

Analyzing the results of a usability study on CrosScan within the framework of the Android Design Principles and Material Design

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ABSTRACT

CrosScan: The Crossword Scanning App is a new Android application that allows users to scan crossword puzzles with the camera and complete scanned puzzles digitally. There are two aspects of the app: (1) scanning puzzles from newspapers, magazines, and other physical media, and (2) solving the scanned puzzles interactively in the application. In this paper, we discuss the current CrosScan prototype and the corresponding usability study. Findings of this usability study reveal that users are happy with the design and would use the final application, but they also believe there is room for improvement in app navigation and aesthetics. We then analyze these results within the framework of Android Design Principles and Material Design, using our findings to propose an iterative redesign of the application.

ACM Classification Keywords

H.5.2. Information Interfaces and Presentation (e.g. HCI): User Interfaces

Author Keywords

CrosScan; Android app design; material design; usability testing.

INTRODUCTION

It is increasingly common for people to use mobile technology to accomplish tasks that had traditionally been done using pen and paper. For example, people use mobile technology to take and organize notes [19]. Whereas conventional note-taking requires pens and pencils, which are often inconvenient to locate, mobile technology makes note-taking convenient and accessible, requiring only a readily available finger. In addition, people often use mobile technology to keep track of their contacts and calendar appointments [8]. Conventionally,

people would have to carry around an address book and a writing utensil to organize contact and event information. With mobile technology, there is no need for a writing utensil, and the device organizes such information for the user, with the added benefit of search functionality and alarm reminders.

In many similar cases, mobile applications are reinventing physical technologies on the digital platform. However, users often do not have an easy way to convert physical information into digital information for interaction on mobile devices. The e-book market, for example, makes it convenient for users to access millions of titles on their mobile devices [21]. However, if the users already own a library of physical books, then there is no way to convert the physical library into a digital library without spending a great deal of time and money. Similarly, there is no solution for automatically converting all the contacts and calendar appointments in an address book into a digital format for use on mobile devices. Hence, users must spend time manually entering a large amount of information into their devices.

Quick Response (QR) codes are one example of a solution that allows users to convert physical information into a digital format. QR codes are notable for their ability to store information efficiently, as well as their accessibility to mobile device users [13]. With QR codes affixed to many physical objects (e.g., for advertising), anyone with a mobile device can quickly scan the code with the camera to obtain digital information, saving time normally spent manually entering the information.

The QR code solution provides inspiration for addressing a problem faced by people who enjoy solving crossword puzzles. If crossword enthusiasts have a physical crossword puzzle they want to solve (e.g. from a newspaper or magazine), there is no way to bring the puzzle into digital format automatically for completion on mobile devices. Thus, they must carry around the puzzle and a pen even though there are Android apps that allow users to complete puzzles digitally. CrosScan: The Crossword Scanning App solves this problem by allowing crossword puzzle solvers to scan puzzles from physical media and complete them on their mobile devices.

CrosScan is a new Android application that allows users to scan crossword puzzles with the camera and complete scanned puzzles digitally. There are two aspects of this project: scan-

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ning puzzles from newspapers, magazines, and other physical media, and solving the scanned puzzles interactively in the application. Thus, once users take a picture of a crossword puzzle, CrosScan reproduces the grid and allows users to enter answers to the clues.

This paper briefly discusses the development of CrosScan, including implementation of image recognition techniques to scan the crossword puzzle grid. However, the main focus of this paper is on the current prototype of CrosScan and the accompanying usability study in which we ask whether users like the design of the app and are able to use it with ease.

RELATED WORK

Crosswords [3] is a crossword puzzle application that allows users to download crossword puzzles into the app from various sources and complete them digitally. This application partially solves the aforementioned problem by bringing puzzles that users can complete physically onto the digital platform. However, the method is indirect, since users can only access the puzzles once publishers release them to the Crosswords app. This means that users can only access a limited database of digitized crossword puzzles, rendering them unable to complete puzzles digitally from a large number of other sources. On the other hand, the Crosswords app provides a successful interactive puzzle-solving experience to users, presenting the crossword grid and clues in an intuitive fashion. CrosScan uses the Crosswords app as an inspiration for the design of its puzzle-solving aspect.

Sudoku Grab [11] is a Sudoku puzzle scanning application created by Dr. Chris Greening. It is similar in design to CrosScan in that it is capable of scanning Sudoku puzzles from physical media so that users can complete them digitally. It differs in that the scanner must recognize a 9×9 grid of numbers, whereas CrosScan must recognize a grid of black and white squares of variable size, as well as a list of clues. However, many of the image recognition methods implemented in the Sudoku Grab app provide inspiration for the image recognition techniques chosen for use in CrosScan.

DEVELOPMENT OF CROSCAN

The first wave of CrosScan development occurred in two stages: implement and test the puzzle scanning image processing algorithm and implement the interactive puzzle completion functionality. The OpenCV4Android library [16] was used to implement the puzzle scanning component of CrosScan. An approach similar to that of Sudoku Grab [11] was used in order to detect the crossword grid. First, CrosScan uses adaptive thresholding [20] to discover edges in the image. Second, CrosScan uses blob extraction [12] to find the largest region of connected edges, which is assumed to be the crossword puzzle grid. Third, CrosScan performs the Hough line transform [5] on edges in this region in order to find lines in the image, corresponding to lines of the crossword grid. Fourth, CrosScan attempts to find the largest set of equally spaced horizontal and vertical lines in order to figure out how many rows and columns of squares there are in the grid. Finally, CrosScan performs adaptive thresholding [20] again in order to figure out which squares are black and which squares are

white. With this grid of black and white squares, CrosScan uses standard left-to-right, top-to-bottom rules to fill in the clue numbers in the grid automatically.

The open-source Sudoku puzzle app, OpenSudoku [15], served as a starting point for the puzzle completion stage of CrosScan development. OpenSudoku contained an interactive puzzle grid that users could fill in using the device keyboard and puzzle lists that organized puzzles on the device. In order to adapt the existing implementation for crossword puzzles, the interactive grid was modified so that it could have arbitrary dimensions, black or white squares, and clue numbers and letters in the squares. In addition, a SQLite implementation for storing Sudoku puzzles was tweaked so that it stored crossword puzzle information in serialized format. Afterwards, an area for viewing clues, an alphabetical keyboard, and a method for entering solutions were added to CrosScan so that users could complete puzzles.

CURRENT PROTOTYPE

This section presents the current version of CrosScan as background for understanding the usability testing protocol and analysis of results. Since the app has two main functions, the start screen consists of two buttons, allowing users to navigate easily between the two (see Figure 1a). When the user selects the “Scan Puzzles” option, it navigates to a camera screen with a button for taking pictures (see Figure 1b).

When the user takes a photo, CrosScan uses image processing to detect the crossword grid (the app does not yet import clues, but usability testing does not rely on that feature). Once processing is complete, it will direct the user to the puzzle naming screen, where the user can view the scanned puzzle grid and name the puzzle (see Figure 1c). The resulting puzzle grid might not be perfect, so the user may interact with the grid to correct issues. If any grid square is the wrong color, the user can tap that square to toggle its color between black and white. If the grid is the incorrect size, the app prompts the user to use the back button to return to the scanning screen.

Once the user corrects any scan errors and names the puzzle, the app opens the puzzle list screen, where the puzzle has been added to the list of scanned puzzles (see Figure 1d). Tapping a puzzle in the list redirects the user to the puzzle solving screen where they can begin solving that puzzle. By long-pressing the puzzle, the user opens a menu with “Play Puzzle,” “Puzzle Info,” and “Delete Puzzle” options. The first and third options are self-explanatory. The second option opens a screen that contains puzzle information, such as title, date of puzzle creation, and percentage complete (see Figure 1e).

The puzzle solving screen uses the Crosswords app as a model, containing a timer, puzzle grid, clue bar, and keyboard (see Figure 1f). The screen highlights the cell selected by the user in yellow, and its corresponding Across or Down entry in blue. It also allows the user to navigate between clues by tapping squares in the grid and toggle between Across and Down by tapping the selected cell again or tapping the clue bar. The app automatically skips over squares already occupied by letters and moves to the next clue once the user completes the current one. The arrows in the clue bar also allow the user to navigate

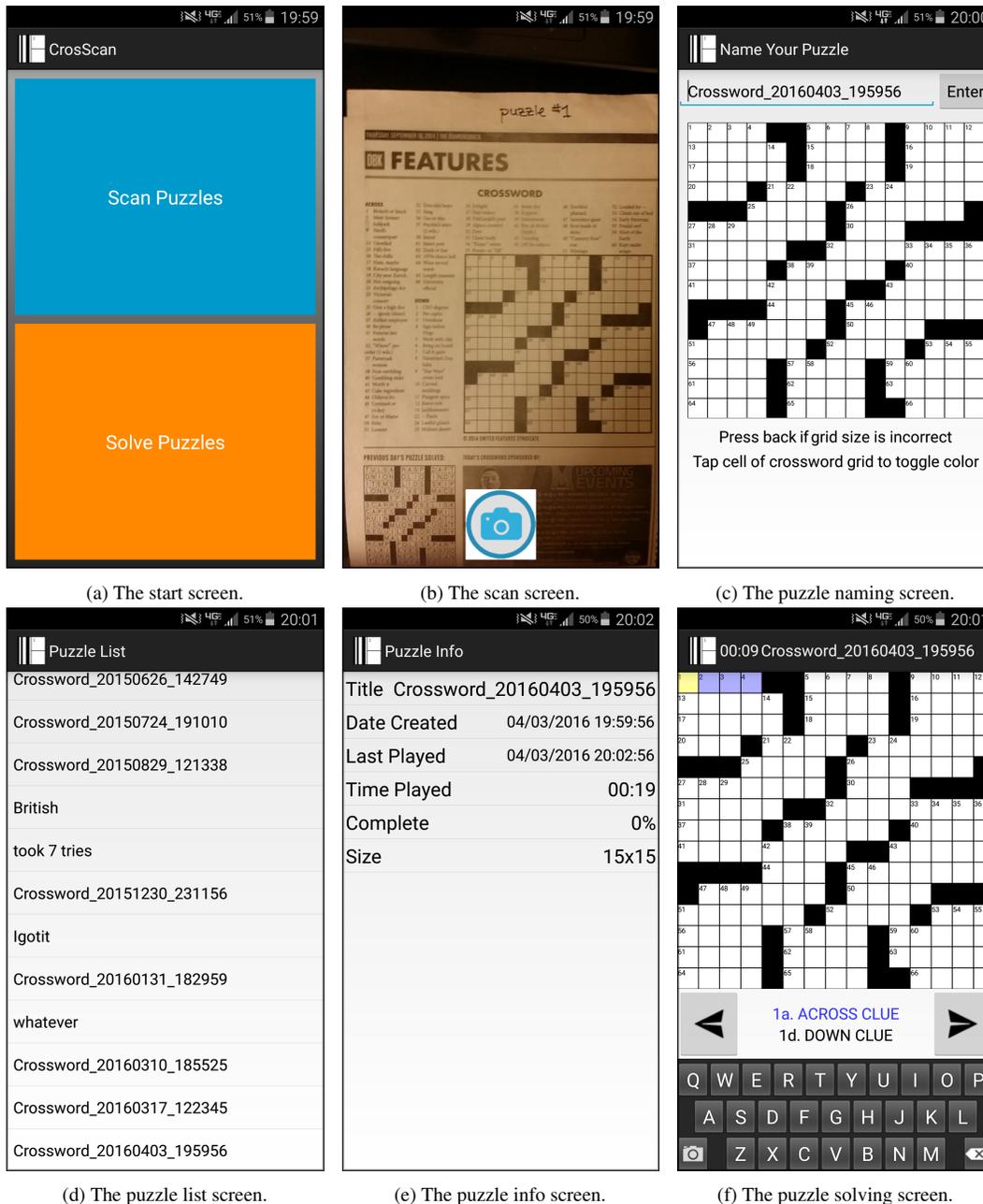


Figure 1: CrosScan screens.

between clues in the puzzle. Users may reference the original photo of the crossword puzzle by selecting the camera icon in the keyboard. Doing so opens an image screen that allows users to zoom and pan the image. Finally, users may delete the puzzle or restart the puzzle from the puzzle solving screen menu. Restarting the puzzle clears the squares, returns the cursor to the first clue, and restarts the timer.

USABILITY TEST PROTOCOL

By asking participants to complete several targeted tasks with the application, usability testing helped reveal how an audience of smart phone users and crossword enthusiasts felt about the

CrosScan experience. Participants were given a Samsung Galaxy Note 3 Android phone to complete the tasks. The study sessions took place in private, quiet areas. Participant actions, remarks, and survey responses were observed and stored on a password-protected computer. We did not record participants via audio or video and the overall procedure took no more than 30 minutes.

In this study, we used two modified versions of CrosScan in order to control the behavior of the application. In the first version of the app, when the user would take a photo of a given puzzle, the phone would always generate the correct crossword

puzzle, pre-programmed into the phone. Thus, the app would generate the puzzle in a controlled manner to simulate intended app use. In the second version of the app, when the user would take a photo of another given puzzle, the phone would generate the incorrect crossword puzzle (a few white squares would incorrectly appear as black squares), pre-programmed into the phone. This version of the app would generate the errors in a controlled manner for consistent observation of steps taken to correct the puzzle grid. After the user finished, we would inform them that the app used pre-programmed puzzles instead of processing the images in real-time during the experiment, but the app behavior would be similar in a final released version.

We first gave participants a summary of the app and asked the following pre-screening questions.

- How often do you do crossword puzzles (multiple times a day, daily, weekly, every other week, monthly, less than once per month)?
- What are your favorite methods for doing crossword puzzles (e.g., newspaper, computer)?
- Do you own an Android smart phone or tablet? If so, how long have you owned an Android device? If not, do you use other smart phones or tablets?

Then, we provided the Samsung Galaxy Note 3 Android device with the modified versions of the CrosScan app and two paper crossword puzzles (labeled #1 and #2) to participants and asked them to complete the following tasks.

- Task 1: Use the app to scan in puzzle #1. Fix the puzzle if it was processed incorrectly. Name the puzzle “puzzle 1” and press Enter.
- Task 2: Navigate to puzzle 1 and begin completing it. The answer to 46 Down is ‘TUT’. Please fill in the answer.
- Task 3: Please use the Restart Puzzle function to clear the puzzle. Delete the puzzle so that it no longer appears in the list of scanned puzzles.
- Task 4: Use the app to scan in puzzle #2. Fix the puzzle if it was processed incorrectly. Name the puzzle “puzzle 2” and press Enter.

Finally, we asked participants to complete a survey in order to gauge their thoughts about CrosScan. The survey contained the following questions.

- Please read through the words below and select as many as you think apply to the CrosScan app. (Participants were given a list of 56 descriptive words [2] with checkboxes next to them.)
- Is this an app you would use? If so, how often would you use it? If not, why not?
- What features are missing from the app? What features would you like to see?
- On a scale from 1 to 7, please rate your crossword puzzle experience with the app (circle one). (Participants were

given a number spectrum where 1 corresponded to “Bad experience,” 4 to “Neutral experience,” and 7 to “Great experience.”)

ANDROID APP DESIGN

We now introduce Google’s Android Design Principles [9] and Material Design [10] in order to provide context in which we have decided to analyze the results of usability testing.

Android Design Principles

Google introduced the Android Design Principles at Google I/O 2013 [18], and they have been well-received by users and developers since. The Android Design Principles are based on extensive research, including the findings of Google’s unpublished Android baseline study, wherein researchers studied the effect technology had on people’s lives through diaries and in-home interviews and observations. Researchers found that people experience joy in using technology as a welcome break or as a means of bringing them closer to their friends [18]. They also found that people experience self-blame when something goes wrong, showing that non-ideal implementations can erode confidence and cause frustration. With these findings, Google focused on human relationships and emotions in creating the Android Design Principles.

Several of the design principles aim to evoke positive emotions, while several of them aim to prevent negative emotions. This notion is based on the finding that it takes at least three positive experiences to undo a negative experience, as revealed in prior psychological studies [14, 4, 6]. Thus, a well-designed app creates several positive experiences and avoids negative experiences completely. There are three pillars of the Android design vision: “Enchant me,” “Simplify my life,” and “Make me amazing.” Since the design vision is about people and their emotions, these three pillars are written from the perspective of users as expectations for the Android experience. There are seventeen Android principles, which fall under the three pillars.

- Enchant me
 - Delight me in surprising ways
 - Real objects are more fun than buttons and menus
 - Let me make it mine
 - Get to know me
- Simplify my life
 - Keep it brief
 - Pictures are faster than words
 - Decide for me but let me have the final say
 - Only show what I need when I need it
 - I should always know where I am
 - Never lose my stuff
 - If it looks the same, it should act the same
 - Only interrupt me if it’s important

- Make me amazing
 - Give me tricks that work everywhere
 - It’s not my fault
 - Sprinkle encouragement
 - Do the heavy lifting for me
 - Make important things fast

Several of these design principles will be discussed in more depth in Usability Test Results and Redesigning the App.

Material Design

Google introduced Material Design at Google I/O 2014 as a means for creating one consistent vision for Android devices of all types and sizes [17]. Material Design attempts to use fundamental human understanding of real-life materials to provide meaning to the UI components with which users interact. This concept of using materials in software design is increasingly common as a means of understanding the possibilities and constraints of design [7].

The core component of Material Design in Android is *material*, which is a virtual surface that has depth in addition to area. Material makes use of edges and shadows to provide the sense that each pixel of the UI has depth in addition to color. The seams and shadows of material provide users with intuition about what they can touch and how it moves.

Users can slide, stack, and lift material like paper within the virtual space of the phone. These animations provide meaning to the actions users can perform and resemble manipulation of paper in the real world. However, material goes beyond the physical limitations of paper, sometimes changing shape or rippling like virtual ink in response to touch. Though material does not have the physical limitations of paper, it uses metaphor to ensure that manipulating it feels natural to users. For instance, buttons in Material Design, rise to the surface, rather than sinking like in traditional user interfaces, giving users the sense that they interact directly with the button when they touch the screen.

Google provides a unified set of Material Design guidelines for all devices [10], including information about style, layout, and standard components. These guidelines help developers to understand best practices and build apps consistent with the rest of the Android platform. Several of these guidelines will also be discussed in more depth in Usability Test Results and Redesigning the App. Material design uses these concepts of tangible surfaces, bold and intentional design, and meaningful motion to create a universal Android experience.

USABILITY TEST RESULTS

Six users participated in the CrosScan usability study. We gained feedback from the study through pre-screening questions, observations during the session, and the survey each participant completed. The discussion of feedback in this section will reference the aforementioned Android Design Principles and Material Design guidelines.

Pre-screening Questions

Through the pre-screening questions, we learned that the participants on average completed crossword puzzles either weekly or monthly (see Figure 2).

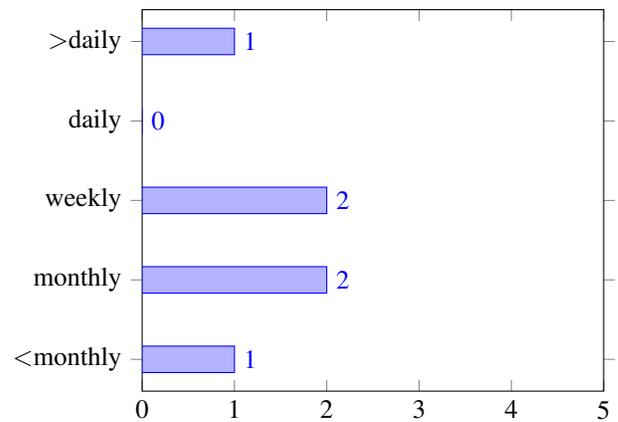


Figure 2: How often do you do crossword puzzles?

Most participants completed those puzzles in newspapers; however, one participant who completed puzzles multiple times a day preferred to use Across Lite [1] on the computer (see Figure 3).

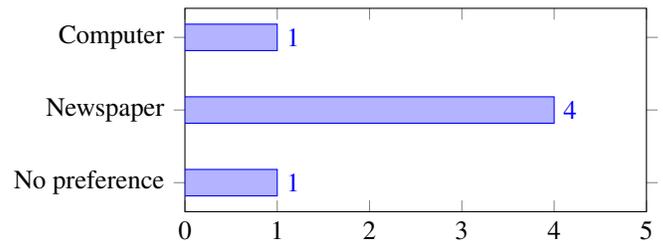


Figure 3: What are your favorite methods for doing crossword puzzles?

Finally, we learned that all users had mobile devices — three owned iPhone, two owned Android, and one owned Windows Phone (see Figure 4).

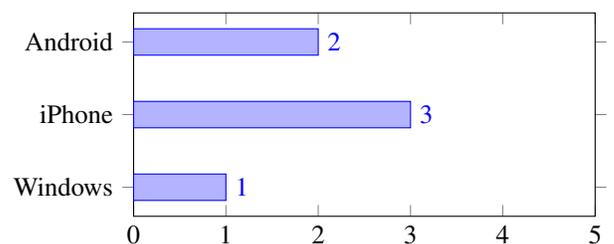


Figure 4: What type of mobile device do you own?

As a result of these pre-screening questions, we learned that a couple of participants represented the app’s primary expected audience of crossword enthusiasts. In addition, all of the participants represented the audience of smart phone users, so

their feedback was informed by their prior interactions with mobile apps.

Evaluation of Task Performance

During the first and last tasks, several participants mentioned that they were not sure whether to include the whole puzzle in the photo during scanning. This feedback implies that there should be some cues telling the user how to line up the photo in order to scan in the crossword grid and clues accurately. In addition, several participants mentioned that the camera had focus issues. These issues are a result of the camera functionality in the app working differently from the default Camera app (which comes with Android). This inconsistency is a clear violation of the Android Design Principles, “If it looks the same, it should act the same,” and “Give me tricks that work everywhere.” The former principle suggests that the camera in CrosScan should work in the same manner as the default Camera app. The latter principle suggests that tricks such as focusing the camera should work in CrosScan, just as they do in the default Camera app. Redirecting CrosScan users to the default Camera app to take the picture and returning the result to CrosScan provides a simple solution to this problem. One consideration for this solution is that we would have to include the aforementioned cues in a creative way so that users would know what to do while in the default Camera app. On the other hand, using the default Camera app would solve the camera focus issue and remedy these violations of the Android Design Principles.

For the most part, users had no issue realizing that tapping certain squares of the crossword grid would allow them to edit the puzzle. In fact, one of the participants commented, “whoa,” in delight when tapping a square for the first time. This positive experience is in accordance with the design principle “Delight me in surprising ways,” and will definitely remain for the next version of the app. However, a couple participants struggled to fix the crossword grid after accidentally changing a few squares. One of the participants accidentally made some changes and then brought up the keyboard in order to rename the puzzle, obscuring the grid so that it could not be fixed. These issues suggest that CrosScan needs a better screen for editing crossword puzzles. One important design principle to consider when redesigning puzzle editing in the app is “Decide for me but let me have the final say.” This principle suggests that CrosScan should provide a default name for the crossword puzzle and assume it successfully scanned the puzzle, bringing users directly to the screen where they can begin solving the puzzle. From that screen, users can have the final say by changing the puzzle name, perhaps by long-pressing the title of the puzzle. In addition, users will have the option to edit the puzzle grid on the Solve Puzzle screen. When CrosScan performs perfectly, users would not have to waste time deciding that CrosScan did a good job. Instead, they are given the final say after CrosScan decides for them.

During the second task, participants succeeded in filling in the answer to a clue. It took a couple of participants a while to learn how to toggle between entering answers to Across clues and Down clues; however, they found out they could toggle by

double-tapping the square in question. In addition, a couple of users found they could toggle by touching the clue bar.

During the third task, the participants realized they would have to find a menu in order to restart or delete the puzzle. Because the Samsung Galaxy Note 3 phone has a hardware menu button on the phone, many users struggled to find the menu. Now, most Android phones do not have a menu button or back button built into the phone hardware. Thus, not incorporating menu actions into the app bar at the top of the screen violates Material Design. For easy interaction, it is imperative that CrosScan have menu buttons in the app bar of all screens where menu actions are required. In fact, many users attempted to find a menu by tapping the app bar, but were not able to find one there. A couple of participants got around this problem by returning to the list of scanned puzzles and long-pressing the current puzzle to restart it that way. Therefore, adding an app bar with a menu in accordance with Material Design will improve the app by making it easier to navigate.

Evaluation of Survey Responses

The first survey question asked users to select from a list of 56 words [2] that they think apply to the CrosScan app. The table in Figure 5 shows a list of words sorted by frequency. The frequencies of these words range from 0 (unselected) to 6 (selected by all users). As can be seen, most of the frequently-selected words indicate positive experiences (e.g., Usable, Organized, Appealing) and most of the infrequently-selected and unselected words indicate negative experiences (e.g., Busy, Complex, Confusing).

Users chose positive descriptors frequently. In fact, every participant selected the descriptors “Easy to use” and “Usable,” which are goals of any app undergoing usability testing. In addition, all but one user selected “Efficient,” “Organized,” and “Straight-forward.” Most users also selected “Fun,” “Consistent,” and “Appealing.” The word “Simplistic,” selected by all of the participants, could be viewed in a positive or negative light. On one hand, simplicity could imply that the app is designed in a way that is simple to understand at first glance, as is suggested by the other most frequent words. On the other hand, simplicity could imply that the app does not have all the features it should have, as is addressed in the third survey question. This connotative ambiguity suggests that “Simplistic” should be replaced in future assessments, perhaps by the positive word “Understandable” and by the negative word “Over-simplistic.”

A few words that could be seen as positive indicators of well-designed apps, such as “Exciting” and “Flexible,” were chosen infrequently. Indeed, it is a goal of this project to ensure that the app is both exciting and flexible, in the sense that users are excited when the app works in a variety of environments (i.e., the app succeeds in scanning various puzzles from different sources in different lighting conditions). In the test setting, with a simulated test app, it would have been difficult to convey these positive experiences due to the lack of different environments. Ideally, the fully developed app will elicit more “Exciting” and “Flexible” assessments than the current prototype achieved in usability testing.

Selected Words by Frequency						
6	5	4	3	2	1	0
Easy to use Simplistic Usable	Efficient Fast Organized Straight forward Useful	Appealing Consistent Fun Reliable Time-saving	Accessible Attractive Desirable Familiar High quality Valuable	Comprehensive Customizable Empowering Predictable Relevant Trustworthy	Busy Exciting Flexible Fresh Inviting Motivating Personal Rigid Sophisticated Stimulating Unconventional	Collaborative Complex Confusing Connected Frustrating Gets in the way Hard to use Inconsistent Intimidating Not valuable Overbearing Overwhelming Patronizing Slow Stressful Time-consuming Too technical Uncontrollable Unpredictable Other: _____

Figure 5: Selected words by frequency.

Users chose negative descriptors infrequently. For example, the words “Busy” and “Rigid” were selected by only one user, and the descriptors “Complex” and “Confusing,” were not selected by any user. This lack of negative feedback indicates that the app is designed in a way that avoids many negative emotions.

The second survey question asked whether CrosScan is an app the participants would use (see Figure 6). In general, participants stated that CrosScan is an app they would use. Four of the participants stated that they would use CrosScan, either every time they came across a physical crossword puzzle or when they wanted to scan several puzzles before going on a trip without Internet access. Two users said they might use CrosScan, either if they had a newspaper subscription or if they did not grow bored of crossword puzzles.

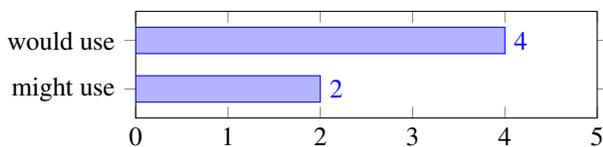


Figure 6: Is CrosScan an app you would use?

The third survey question asked what features were missing from the app. Two participants suggested that they should be allowed to share and collaborate on puzzles. Though sharing puzzles would promote a positive user experience, it is not the goal of the app due to the copyright concerns of distributing authors’ puzzles to friends who have not paid for them. Three participants mentioned that they would like a better view of the puzzle when solving it. They suggested being able to adjust the size of the puzzle, as well as being able to switch views so that

they can see a listing of all the clues. Thus, creating a better view of the Solve Puzzles screen is a major consideration for the future of the application. One participant mentioned that the application is “not very visually appealing.” Adherence to Android Design Principles and Material Design is an important step toward solving this issue in future iterations of CrosScan.

The fourth survey question asked users to rate their crossword puzzle experience with the app on a scale from 1 to 7 (see Figure 7). The median rating of the participants was 6.5. This suggests that CrosScan provides a very good experience to users of the app. However, it also suggests that there is room for improvement in the proposed redesign of the app.

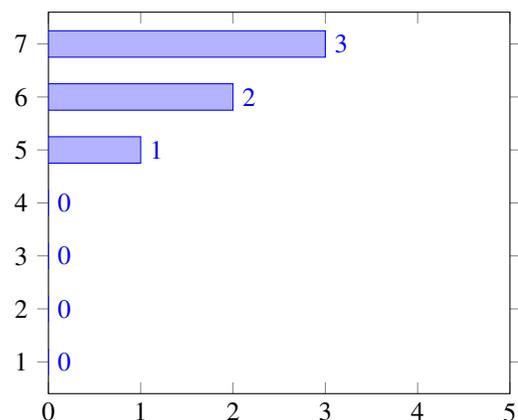


Figure 7: Rate your crossword puzzle experience with the app.

REDESIGNING THE APP

We consider user feedback from the usability study in tandem with the Android Design Principles and Material Design to

propose design iterations and improvements for the next stage of CrosScan development. Figure 8 shows some redesigned screens for the next CrosScan iteration. Each of the screens includes a status bar (at the top of the screen), an app bar (below the status bar), main content, and a navigation bar (at the bottom of the screen). The status bar is a universal feature of the Android platform, but it is important to point out that the color of the status bar in Figure 8 is selected from a palette of colors specified by Material Design. Likewise, the app bar color is chosen from the same palette of colors as a complimentary color to the status bar. As mentioned in Evaluation of Task Performance, Android devices no longer rely on hardware buttons (particularly a menu button, a home button, and a back button) for navigating apps. Android now includes a software navigation bar at the bottom of the screen, as shown in Figure 8, as a solution to this problem.

Figure 8a shows the new start screen for CrosScan. Instead of making users decide whether they want to scan puzzles or solve puzzles, the app launches directly into the list of puzzles. If users want to solve puzzles, they can tap a list entry to open the solve screen for the corresponding puzzle. This behavior is similar to the previous design, except now it takes only one step for users to begin solving a puzzle, instead of two. If users want to scan a puzzle, they can tap the floating action button (FAB) in the bottom right corner of the screen. The FAB is a major Android component introduced in Material Design, which is often used to designate the primary action of a screen. The FAB casts a shadow to give the sense that it floats above the content below it, rising up to meet the user's finger when tapped. The color of the FAB is also chosen from the Material Design palette as a complementary accent color, designed to draw attention. Tapping the FAB redirects users to the default Camera app to take a picture of a crossword puzzle. Using the default Camera app solves a couple of problems encountered in usability testing and supports the Android Design Principle, "If it looks the same, it should act the same," as discussed in Evaluation of Task Performance.

Once users take a picture in the default Camera app, they are immediately redirected to the solve screen of CrosScan. Rather than asking users to name and edit the puzzle first, they can begin completing the puzzle immediately. This design decision supports the principle, "Decide for me but let me have the final say," as discussed in Evaluation of Task Performance. The solve screen will show progress bars for the grid and clues as the grid and clue recognition algorithms finish, and then it will eventually display the content as seen in Figure 8b. Loading the content asynchronously gives users the opportunity to name the puzzle while the puzzle is loading. They can do so by tapping the pencil icon in the app bar, which leads to the edit puzzle screen discussed later. There is also an overflow menu icon in the app bar, which allows users to perform actions, such as deleting the puzzle, which users would need the hardware menu button to perform in the old version of the app. The overflow menu reinforces the Android Design Principle of "Only show me what I need when I need it." Hiding actions that aren't essential at the moment in the overflow menu ensures that users are not overwhelmed by a large number of options. The pencil and overflow menu icons, as well as the

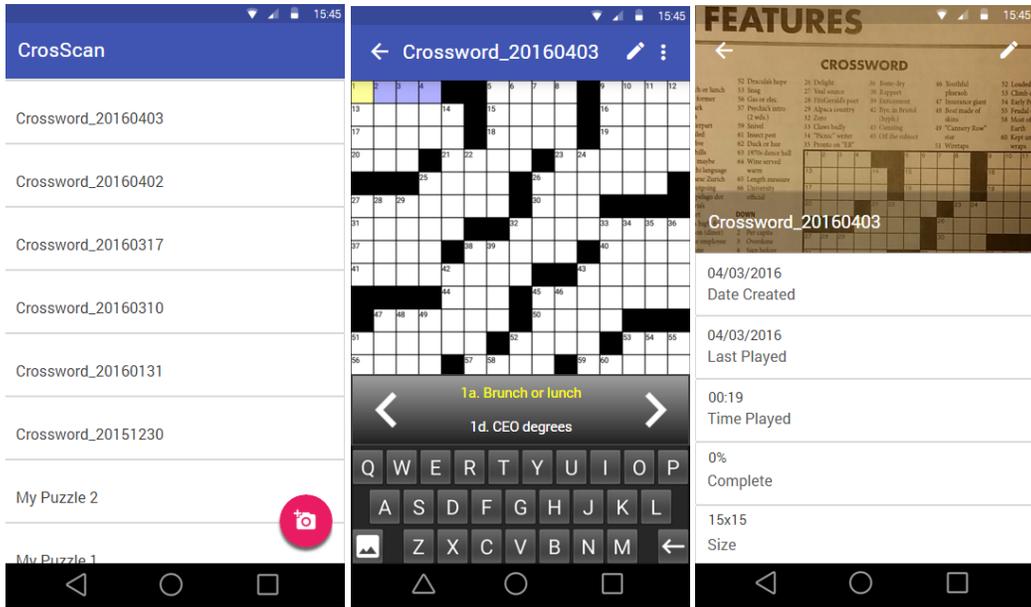
two icons in the clue bar and two icons in the keyboard are part of the gallery of icons provided in the Material Design guidelines.

Additionally, in response to survey feedback requesting being able to resize the crossword grid, users can pan and zoom the grid by performing standard drag and pinch gestures. As can be seen in Figure 8b, the grid disappears below the clue bar. By either dragging the grid or navigating to the squares of a clue obscured by the clue bar, users can see this portion of the grid. This functionality gives the user flexibility when solving puzzles of all sizes. The rest of the solve screen works similarly to the previous version of CrosScan.

Figure 8c shows the redesigned puzzle info screen. In this screen, the app bar is extended so that it contains the picture of the crossword puzzle in addition to icons for navigation. Including the photo in this screen quickly gives users information about the puzzle, coinciding with the Android Design Principle, "Pictures are faster than words." The arrow icon allows users to return to the previous screen from which they navigated to the info screen. By including this button in the edit and info screens, users can easily navigate between the screens of the app, ensuring the design principle, "I should always know where I am." The pencil icon once again allows the user to edit the puzzle by navigating the edit screen. Including this icon in multiple places in the app creates a universal experience within the application in accordance with the design principle, "Give me tricks that work everywhere." The rest of the info screen contains information about the puzzle, displayed in a list, similar to the previous version of CrosScan.

The edit screen is new to the iterative redesign of CrosScan, providing a solution to some issues raised by participants during usability testing, as discussed in Evaluation of Task Performance. The CrosScan edit screen shown in Figure 9 allows users to toggle puzzle squares between white and black (see Figure 9a), add rows and columns to the puzzle grid (see Figure 9b), and remove rows and columns from the puzzle grid (see Figure 9c), as well as rename the puzzle. Renaming the puzzle is possible through the text entry field in the app bar. During usability testing, an issue was encountered where the keyboard obscured the grid even after the user was done typing the title of the puzzle. This issue is fixed in the redesign due to the navigation bar at the bottom of the screen. When the keyboard opens, the back (triangle) button in the navigation bar rotates to indicate that the keyboard is visible. By tapping this rotated button, it is possible to close the keyboard and prevent it from obscuring the grid once the user finishes typing.

Users can switch between the three edit functionalities of this screen by using the buttons in the bottom bar. Due to positive feedback about the toggling of squares during user testing, this feature is the same in the new version of CrosScan as it was in the previous version. Users can access this feature with the toggle squares option in the edit screen. With the add squares option, users may tap the rectangles surrounding the grid to add new columns and rows of white squares to the puzzle. If they do so, then a dialog box from Material Design (called a *snackbar*) appears, allowing users to undo the addition of the row or column of squares. This design pattern follows the

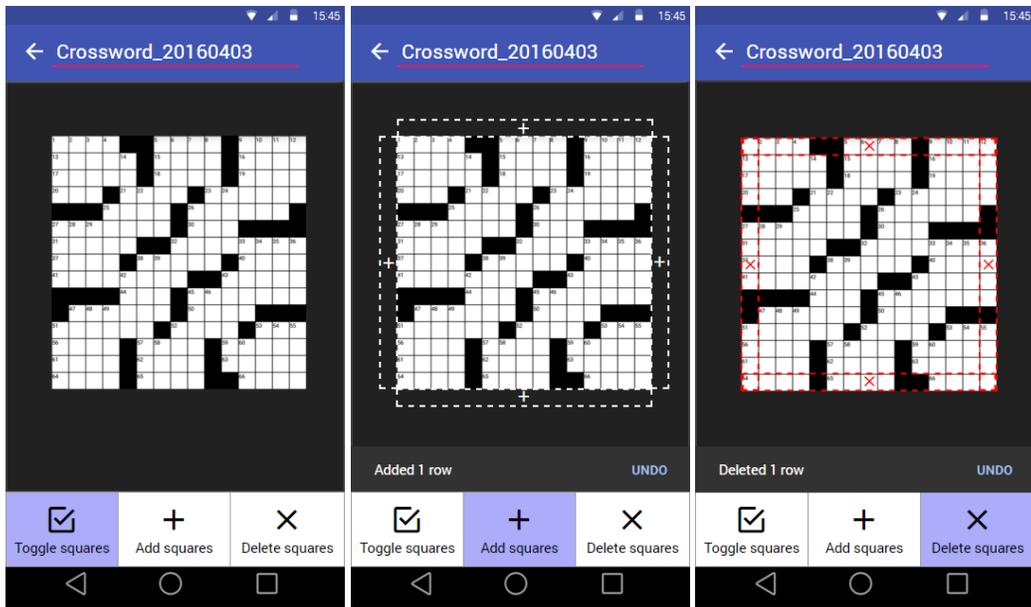


(a) The start screen.

(b) The solve screen.

(c) The info screen.

Figure 8: CrossScan redesign screens.



(a) The toggle screen.

(b) The add screen.

(c) The delete screen.

Figure 9: CrossScan redesign edit screens.

Android Design Principle of “Decide for me but let me have the final say.” When the app allows users to undo actions, it gives them the final say and lets them find the best way to edit the puzzle. Users can then navigate back to the toggle squares screen to fill in black and white squares in the added rows and columns. With the delete squares option, users can delete rows and columns of squares in a similar manner to the add squares screen.

Overall, this redesign of the CrossScan app provides solutions to the issues raised by participants during usability testing. Using the Android Design Principles and Material Design as a basis for app design makes it easy to identify and implement solutions. For example, several users attempted to find the solve screen menu by tapping the app bar. The Android Design Principle, “Give me tricks that work everywhere,” helps to identify that there should be a menu available in the app bar

as in other Android apps. Material Design provides intuition into what the menu icon should look like, where it should go, and how it should be implemented to uphold the design principle, “Only show me what I need when I need it.” Therefore, considering user feedback within the framework of Android Design Principles and Material Design is an effective strategy for successful iterative app design.

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