideally, we would expect identical figures for each target group indicating that the application has met its accessibility goal. Additionally, we would anticipate the task completion rate to be significantly higher than the error rate.

- **Mean and Median Analysis for Task Completion Rate and Error Rate**

Comparing the mean and median task completion and error rates for each target group assists us in understanding the average and central tendencies for task completion periods.

Typically, we would expect users within the same group to have identical mean and median figures. However, the opposite is also possible in cases where the data is skewed, indicating that individuals with the same conditions do not take identical times to finish tasks. In such cases, it would be crucial to further investigate the reasons behind these figures.

- **Heatmap of Total Completion Times for Different Scenarios**

Heatmaps are data representations in which higher color intensity corresponds to higher values. We will utilize a heatmap to display the total completion times for different scenarios within each user group. This visualization will emphasize the total completion times across scenarios for each user group, rather than focusing on individual test subjects.

- **Bar Plots for Frequently Used Features and User Struggles**

Generating stacked bar plots for various application features among different groups helps us identify which features are popular within each group and whether different groups prefer different or similar features.

Similarly, creating comparative bar plots for the features users struggle with the most helps us understand whether those struggles are specific to certain groups or if most users struggle regardless of the group they belong to.

In summary, this section provided a brief introduction to the UEQ and an overview of the application interface, including its features. Additionally, we discussed the evaluation metrics we will collect, along with the statistics to be applied to them. The following sections provide more information on the actual testing process and present the experiment results in more detail.

4. EVALUATION PROCESS

This chapter of the work includes various test scenarios that were created for data collection purposes. These scenarios were designed to be sufficiently complex to provide a comprehensive understanding of user performance. Additionally, it includes final interviews that were conducted with the participants to collect their feedback on their experience with the application.

4.1 Test Scenarios

As already mentioned, color blindness and dyslexia present specific challenges. Individuals with color blindness may have difficulty distinguishing certain colors. Therefore, during testing, our focus should primarily be on color contrast and observing the results. Dyslexic individuals, on the other hand, have learning difficulties that primarily affect reading and spelling. During usability testing with these users, our focus should be on determining whether they can understand the instructions clearly and whether the text has appropriate spacing and font.

The following test scenarios were created to assess accessibility for both individuals with color blindness and dyslexia. Each scenario was tested with users from all groups. In creating these scenarios, we aimed to make them complex and comprehensive enough, so that the results accurately reflect practical use.

4.1.1 Create a New Account and Review Cards

1. **Creating a New Account:**
 - The user inputs the necessary information: first name and last name, phone number, and password.

- Success Condition: Account creation is successful, and the user receives a confirmation message and is redirected to the dashboard screen.
- Fail Condition: If any of the required fields are not filled or incorrectly filled, display an error message prompting the user to correct the input.

2. Reviewing Cards in the Dashboard:

- The user navigates to the dashboard and locates the section for the owned cards.
- The user can view a list of added cards with details.
 - Success Condition: The cards section is clearly labeled and easily accessible, and the card details are displayed clearly.
 - Fail Condition: If the cards section is not easy to locate or if the text color or size makes it difficult to read the card details, the user may struggle to review their cards.

4.1.2 User Dashboard Orientation

1. User Sign-in:

- The user is presented with the sign-in screen and inputs the sign-in information: phone number and password.
 - Success Condition: The input information is correct, and the user is redirected to the dashboard screen.
 - Fail Condition: The input information is incorrect and an error message is displayed indicating the user should re-input the correct information.

2. Navigating Dashboard Screen:

- Upon accessing the dashboard screen where all essential information and card actions are available. The user attempts various operations such as viewing account details, viewing transaction history, or accessing settings.
 - Success Condition: The user can easily locate all desired buttons or labels without feeling overwhelmed.

- Fail Condition: If any buttons or labels are difficult to locate or if the user feels overwhelmed, it may indicate a usability issue.
- In case the user gets stuck in some steps, the “help” screen is provided for them, which contains some useful tips and tricks for users to perform actions.

3. **Accessibility Check:**

- The dashboard screen follows specific rules for users with color blindness and dyslexia.
 - Color contrast is appropriately adjusted to help users with color blindness.
 - The appropriate text size and font choices are used to help the readability, especially for users with dyslexia.
- Success Condition: The dashboard screen is accessible to all users, including those with color blindness and dyslexia.
- Fail Condition: If the dashboard screen does not meet necessary accessibility standards, some users may feel excluded.

4.1.3 User Preference Settings

1. **User Sign-in:**

- The user is presented with the sign-in screen and inputs the sign-in information: phone number and password.
 - Success Condition: The input information is correct and the user is redirected to the dashboard screen.
 - Fail Condition: The input information is incorrect and an error message is displayed indicating the user should re-input the correct information.

2. **Locating User Profile:**

- In the dashboard screen, the user looks for the user profile option where they can find the “edit profile” button where they can edit the existing first name and last name, phone number, and password.
 - Success Condition: The user easily locates the settings without any difficulties.

- Fail Condition: The user struggles to find the settings because of poor design.

3. Viewing and Editing Information:

- After locating the edit button, the user clicks it.
- The user is presented with the existing user information.
- User can update desired fields.
 - Success Condition: The user can view and modify the desired information without facing any issues.
 - Fail Condition: The user cannot edit or save the changes or the changes could not be applied for some reason.

4. Feedback after Actions:

- After modifying user information, the user receives clear feedback indicating the success or failure of the operation.
- If the changes are saved successfully, a confirmation message is displayed.
- If any errors or issues are preventing the changes from being applied, provide an informative error message on how to resolve the issue.
 - Success Condition: The user receives clear feedback confirming the success of the operation or an informative error message in case of failure.
 - Fail Condition: If the feedback message is unclear or indicates an error without providing information on how to resolve it, the user may feel confused.

4.1.4 Transferring Money

1. User Sign-in:

- The user is presented with the sign-in screen and inputs the sign-in information: phone number and password.
 - Success Condition: The input information is correct and the user is redirected to the dashboard screen.
 - Fail Condition: The input information is incorrect and an error message is displayed indicating the user should re-input the correct information.

2. Locating Transfer Money Button:

- The user looks for the “transfer” button on the dashboard screen which should be clearly labeled and easily accessible.
 - Success Condition: The user easily locates the button without any struggle.
 - Fail Condition: The user feels overwhelmed or confused when trying to find the button.

3. Performing Money Transfer

- After the button is located, the user presses the button to initiate money transfer.
- The user is required to enter a 16-digit card number and the desired amount, then click the “Continue” button to transfer money.
 - Success Condition: The user can complete the transfer smoothly without encountering any issues.
 - Fail Condition: Issues are preventing the transfer from being completed, displaying an error message with guidance on how to resolve it.

4. Display Feedback:

- After completing the transfer, the user receives a confirmation or failure message based on the action.
- If the transfer is successful, display a confirmation message.
- If any errors or issues are preventing the transfer from being completed, provide a detailed error message with the failure reason.
 - Success Condition: The user receives a clear confirmation or failure message based on the result of the operation.
 - Fail Condition: If the feedback message is unclear or indicates an error without providing information on how to resolve it, the user may feel confused.

4.2 Test Conditions

To ensure consistency and structure in the evaluation process, we have defined the following conditions which will be maintained throughout the testing stage.

Table 1. Evaluation Protocol

Evaluation Protocol	Details
Conditions	
Provision of Cellular Phone	Participants will be provided with an Android device pre-installed with the application.
Evaluation Format	The testing is preferably conducted face-to-face; however, depending on participants' availability, sessions can also be conducted via video call.
Evaluation Independence	Each test subject will perform evaluation independently, without interaction with other participants.
Time Allocation Flexibility	Test subjects will have unlimited time to complete the evaluation protocol at their own preferred pace.
Post-testing Interview	After completing the scenarios, each test subject will participate in a short interview to provide feedback on the user interface and evaluation process. This will involve a combination of Likert scale and open-ended questions.

4.3 User Interview Questions

In this section of the work, we have added interview questions for the test users to understand their feelings about the application. As previously mentioned, the test users consist of three distinct groups of people: people with dyslexia, color blindness, and no disability.

We have prepared a total of 10 questions, with eight of them offering 5 Likert scalar values as possible answers. The first question inquires about the experience of using mobile phones in

years. The last question is an open-ended question aimed at receiving overall experiences and any suggestions for improvement. The table below displays the complete list of questions:

Table 2. Interview Questions

Question #	Question Content	Question Type	Input Range
1	For how long have you been using a cellular phone?	Open-ended	Unbounded
2	How easy was it to navigate through the application's menu and options?	Likert Scale	1-5
3	Please rate the text readability within the application, where 1 is not readable at all and 5 is all text is readable.	Likert Scale	1-5
4	Please rate how crowded the screens feel within the application, where 1 indicates a very crowded and overwhelming layout and 5 indicates a spacious and easy-to-navigate design.	Likert Scale	1-5
5	How would you rate the contrast between the text and background colors where 1 indicates very poor contrast and 5 indicates excellent contrast?	Likert Scale	1-5
6	How well does the application use icons and symbols, where 1 means very poorly and 5 means very well?	Likert Scale	1-5
7	How would you rate the ease of using the application's functionalities that you have tested, where 1 indicates very difficult and 5 indicates very easy?	Likert Scale	1-5

8	Please rate the clearness of the feedback messages provided by the application when performing tasks, where 1 means unclear and 5 means very informative.	Likert Scale	1-5
9	Please rate the color and font choices provided within the application, where 1 indicates insufficient choices and 5 indicates sufficient choices that meet your preferences and needs.	Likert Scale	1-5
10	Please share your overall experience with the application in a few words, as well as any suggestions you may have for future improvements.	Open-ended	Unbounded

In the subsequent chapter, we provide the evaluation results, analyzing the data collected from participants' experiences with the application. Through this analysis, we aim to identify the application's strengths, areas for improvement, and valuable comments from the users that will assist us in enhancing and optimizing it for future usage.

5. EVALUATION RESULTS

This chapter presents the results of our comprehensive evaluation process. Throughout the evaluation stage, we collected a combination of qualitative and quantitative data from a diverse group of test users, categorized into three distinct groups: individuals with dyslexia, color blindness, and neither of these conditions. Within each group, we worked with three individuals from various backgrounds, ages, and genders. To uphold anonymity, we have assigned titles to our test subjects as following: D1, D2, and D3 for Dyslexia; CB1, CB2, and CB3 for color blindness; and N1, N2, and N3 for neither of these conditions.

For our analysis, we collected two data models, as outlined in the previous chapter. The first model includes the elapsed time for each scenario by each participant. As a reminder, we

defined four test scenarios, denoted as S1, S2, S3, and S4. These scenarios were introduced in detail in the previous chapter and are summarized as follows:

S1: Create a New Account and Review Cards

S2: Existing User Dashboard Orientation

S3: Existing User Preference Settings

S4: Existing User Money Transfer

For the sake of simplicity, we will refer to these scenarios as S1, S2, S3, and S4 in the following analysis. The table below presents the information on scenario data regarding how many seconds it took to complete each scenario by the test users:

Table 3. Scenarios Data

User/Scenario	S1	S2	S3	S4	Total (In minutes)
D1	74	104	60	30	4.46
D2	63	80	27	33	3.38
D3	37	118	48	26	3.81
CB1	38	49	23	42	2.53
CB2	37	80	25	20	2.7
CB3	52	53	19	30	2.56
N1	34	40	30	32	2.26
N2	32	42	29	25	2.13
N3	40	39	20	25	2.06

Note: Completion times are provided in seconds. Total time is calculated in minutes.

By examining the raw data from *Table 3*, we can already identify the differences among the groups. However, as the chapter progresses, we will conduct a more thorough analysis of the data to gain deeper insights into the behaviors of the different groups.

The second set of data we collected refers to the post-testing interview, consisting of ten questions about the evaluation process. This dataset is more comprehensive and helps use

understand whether the application achieved its goal of accessibility or not, as well as insights into the expectations of different user groups regarding mobile applications based on their needs and preferences. The interview responses are presented in the table below, where columns beginning with ‘Q’ followed by a number represent the user's answers to the respective question. These questions were previously given in *Table 2* in the previous chapter.

Table 4. Post-testing Interview Data

User	Q1	Q2	Q3	Q4	Q5	Q6	Q7	Q8	Q9	Q10
D1	15 years	5	5	5	5	4	4	5	5	Often mobile applications are too complicated to use, this one was simple. Liked, text-to-speech function and font selection. Suggestion, card scan option in money transfer, language option with Azerbaijani.
D2	8 years	4	5	4	5	4	5	5	5	Application is simple to use. Liked, text to speech function and font selection. Suggestion, card scan option in money transfer, language option with Azerbaijani and more functionality.
D3	15 years	4	5	3	3	5	4	4	5	Liked the simplicity, but there could have been more functionalities. Suggestions, template creation to reduce repetition, texts in “help” are too long, also it would be better to add button/links which redirects to the

CB1	12 years	5	5	5	5	5	5	5	5	described action and language option with Azerbaijani, and change background option. Application is simple to use. Liked, text to speech function and font selection. Suggestion, card scan option in money transfer, language option with Azerbaijani and more functionality.
CB2	9 years	4	5	4	5	5	4	4	5	Liked simplicity and color choices. Suggestions, more functionalities, feedback messages could be more informative, copy card details, Azerbaijani language option and more background color options.
CB3	12 years	4	5	4	5	4	3	4	2	Liked simplicity. Suggestions, to choose card in “transfer”, more background color options, more functionality, and Azerbaijani language option.
N1	12 years	4	5	5	5	5	2	3	5	Liked simplicity. Suggestions, to choose card in “transfer”, more options in “edit profile” such as profile picture, more functionality, and

N2	10 years	5	5	4	5	5	4	4	5	Azerbaijani language option. Liked simplicity and text-to-speech. Suggestions, add more spacing between sections, copy card information, more informative feedback messages, and Azerbaijani language option.
N3	8 years	5	5	5	4	5	4	5	4	Liked simplicity and text-to-speech. Suggestions, more functionality, copy card information, add speech-to-text, and Azerbaijani language option.

In *Table 3*, we see that people with dyslexia took longer to finish all four tasks compared to others. They also had more fluctuation in their completion times. On the other hand, people without color blindness or dyslexia finished the tasks quickly, almost like those with color blindness. This suggests that using the right colors, as found in interviews, helped these people finish tasks just as well as those without disabilities. Even though people with dyslexia said they had no trouble understanding commands or reading, they still took longer to finish tasks, showing that dyslexia can slow down reading.

The figure below illustrates the findings mentioned above:

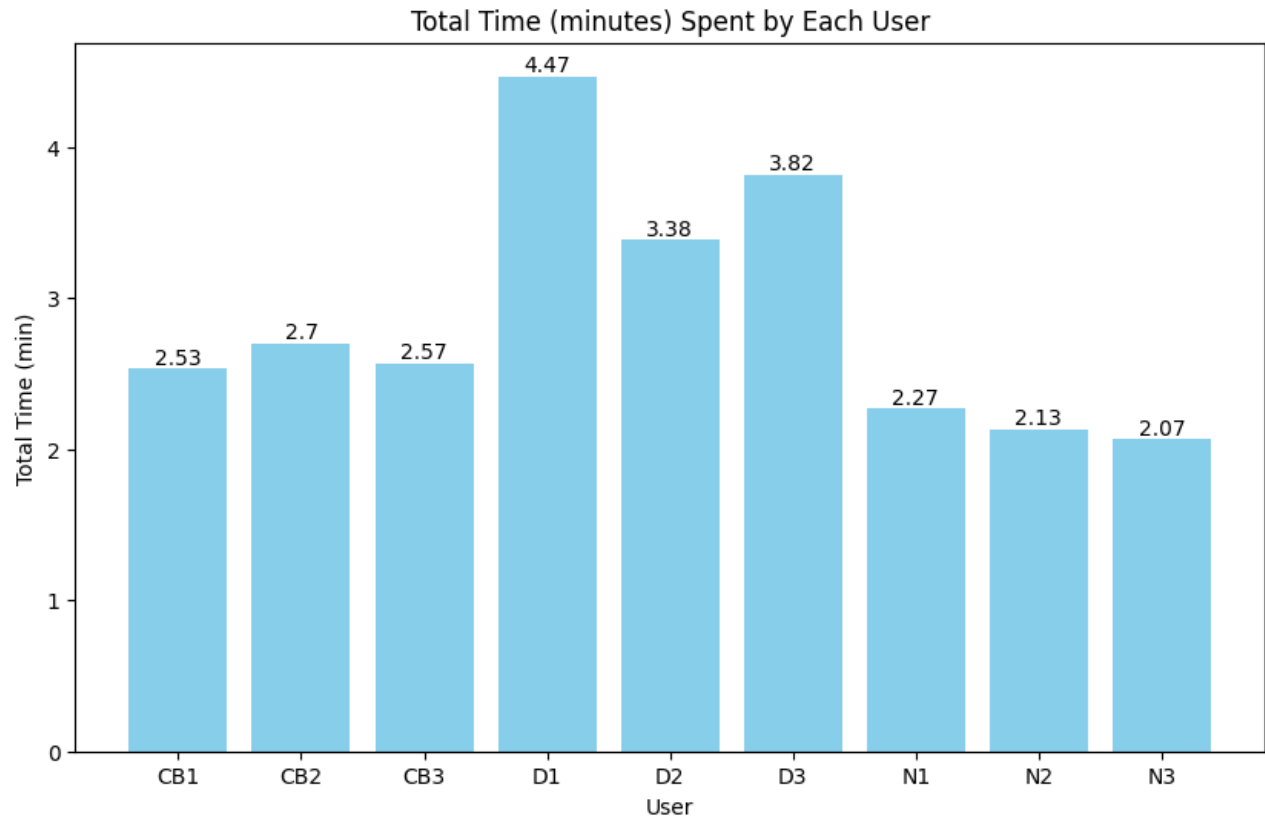


Figure 9. Total Time Spent by Each User

To gain a better understanding of the time spent on each scenario by each user, we created a scatter plot with all three components: user, scenario, and time (in seconds). The plot is displayed in the figure below:

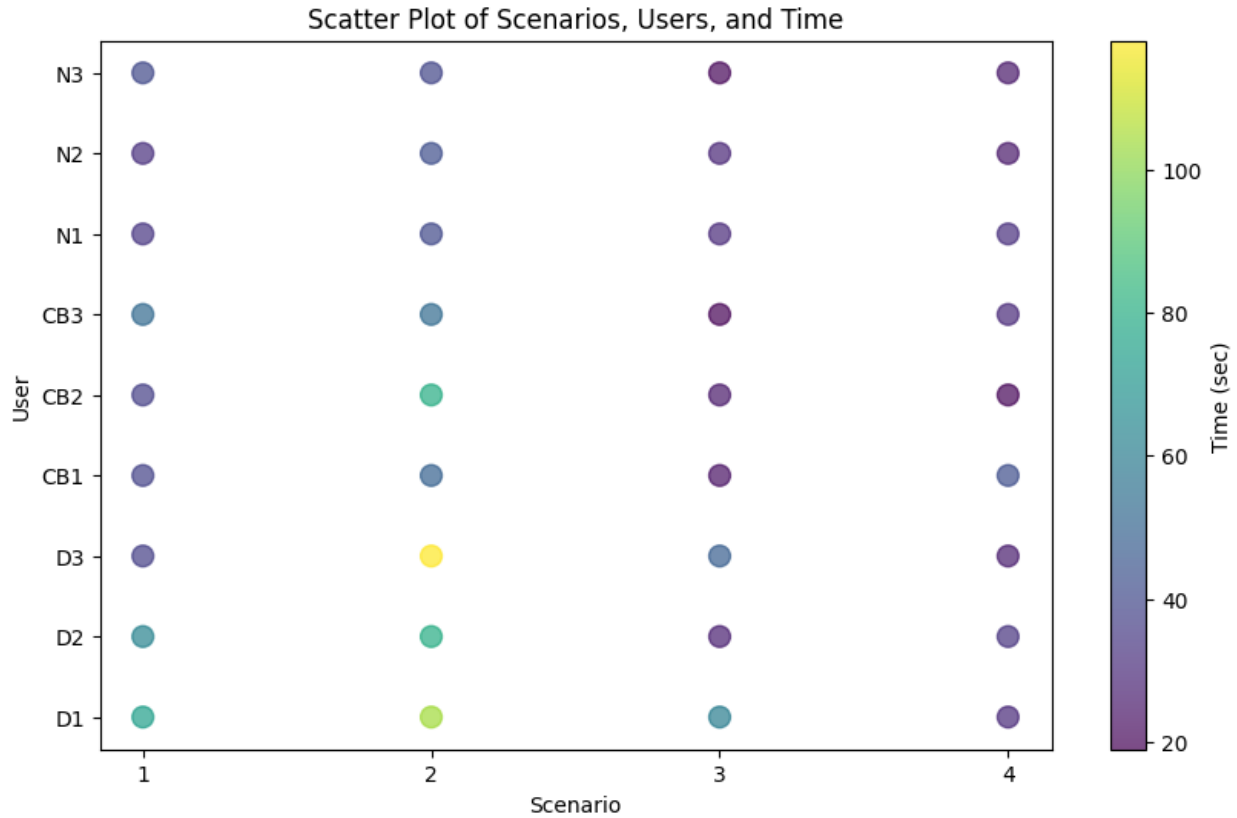


Figure 10. Scatter Plot of Scenarios, Users, and Time

Figure 10 highlights several important points in the data. Firstly, we learn that the quickest scenario was the fourth one, which involved money transfer from existing users, closely followed by the third scenario, which involved editing existing user information. In contrast, the second scenario, which involved a walkthrough of the dashboard, took the longest to complete.

As indicated by the color map, dyslexic users, in particular, took significantly longer to review the dashboard. One of the main reasons behind this result was their interest in the “help” screen and text-to-speech feature more than the other two groups. Consequently, they took more time to thoroughly test these features. This also provides insights into the behavior and interests of the groups.

The figure also reveals another noticeable pattern: users without dyslexia or color blindness completed all scenarios in under a minute, as deduced from the color map. In contrast, the other two groups of users displayed a wider range of completion times for different scenarios. However,

within each group, the values are consistently close, with no outlier values. This indicates that individuals within each group displayed similar behaviors.

Lastly, to emphasize the total completion time across scenarios for each user group rather than individual test subjects, we have created a heatmap plot. The plot is presented below:

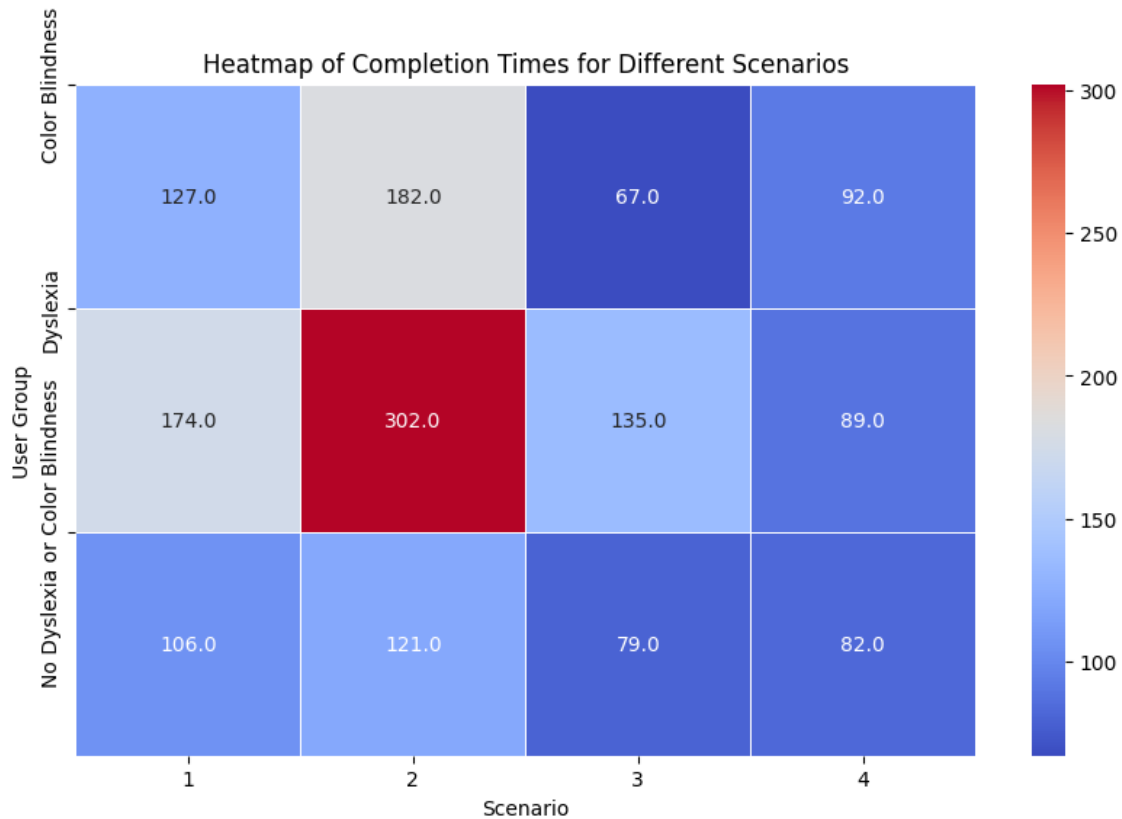


Figure 11. Heatmap of Total Completion Times for Different Scenarios

Figure 11 complements the findings from Figure 10. As deduced from the heatmap, the quickest completion time was achieved by the Color Blindness group, taking only 67 seconds in total for the third scenario. In contrast, individuals with dyslexia took the longest time to complete the second scenario, as previously mentioned.

Another important observation is that, while dyslexic individuals ranked last in completion times for the first three scenarios, users with color blindness displayed the slowest performance in

the fourth scenario. However, it's important to note that, unlike the other scenarios, completion times for the fourth scenario were very close among all three groups.

Post-testing interview results help us understand which features received the best and worst ratings among user groups. Ideally, we would like all features to receive full points from all users. However, as shown in *Table 4*, different rating values exist for different features. Therefore, we are particularly interested in learning whether specific questions, such as Q5, which assesses the color contrast between text and background, received high ratings among color-blind participants. A low rating would suggest that the application did not achieve its goal of accessibility. Additionally, for this analysis, we have renamed the features from Q# to more descriptive texts, as shown in the figure below.

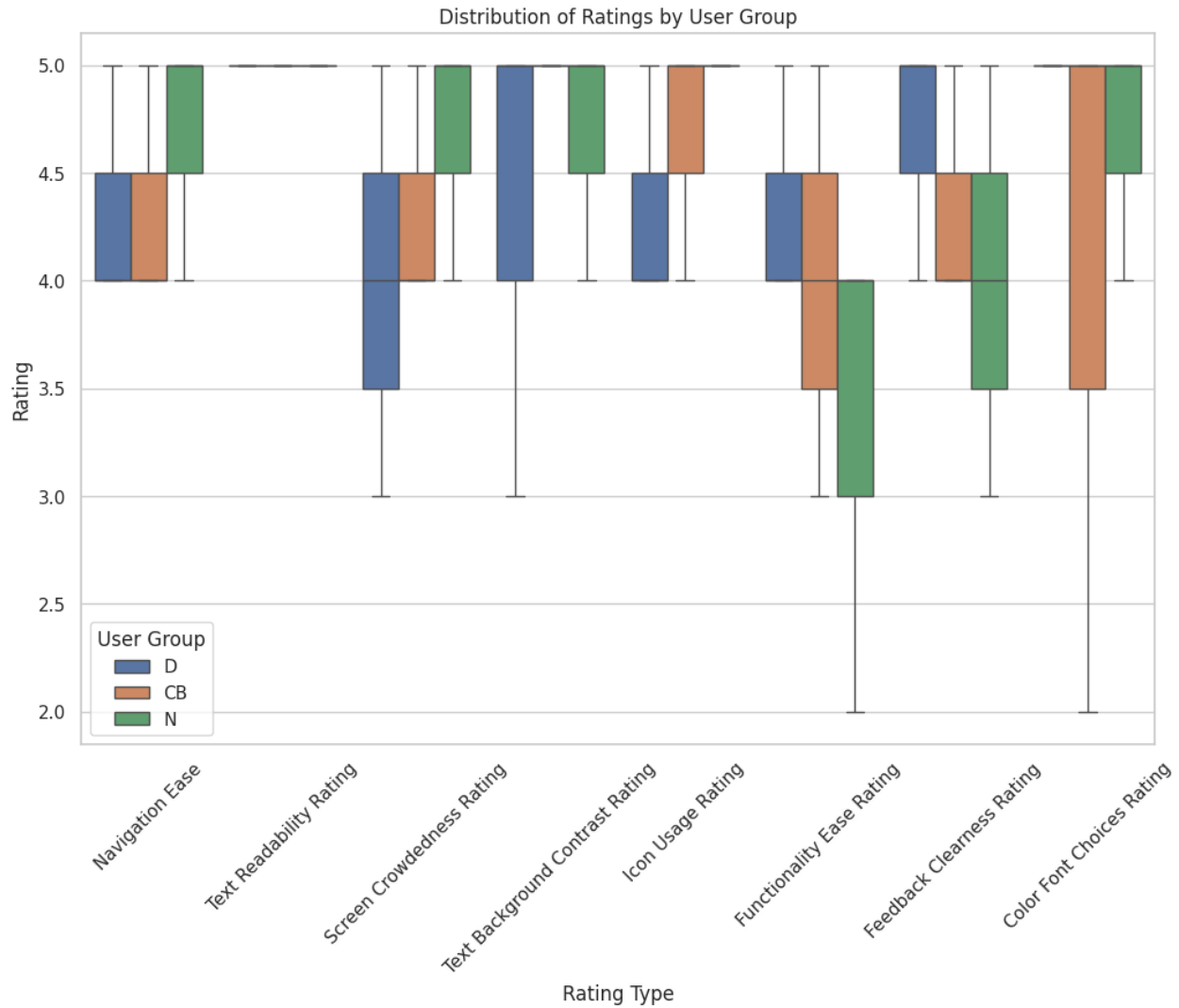


Figure 12. Ratings Distribution by User Groups

The figure above consists of bar plots, which are good at explaining data with a range. From these plots, we can deduce minimum, maximum, and average values, as well as identify any outliers. Upon examination of the figure, we observe that only text readability achieved a rating of 5 from all test users. Moreover, the lowest rating, with a value of 2, belongs to functionality ease and color font choices. Notably, the latter rating was given by one color-blind user, which is concerning, as it indicates dissatisfaction with the color choices provided and suggests a preference for alternative options.

We also notice that, on average, most of the ratings were above 4, with only a few responders rating some features 3 or 2. Additionally, participants from all groups agree that functionality ease deserves a low rating, averaging 3.8, primarily because they believe the application lacks sufficient functions, and the “transfer” function could have been better implemented.

To create the mentioned table, we cleaned the data from the raw format provided in *Table 4* and divided it into two groups: “Likes” and “Suggestions” made solely by the three user groups and their intersections. This approach allows us to extract meaningful insights from the user comments.

Table 5. Post-testing Interview Comments Grouped by Users

User Group	Likes	Suggestions
D	The font selection	Add a card scan option in the money transfer. Implement template creation to reduce repetition. Shorten texts in the “help” screen. Add buttons/links that redirect to described actions. Consider adding more functionalities.
CB	The color choices	Provide more informative feedback messages. Add the ability to copy card details. Offer more background color options.
N		Increase spacing between sections. Add speech-to-text functionality and the option to choose a card in "transfer", and more options in "edit profile" such as profile picture.
Intersection	The simplicity of the application and the text-to-speech function	Add a language option with Azerbaijani.

We learn from the comments table that all user groups liked the application's simplicity and the text-to-speech function. Furthermore, dyslexic users appreciated the font selection, while the color-blind group favored the color choices. Conversely, the third group did not focus on font or color choices, as they did not have any reading or visual impairments. Thus, they did not mention any additional features they liked apart from those in the intersection part.

In terms of suggestions, all groups mentioned adding a language option with Azerbaijani. Some users, especially those with dyslexia, mentioned difficulties in learning additional languages. Nonetheless, even those who know English suggested that adding an Azerbaijani language option would be beneficial. Regarding additional suggestions made solely by the corresponding groups, they were mostly influenced by their respective conditions. For instance, users with dyslexia proposed implementing a card scan option in the "transfer" function, as manually inputting a 16-digit card number is time-consuming for them. They also recommended shortening the text in the "help" screen and adding links/buttons for easier navigation. Similarly, members of the color-blind group suggested adding more color background options, along with the ability to copy the card number and provide more informative feedback messages. Lastly, the suggestions from the third group did not directly address color or font-related issues, as those were not their primary concerns. Instead, they proposed more specific enhancements such as increasing spacing between sections, adding a card choice feature in the "transfer" function, enabling profile picture selection, and including speech-to-text options.

To summarize, in this chapter, we analyzed the data collected from three different user groups during and post-evaluation. The figures generated from this data helped us gain valuable insights into the preferences and needs of people with dyslexia and color blindness. The next chapter concludes the entire process and discusses future improvements based on our observations and the comments from the test participants.

6. CONCLUSION AND FUTURE WORK

Technology should be accessible to every individual regardless of their conditions. The primary motivation behind this work was to identify the main challenges faced by individuals with dyslexia

and color blindness and to develop evaluation metrics based on the UEQ principles to assist them. Those metrics can be applied to the development of any application, ensuring accessibility for all.

We began our research by examining both conditions: their medical definitions, statistics, and treatments, as well as predefined design patterns that should be implemented to ensure the accessibility of the application for these individuals. We learned that dyslexia is a reading and understanding disorder, affecting 15-20% of the world's population, displaying symptoms. Color blindness, on the other hand, is rarer than dyslexia, mostly found in men, and is harder to recognize because its symptoms are easily dismissed. Both conditions are currently incurable medically, which is why certain rules and regulations should be followed to make technology accessible for individuals with these conditions.

Subsequently, we provided a brief introduction to the UEQ and explained how we would apply its principles in our work. The UEQ is a widely used method for measuring users' subjective impressions of the UX of products. Its purpose is to enable users to express their feelings and impressions about a product under investigation in an effective way. Each UEQ item consists of opposite-meaning adjectives and a range of 7-point Likert scales in between. In our study, we applied the UEQ principles in post-testing interview questions, where a total of 9 users from 3 different groups (individuals with dyslexia, individuals with color blindness, and individuals with neither of these conditions) expressed their feelings about the entire evaluation process and the interface design.

The mobile application we used for the evaluation was introduced in the third chapter. It is a mobile banking application titled “HNK Bank”, designed with people with dyslexia and color blindness in mind in terms of font and color choices. The application is simple, with few functionalities such as “transfer”, “text-to-speech”, “edit profile”, and a “help” screen providing tips and tricks for users who struggle with certain actions within the application.

We defined four scenarios to test with the users. Firstly, users were required to create a new account and review the cards associated with the account. Then, they were instructed to log in to the application using their phone number and password and navigate through the application without performing any specific functions, primarily to evaluate font and color choices as well as the usability of the “help” screen. Next, users were asked to edit existing user settings by changing

their name, phone number, or password. Lastly, users were prompted to perform a money transfer by entering a 16-digit card number and the desired amount. These scenarios were carefully defined to reflect real-life situations. Throughout the testing process, no intervention was made, and the time taken for each scenario was measured and documented for later analysis.

After evaluation with each user, a brief interview consisting of 10 questions was conducted with them. The interview contained 8 Likert-scaled questions with a range of 5, following the UEQ style. The interview questions were selected to cover a wide range of possible accessibility features, such as text readability, color contrast, font choices, and more. The final question was intentionally left open-ended to allow users to express their feelings about the process and provide suggestions for improving the application for future use.

In Chapter 4, we presented the statistics and figures derived from the testing scenario data and post-interview data. To summarize the results, we found that, in general, users with dyslexia took longer to complete the scenarios compared to color-blind individuals, while the third group, comprising individuals without either of these conditions, took the least amount of time, as expected. However, the results for color blindness were very close to theirs. The figures also revealed that the second scenario, which involved a walkthrough of the dashboard, took the longest to complete, whereas the quickest scenario was the fourth one, involving money transfer from existing users, closely followed by the third scenario, which involved editing existing user information. Even looking at the individual scenario times, we observed that dyslexic individuals ranked last in completion times for the first three scenarios, except for the fourth scenario, where users with color blindness displayed the slowest performance. However, the results of the fourth scenario were very close in each group.

The post-interview data provided valuable insights into the expectations of different user groups regarding a mobile application. Overall, the application received positive ratings in all categories. All nine users rated text readability with a score of 5, indicating good accessibility. On average, most ratings were above 4, with occasional scores of 3 or 2 for some features. The lowest rating, averaging 3.8, was for functionality ease. Users noted that the application lacked functions, particularly suggesting improvements to the “transfer” function in response to the tenth question.

Finally, we analyzed the user comments by cleaning and categorizing the data different sections. Based on the comments, we observed an overall agreement among users that the application is simple and easy to use. Additionally, they appreciated the helpfulness of the text-to-speech function. Furthermore, all users suggested that the application should include a language option for Azerbaijani. This recommendation was particularly emphasized by dyslexic users, who mentioned the challenge of learning a second language. When we observed the distinct comments made by the groups, we noticed an obvious pattern in their needs and behaviors. The dyslexic participants primarily focused on font and readability, and their suggestions mostly focused on making the application more accessible for them. Similarly, color-blind users liked and suggested color-related features. The third group, on the other hand, which comprised users without any of these conditions, was able to focus on other aspects of the application that were not the primary focus of the first two groups.

In conclusion, the analysis results suggest that overall, users did not encounter major difficulties in reading and understanding the application. This indicates that selecting appropriate font and color options can enable the design of an accessible application for individuals with dyslexia and color blindness. Moreover, their insightful suggestions would greatly contribute to further improvements.

For future development, it's essential to implement the Azerbaijani language, as collectively suggested by all participants. Additionally, while the current simplicity of the application was well-received by the users, there is a need for expansion in functionality for the future. While the application received high ratings from all user groups, it's likely that as complexity increases, accessibility may diminish. Therefore, future iterations should focus on expanding functionality while maintaining accessibility.

Furthermore, the application might be further improved to support individuals with other conditions, such as visual or hearing impairments. Given the positive reception of the text-to-speech feature, further improvement in this area could greatly benefit users with visual impairments. Additionally, implementing a speech-to-text feature would support users with visual and hearing impairments. These enhancements align with the aim of accessibility for all users.

References

- (2023, 08 07). Retrieved from National Eye Institute: <https://www.nei.nih.gov/learn-about-eye-health/eye-conditions-and-diseases/color-blindness/types-color-vision-deficiency>
- About Colour Blindness*. (n.d.). Retrieved from <https://www.colourblindawareness.org/colour-blindness/>
- Aliyeva, M. (2024). *Applying the Principles of the User Experience Questionnaire (UEQ) to the Design and Evaluation of Mobile Banking Applications that Support Persons with Disabilities*.
- British Dyslexia Association*. (n.d.). Retrieved from <https://www.bdadyslexia.org.uk/dyslexia/about-dyslexia/what-is-dyslexia>
- Colour Blind Awareness*. (n.d.). Retrieved from <https://www.colourblindawareness.org/colour-blindness/treatment/>
- Darejeh, A., & Singh, D. (2013). A review on user interface design principles to increase software usability for users with less computer literacy. *Journal of computer science*, 9, 1443.
- Francese, R., Monaco, C., & Nicoletti, C. (2018). An Android application for helping in the identification of Children with Reading Difficulties. *Proceedings of the 4th EAI International Conference on Smart Objects and Technologies for Social Good* (pp. 226–231). New York, NY, USA: Association for Computing Machinery. doi:10.1145/3284869.3284915
- Hasanguliyeva, F. (2024). *Using UEQ Principles and Heuristics Development of a Mobile Banking Application for Persons with Dyslexia and Color Blindness*.
- International Dyslexia Association*. (2020). Retrieved from <https://dyslexiaida.org/dyslexia-basics/>
- Iqbal, M. W., Shahzad, S. K., Ahmad, N., Amelio, A., & Brodic, D. (2018). Adaptive interface for color-blind people in mobile-phones. *2018 International Conference on Advancements in Computational Sciences (ICACS)*, (pp. 1-8). doi:10.1109/ICACS.2018.8333488
- Kariyawasam, R., Nadeeshani, M., Hamid, T., Subasinghe, I., Samarasinghe, P., & Ratnayake, P. (2019). Pubudu: Deep Learning Based Screening And Intervention of Dyslexia, Dysgraphia And Dyscalculia. *2019 14th Conference on Industrial and Information Systems (ICIIS)*, (pp. 476-481). doi:10.1109/ICIIS47346.2019.9063301
- Krasnova, A., Romanova, A., & Susanov, A. (2023). Mobile application for people suffering from color blindness. *E-business technologies conference proceedings*, 3, pp. 140–146.
- Martin, C. E., Keller, J. O., Rogers, S. K., & Kabrinsky, M. (2000). Color blindness and a color human visual system model. *IEEE Transactions on Systems, Man, and Cybernetics - Part A: Systems and Humans*, 30, 494-500. doi:10.1109/3468.852442

- Martins, V. F., Lima, T., Sampaio, P. N., & de Paiva, M. (2016). Mobile application to support dyslexia diagnostic and reading practice. *2016 IEEE/ACS 13th International Conference of Computer Systems and Applications (AICCSA)*, (pp. 1-6).
doi:10.1109/AICCSA.2016.7945710
- McDonough, M. (2023, December). *Harvard Medicine*. Retrieved from <https://magazine.hms.harvard.edu/articles/dyslexia-and-developing-brain>
- Mediline Plus*. (n.d.). Retrieved from <https://medlineplus.gov/ency/article/001002.htm>.
- Schrepp, M. (2015). *User Experience Questionnaire Handbook*.
- Schrepp, M., Hinderks, A., & Thomaschewski, J. (2017). Design and evaluation of a short version of the user experience questionnaire (UEQ-S). *International Journal of Interactive Multimedia and Artificial Intelligence*, 4 (6), 103-108.
- Tenemaza, M., Navarrete, R., Jaramillo, E., & Rodriguez, A. (2019). Specific dyslexia exploratory test (TEDE): Two tasks using augmented reality. *Advances in Usability, User Experience and Assistive Technology: Proceedings of the AHFE 2018 International Conferences on Usability & User Experience and Human Factors and Assistive Technology, Held on July 21–25, 2018, in Loews Sapphire Falls Resort at Universal Studios, Orlando, Florida, USA 9*, (pp. 925–933).
- Zhou, L., Bansal, V., & Zhang, D. (2014). Color adaptation for improving mobile web accessibility. *2014 IEEE/ACIS 13th International Conference on Computer and Information Science (ICIS)*, (pp. 291–296).