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Producing An Effective Mobile Application For Rapid Microplate Analysis: A Design Study

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ABSTRACT

A microplate is a common piece of laboratory equipment consisting of multiple wells that hold a small amount of liquid, much like a miniature test tube. These plates come in a range of different sizes and are typically used in microplate analysis to determine the concentration of a substance within a solution and hence a compounds's efficacy in inhibiting growth of an organism.

Microplate analysis is conducted on microplate readers which use light of a specific wavelength sent through microplate wells to measure absorbance. However, microplate readers are both bulky and expensive. A mobile application that uses the device's mobile camera to capture and analyse microplates provides a low-cost, portable alternative to microplate readers and has a range of applications from laboratory and field work to teaching laboratory techniques. Prior work developed a basic prototype to do the basic capture and analysis of microplates using a mobile device, We aim to expand the prototype into an effective and usable mobile application that allows users to easily conduct a range of microplate analyses and visualise the results which scores on average above 68 on the SUS questionnaire.

We follow a user centered approach, with multiple application design cycles. Incorporating a contextual inquiry and task analysis to allow us to fully understand the current process and the users desired tasks and behaviors. The design cycles begin with a low-fidelity prototype before a fully functioning prototype is developed and tested.

The prototypes are evaluated with a usability laboratory test and a System Usability Scale on a sample group (n=9) of regular microplate users to determine the effectiveness and perceived usability of the application.The final evaluation revealed the application scored an average SUS score of 88, which is a significant margin above the average SUS score of 68. The final functional mobile application can be used not only as a replacement to microplate readers in underfunded or remote laboratories, but also as a complement to current conventional microplate readers. The final application could also be used in a teaching context to educate students about processes and equipment used in laboratories.

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1. INTRODUCTION

Microplate readers are widely-used in laboratories and can conduct absorbency, florescence and luminescence measurements. Microplate readers are often run via software on a desktop computer, placed on a tabletop and rarely moved. Microplate readers although common in many laboratories cost hundreds of thousands of rands meaning many underfunded and isolated laboratories do not have access to them limiting the types of research these laboratories can conduct and reducing the quality of experiments is greatly reduced. Microplate readers analyse multiwell microplates which are favoured by scientists as they allow multiple experiments to be conducted simultaneously. Compounds are often tested in duplicate or triplicate in the mutiwell plates to compensate for pippetting errors.

Previous research has investigated the potential for smartphones to leverage their inbuilt cameras to capture standard microplates of different sizes to produce concentration values without the use of traditional microplate readers. Research conducted by Bellairs et al. developed a prototype application that had both well detection and colour analysis modules. The well detection module identified the wells in the pictured microplate and allowed the colour analysis module to extract pixel colour values which were then used to derive the compounds concentration. They managed to achieve results within 8 percent of a traditional microplate reader while other approaches have come even closer with different approaches [4, 40].

While previous research has steadily improved the accuracy of mobile applications there has been little to no focus on the usability or interface of the applications themselves. Usability is a property that describes how easy a product's interface is to use. Usability is important as it affects the user's experience whilst using the product. Should the user get lost or get confused with the interface they will simply stop using the application or make errors whilst conducting a task. How usable the application is also influences the applications adoption rates and can determine the productivity of the user [32].

The aim of this research is to fill the usability gap overlooked by other research and develop a low-cost, intuitive and effective application that users consider usable. The application allows users to conduct a rapid analysis of a microplate assay and analyse the results via clear and simple visualisations. The application was evaluated with the the System usability Scale (SUS) questionnaire to determine its perceived usability and the success of the application design and interface [10].

2. BACKGROUND

The following section provides an overview of current usability practices and tools used in order to develop and evaluate a mobile application. Similar applications are also reviewed.

2.1 Requirements Gathering

Gathering information is a critical part of developing a usable, effective application. The information gathering process involves interacting with the actual users of the application and produces data that is used in the design process. The following techniques and tools are essential in aiding the capturing and analysis of information about the user.

2.1.1 Master Apprentice Model

The Master-Apprentice model is a common technique used in contextual inquiries and is a form of Apprenticeship where the interviewer, the Apprentice, engages with the actual user, the Master, in their work environment. The Master teaches the Apprentice how to do the required job. This type of relationship is effective as the process of doing the task reveals to the Apprentice actions that the Master wouldn‘t consider important and have been developed through years of experience. [8]

2.1.2 Contextual Inquiry

A contextual inquiry is a set of concepts that guide the design of information gathering sessions and is grounded in its use of context. Interviews should be conducted in the the actual users typical work environment. A Contextual inquiry focuses on getting the user to explain their work experience and tasks as they work and begins by establishing a relationship, such as the Master-Apprentice model, with the user. The core part of the process is the inquiry into the users actions. Notes are taken on what the users says, does and how we interpret those actions. The interviewer interrupts the user to clarify actions but often there are prolonged silences in which only observation takes place.[21]

2.1.3 Personas

Personas are abstract representations of users and are used to guide design. These user profiles are derived from contextual inquiries and are often used not just to aid design and design decisions but to create user scenarios and provide a means of justifying and communicating the design to all project participants [33].

2.1.4 Task Analysis

A task analysis is a method of collecting information, classifying the information into groups and interpreting the data to produce user defined tasks. Information taken from previous contextual inquiries is broken down into tasks. A task analysis is about learning what the user‘s goals are and how they achieve those goals.This is done in order to identify tasks that need to be supported by the future application. A common task analysis is a Hierarchical Analysis. This technique involves the breaking down of broad tasks into ordered subtasks. [2]

2.2 Design

The process of designing an usable application incorporates different methodologies while following design guidelines. This section outlines basic tools common in developing usable applications.

2.2.1 User Centered Design

User centered design broadly describes the process in which actual users are involved in the design of a product and as a result have an influence on the final product. The user is often consulted during different phases of the product design with regards to their requirements and opinions. To varying degrees the user is a stakeholder in the project which ensures that the user can make use of the end product as intended and with minimal effort [1].

2.2.2 IDEO Rules

IDEO rules are intended to guide the brainstorming of ideas and ensure that the highest quantity and hopefully quality ideas are produced from brainstorming sessions. Examples of IDEO rules include: One conversation at a time, Deferring judgment and Building upon other ideas [24].

2.2.3 Iterative Design

A design cycle begins with Investigation, followed by Design, Creation and finally Evaluation, after which the cycle is then repeated. Iterative design involves the use of design cycles to incrementally improve on a product [27]. During the design phase of the design cycle, prototypes are developed to demonstrate to the user to evaluate their effectiveness and clarify the user‘s requirements. These prototypes are scaled up in fidelity beginning with a low fidelity paper prototype approach and ending with the high fidelity functional product. For low fidelity, paper prototypes are often chosen as they allow the researcher to express the design and demonstrate functionality whilst allowing the user to feel the design is not complete and can be readily changed [34]. The Wizard of Oz technique is often used with paper prototypes during the evaluation stage of the design cycle and involves one researcher performing the role of the 'Machine', operating the paper prototype so that it appears to the user that they are interacting with an actual working system [11].

2.3 Usability

Usability is made up of five quality components namely: Learnability, Efficiency, Memorability, Errors and Satisfaction. Utility, whether the application provides the appropriate features, is also an important quality and together with usability defines how usable the application is considered to be [32]. A number of environments and metrics can be used to assess usability. The challenges of designing usable applications and the different usability tools and techniques are discussed below.

2.3.1 Challenges

Designing mobile applications for human interaction is a difficult problem [14, 22].Users are mobile, do not have formal training, have incomplete and varying information on context and have to contend with frequent interruptions during mobile device use [12]. Mobile phones are small, with limited input devices and unreliable and expensive connectivity to other services [39].As mobile phones become more prolific and the industry evolves, the range of different screen sizes and resolutions makes designing for these devices more complex and usability test results may differ between devices[42].

Solutions to the challenges are dependent on the context in which the mobile device will be used. Huang proposed a 3D orientated interface as a viable solution to limited screen size on mobile devices[22]. Other general suggestions including the use of alternative keyboards to the standard QWERTY layout, as well as a stylus to make basic input more reliable and accurate.

2.3.2 Usability Measures

There are a group of generally accepted measures to be used when evaluating usability. The ISO 9241 standard for usability classifies the measures into three groups: 'effectiveness', 'efficiency' and 'satisfaction' [15]. These three groups are broken down into subgroups in a number of discussions on the subject [31, 38]. Examples of these measures in use are: average time taken to complete a task, the number of errors made during the task and average task completion scores[37]. These measures are used to measure quality of use and are influenced by factors such as the functionality of the application and the reliability of the system. However the context of use is key. Deciding on which usability measures are to be incorporated in a usability study is important as it provides a metric that indicates how usable the developed application is and what areas usability problems reside. Because of the importance of context of use for an application there is no general rule for which usability measures are chosen and combined however it is suggested that a reliable measure of usability can only be obtained by using the above measurements on representative users in a representative environment performing representative tasks [7].

2.3.3 Usability Methodologies

Evaluating the usability of an application is an important factor in judging whether an application will behave as expected and will meet the requirements of the user [18]. Most studies agree on three principle methodologies for evaluating usability. The three approaches are follows; laboratory, field and hands-on environments.There is, however, contention as to which technique yields more information to the researchers. All three approaches involve recording the participants interactions with the application and are conducted by one or more researcher.

Usability Laboratory tests are conducted in an environment that is strictly controlled by the researcher. The participants are asked to complete a set of tasks and their actions are closely observed and recorded. A Laboratory setting makes it easy to record the user's interaction with the application and capture their reactions to design elements. However this methodology, unlike field testing, does not account for unreliable network connectivity or interruptions that happen in a real world context [42].

Field testing requires the user to interact with the application in the real environment in which they would ordinarily use the application whilst being recorded. This methodology ensures that the dynamic mobile context is taken into consideration and, depending on the application, can provide a more realistic evaluation. This methodology is, however, more complex than the laboratory environment as the researcher has less control over testing conditions and participants. Additionally recording the participant and noting their reactions can often be more costly and time consuming as custom recording hardware is often required [42].

The Hands-on methodology uses a group of measurements designed to quantitatively measure the usability of the mobile application. Measurements such as simplicity and accuracy are measured in the application through use by participants and are then linked to usability goals. However in many studies the measurement methods are not adequately defined and often do not cover newer interactions such as tapping and gestures [30].

Zhang et al. argue that laboratory testing is more suited to applications that have no need for different network conditions and are not used in a dynamic moving context [42]. Field testing, however, is more suited to applications that are difficult to replicate in a laboratory and are dependent on a mobile context. Nayebi et al. concluded that a combination of field studies and hands-on measurements could provide more significant usability information[30]. Betiol et al, however, identifies laboratory environments as being the preferred environment for testing [6]. A suitable evaluation environment for usability studies is clearly disputed, Kjeldskov et al. provide a highly in depth and thorough review of Mobile HCI research and their choice of environment over a number of years [26]. They found that 49% of studies in 2009 used the laboratory approach, 35% of studies opted for the field study approach and finally applied studies accounted for 30% of all research, with the deficit being methodologies that are less prevalent. This demonstrates that a laboratory approach is most commonly used. However the most appropriate testing methodology is often context and application dependent.

2.3.4 Evaluation Techniques

User evaluations are conducted using actual representative users that would commonly use the application. The Think-aloud protocol is used during user based evaluations and is a means of encouraging the participant to voice their thoughts while using the application, providing a flow of consciousness. Expert evaluation,however, uses usability and HCI experts to evaluate designs. Kjeldskov et al. studied expert evaluation and user-based evaluations from within a laboratory environment [26]. They found that the heuristic evaluation makes it harder to identify usability problems related to the support for collaborative work and in general fared worse than the user based think-aloud evaluation. However, there is very little research that evaluates other mobile usability studies approaches in laboratory environments; the majority of research focuses on one or the other approach individually.

2.4 Mobile Phone Microplate Assay Readers

A number of studies have developed mobile applications for the analysis of various chemical and paper assays. However, most applications focus on the analysis and detection task, while few consider the interface design and usability, which are important considerations for an effective application.

Vashist et al. developed an application for smartphones that conducted colourmetric imaging on microtiter plates. Their application could analyse 96 or 24 well microtiter plates and utilized a dark box solution with another phone providing illumination from below the captured microtiter plate. Their solution demonstrates the potential that phone cameras have to analyze assays plates[40].Their solution also provides a useful comparison between their phone based solution and existing solutions using laboratory equipment.They managed to provide a solution that when compared to current laboratory equipment has no noticeable difference in analytically sensitivity. However, there was little focus on the mobile application and interface developed for this solution and no mention of usability evaluations.

Guan et al. produced a smartphone application that analyzes a paper-based blood assay designed in a barcode-like fashion [19]. The smartphone application scans the bars of the assay with the smartphone's camera, processes the data and produces information about the blood's type. The application identified 98 blood samples, an accuracy comparable to equipment used in Red Cross Australia‘s laboratories [19]. Their application was developed for the Android operating system and managed to obtain all eight ABO/RhD blood types.However,the application‘s usability was not measured although they gave an example of a possible, but rudimentary, interface.

Berg et al. developed a hand-held piece of equipment consisting of a smartphone and a 3D printed mechanical attachment with a light emitting diode (LED) array to illuminate a 96 well assay plate [5]. An Android application with a machine learning algorithm processes the data, which is visualized and displayed to the user. Their solution achieved 99.6% accuracy compared to conventional microplate readers when testing mumps IgG on a enzyme-linked immunosorbent assay (ELISA). The hand held platform was cost effective and portable but only supported a 96 well ELISA plate which, although popular, is only one of a range of different sizes of assay plates.The study only briefly described the application, use cases and screenshots but has no indication of any usability tests. The research claims the device could assist health-care professionals, but no supporting data is evident. They also made use of a relatively complicated 3D printed mechanism that is constructed using expensive equipment not available in resource poor areas and arguably would not get near the accuracy without it.

This work continues the initial prototype developed by Bellairs et al. Their primary goal was to develop an Android application that served as a mobile, portable, low cost solution for analyzing assay plates [4]. Their solution achieved an average error of 7 percent when used with a DIY dark box solution. Critically their prototype also supported different size assay plates and allowed the user higher degrees of control of the variables than previously discussed mobile microplate reader solutions. The way the user interacted with the Android application was described however there was no focus on the user interface.

3. METHODOLOGY

The steps taken to gather information about the user and the two application design phases are defined below. The information gathering is conducted in order to fully understand the user and develop an application that has been improved based on their feedback. As a first step the users requirements and desired tasks were determined. Users were recruited via the University of Cape Town (UCT) Chemistry and Pharmacology department and were students with experience using conventional microplate readers. Users were not selected based on race, gender or age. One participant was used for the contextual inquiry, two participants for the initial prototype and nine participants to evaluate the final application. A contextual inquiry, task analysis and persona [21, 33] were used to elicit this information, which was then used to develop the prototypes described below. The final functional application was tested using a usability Laboratory methodology [23] and the effectiveness and usability of the application was determined using the SUS questionnaire[10].

3.1 Design Aims

The aim is to create a low-cost, intuitive and effective application that users would frequently use. The application should score on average 68 or above when evaluated with the SUS questionnaire and should provide users with a means to conduct a rapid analysis of a microplate assay and analyse the results via clear and useful visualisations.

3.2 Requirements Gathering

3.2.1 Contextual Inquiry

The contextual inquiry took the form of a one-hour one-on-one interaction with an actual user of the future application. All interaction was recorded via a microphone and was transcribed post interview. The interaction used the Master-Apprentice model [8] allowing the user to do a full run through of the process they take when conducting a conventional plate analysis. We took the role of the Apprentice and interjected only to clarify what the user was doing before resuming watching the user perform their normal activity. The inquiry was conducted in the user's workplace and we encouraged the user to think aloud as they conducted the plate reading. The interaction was broken down into three stages: the user was given an introduction and context as to why the inquiry was taking place, the user conducted the conventional reading of a microplate and finally the user was given a chance to input and voice any concerns or recommendations while we clarified any parts of the interaction that were unclear.

3.2.2 Task Analysis

In conjunction with the contextual inquiry, a task analysis investigated the process taken by user to read a microplate in order to produce a list of tasks that could then be arranged into a list of ordered sub-tasks. The tasks firmly focused on the user and the various methods they used to accomplish plate reading. The tasks were ordered on a hierarchical basis and are as follows.

Task: Conduct a microplate assay reading.

1. Capture plate using the plate reader.
   (a) Place assay plate on machine tray.
   (b) Close machine tray.
   (c) Open machine software on computer.
   (d) Adjust wavelength setting of test to appropriate indicator wavelength.
   (e) Set plate size.
   (f) Select read.
2. Collecting the results.
   (a) Copy results from machine software output.
   (b) Paste results into Excel spreadsheet.
   (c) Email spreadsheet or upload to Google Drive.
3. Analysis.
   (a) Conduct a conditional formatting test using Excel to rapidly check whether the plate recordings correspond to the plate visually.
   (b) Take each drug and log its concentration.
   (c) Take the tables cells and copy them into the 'Prisim' program.
   (d) Plot each of the compounds points on the graph.
   (e) Fit the sigmoidal curve to the data.
   (f) Read off IC50 value.

Typical plate setup for reading Four compounds tested in a 96 multiwell assay plate. Each compound is placed in different columns filling 12 wells per column. Two of the compunds are the experimental compounds and are tested in triplicate. Chloroquine and Amodiaquine, antimalarial drugs, are used as controls and fill the remainder of the space on the plate. Serial dilution is typically used across a whole column with a starting concentration of 1000 moles per liter leading to 11 points in the IC50 curve. The IC50 curve is made up of the log of the concentration of the contents of the compound wells against the percentage inhibition of compound growth.

3.2.3 Development of a Personae

The development of a persona for the user is important as it allows us to create a reliable and realistic representation of the user and our key targets. The user persona was based the questions our users answered, represents the user's expectations and tries to reflect what the user is most likely to use the application for and in what way. We aimed to distill the major requirements and needs the users would have in order to have an easy reference point for making interface design decisions and informed decisions which can be made based on user behaviors [33]. The developed personae is detailed in the Supplementary material.

3.3 Application Design

We followed a user-centered approach, engaging the user and iteratively developing prototypes to incrementally improve the application. The designs all follow design principles listed below and the two cycles begun with brainstorming ideas, followed by development of prototypes with increasing fidelity. This methodology allowed a broad spectrum of ideas to be slowly refined based on feedback from the user. The low fidelity approach also encourages more engagement with non-technical users [29].

3.3.1 Design Principles

Throughout brainstorming and prototype design cycles design principles are used to guide interface decisions and ensure improved usability. Design principles suggested in studies [20] and industry guidelines [17]were are listed as follows from highest priority to lowest: Natural Usage [20] , Navigation [17, 20] , Consistency [17, 20] , Feedback, Intuitive and contextual input methods [13] , Tolerance for errors [13] and Colour [41]. The listed principles are elaborated further in Supplementary materials.

3.3.2 Initial Designs

The initial design process involved brainstorming a number of alternative designs. The goal was to produce a large volume of ideas using the IDEO rules [25]. The ideas generated were evaluated for their strengths and weaknesses based on their design principles and perceived usability. The ideas were also ranked according to criteria according both originality, suitablity and originality [35]. Based on those criteria a design for the interface was chosen to be developed into a low fidelity prototype.

3.3.3 Low Fidelity Paper Prototype

The initial prototype for the microplate reader application was developed in the form of a paper prototype.The prototype consisted of a length of paper demonstrating the screen that was pulled behind a phone frame sketched onto a piece of paper. We then used the Wizard of Oz [11] demonstration approach during the demonstration to the user with one of us acting as the 'machine' controlling the sliding movement of the prototype. The feedback, recorded via microphone and transcribed, was analysed and changes prioritized which were then integrated into the design for the fully functional prototype.

3.3.4 Fully Functional Prototype

The fully functional prototype was developed in Android Studio [16] in Java. We chose Android as there are greater numbers of lower cost smartphones running Android in Africa. This gives the application greater distribution and accessibility potential than other systems such as Apple's IOS. The application, which can be run on most Android smartphones, was based on the previous low fidelity paper prototype. The feedback given during the initial user evaluation stage was built into the new prototype and integrated with the colour processing and well detection modules to complete a working prototype which was used for the final user evaluation.

3.3.5 Data Visualisations

The developed application also contains visualisations of the captured microplate assay analysis. These visualisations take the form of a conditionally formatted table based on concentration results and a graph that plotted the compounds degree of inhibition versus the log of the serial dilution. The table has a colour spectrum from red to black and the graph allows the user to analyse individual compounds and read off their IC50 values.

3.4 User Evaluation

3.4.1 User Sampling

A group of nine participants evaluated the final application. The participants were sourced from the Chemistry and Pharmacology department at UCT and were asked to sign consent forms before the evaluations began. The users were selected using the convenience sampling technique. This sampling technique selects participants due to their convenient accessibility and proximity. This technique was used as it is fast and inexpensive [28].

3.4.2 Laboratory Evaluations

Each participant was briefed on the application, asked to fill in the consent form and was then instructed to conduct a microplate reading of the supplied microplate assay using the developed application. The participants were all given the same microplate assay asked to use the Think aloud protocol voicing any concerns or confusions during the applications usage. The tests were recorded with both audio and visuals. An observer also recorded the participants thoughts or questions generated by the Think Aloud protocol. The researcher conducting the test remained neutral and only explained interactions to the user if prompted.

3.4.3 SUS Questionnaire

Upon completion of the tasks the users were given the SUS questionnaire and asked to fill in their answers. The SUS questionnaire was used to evaluate the applications perceived usability and was used as it is free, short, used in the majority of usability studies and considered highly reliable. The SUS questionnaire was used to evaluate the final fully functional prototype and was the final step in the evaluation process.

4. RESULTS AND DISCUSSION

4.1 Paper Prototype

The paper prototype was based on a design selected in the initial brainstorming phase. The prototype consisted of two elements, a frame of a smartphone and a strip of screens. The prototype simulated a side scrolling application by placing the first screen on the strip behind the frame and pulling the strip along as the user swiped to the next screen. Figure 1 shows the frame and the strip slider with examples of two of the screens. The full paper prototype can be found in Supplementry Material.

The evaluation session was recorded with the permission of the participants. For the user evaluation, The following suggestions were given by the user and have been ordered by priority by importance with the highest first: Portions of text be replaced or supplemented by icons, the instructions screens should be consistently present or can be reset and the users should be given the option to skip the visualisation of the analysis and just export the results. Users also suggested the IC50 value be given under the sigmoid curve with a possibility of an error or standard deviation. Users requested the ability to display which compounds are displayed on the sigmoid graph visualisation and that the compounds be differentiated by colour. In terms of the input screen the users felt there should be appropriate restrictions to ensure errors are less possible. Finally the users suggested adding a feature that allows them to revisit previous readings and analysis which should be stored on the device.

Overall the users felt the application had an appropriate flow and feel and accurately represented a microplate reading on a conventional reader. The users appreciated the applications attempt to represent the microplate in reality and found the analysis features useful. Users also commented that they frequently use Google Drive to upload their results over methods such as OneDrive or physical memory cards.

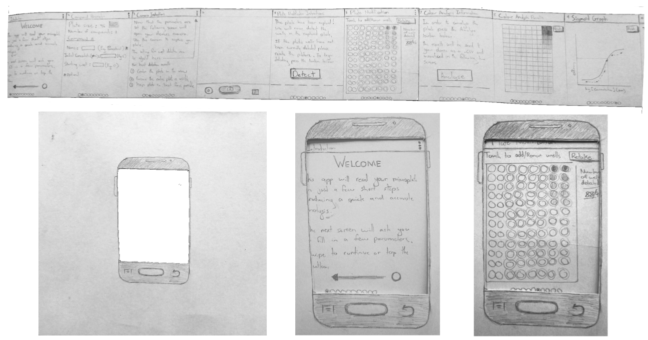

Figure 1: Base and Slider with Example Screens

4.2 Fully Functional Application

The final application was improved upon based on the suggestions during the low fidelity evaluations. All suggestions were incorporated with the exception of the ability to revisit previous experiments. This was due to time constraints. Additional features were also added to improve the utility of the application. These features included the incorporation of control compounds, manipulating of well detection settings and an indicator representing the number of wells detected. The input methodology was reworked to better constrain the input possible and represent an input method familiar to the user. Other small design principles were applied such as the differentiating of the detect and analysis button through both colour and shape channels. Screens of the final application are available in Supplementary Material.

4.3 Evaluation Results

4.3.1 SUS Score Analysis

In order to determine the applications perceived usability the participants scores for each question are added together and then multiplied by 2.5 to then convert the original scores of 0-40 to 0-100. All participants scores were then averaged in order to produce a final score representing usability for the system. An average score of above 68, derived from a large sample pool of evaluated systems, will indicate the application is considered usable [9, 10].

4.3.2 SUS Scores

The average SUS score for the nine participants was 88,05. This score however is not a percentage but simply an indicator. Bangor et al. collected data on a variety of systems and constructed a grading scale with a relationship between SUS scores and adjectives in order to better explain the SUS scores [3]. Based on their research the grading score for our system is a B which has the adjective 'Excellent' correlated to it. Research conducted by Sauro also looked into the relationship between SUS scores and how likely users are to recommend a system [36]. It was found that a SUS score of 85 (+- 5) tends to indicate that the system will be promoted. Our system with a score of 88.05 falls into the category of 'Promotor' [9].

4.3.3 User Suggestions and Comments

Users provided a number of suggestions to potentially improve usability. The most commonly suggested was the enlargement of labels on the visualisations. Users also requested Dropbox as a method of uploading results. The compound input screen was an area of interest with users suggesting the keyboard be minimized after the entering of an initial concentration. Some users felt the input for the number of compounds was not clear enough but majority of users found the input plate method intuitive and useful as it provided a rapid method of entry and closely mapped to real life. Overall the users found the application's interface look and feel to be appealing and simple to navigate.

4.3.4 Observations

There were a few notable interactions observed by us during the evaluations. Users frequently had trouble accessing the settings menu to adjust well detection settings and found the settings menu unintuitive. Users felt they did not know which settings had the greatest effect on well detection and how big the intervals needed to be in order to make a visible impact on the detection. One clear missing element that the application is lacking and can have an effective on usability is the limited error catching. Often users would fill in a field incorrectly or neglect to add necessary data and the application would only catch the error later in the analysis process. This added delay meant unnecessary user effort in order to go back a number of steps before being able to correct their mistake.

4.3.5 Visualisation Scores and Suggestions

In addition to the SUS questionnaire users were asked three questions regarding the two visualisations of the captured plate. These visualisations included the conditionally formatted table and the graph displaying the standard curve and IC50 value. The visualisations were well received by the users with an average score of 93 percent for the questions indicating the users would frequently consult the visualisations and found them both useful and intuitive.

5. CONCLUSIONS AND FUTURE WORK

By following a user-centered design approach we developed an application that scored an average SUS score of 88, a large margin above the sample pool average score of 68. This score indicates that our approach produced an application that is considered both usable and effective. Users expressed their interest in using the application in their workplace and found the interface intuitive. The visualisations we developed were also a success with majority of users commenting that they found them useful and would use them frequently. The usable application has great potential for preliminary analysis of microplates and can likely be used in a teaching context. Future work could improve upon our application by adding additional features such as the revisiting of previous readings.

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7. SUPPLEMENTARY MATERIAL

7.1 Design Principles

Table 1: Design principles

Natural usage	The application we developed needed to be user friendly. To ensure this users need to be informed about what steps to take within the application. Instruction pages were used to guide the user through the application.
Navigation	The navigation through the application needed to consistent throughout and leads to improved learning and a more comfortable environment. Part of effective navigation is always making sure the users knows where they are.
Consistency	This is the most basic of design principles followed and means similar information and actions needs be be put in a similar position
Feedback to the user	When processing information users should never be left wondering what the application is doing. Information should be constantly fed to the user and there actions should have appropriate feedback
Intuitive and contextual input methods	The methods of inputting information should be consistent, intuitive and based on the type of task. The need to input text should be minimized.
Tolerance for errors	Warnings and error correction functionality should always be provided and a tolerance for error should be designed into the application
Colour	Colour can be leveraged as an important tool in differentiating visual elements and focusing attention. A consistent colour palette should also be user throughout the application.

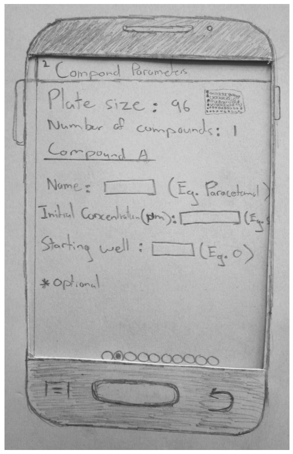
7.2 Personae

Table 2: Example Persona

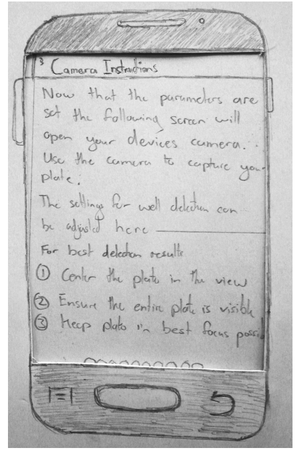
Honours Chemistry Student	Jane Doe
Demographics	
	22 Years old
	BSc Postgraduate
	Only child
	High School Qualifications
Goals and Characteristics	Relatively new to scientific experiments and the equipment used.
	Concerned about safety and eager to learn as much as possible.
	Known to be concerned with efficiency and wants experiments to be done quickly.
	Often does not have access to equipment.
	Quickly grasps new concepts.
Environment	Frequently shifting between workplaces and has no set schedule.
	Is still new to many laboratory procedures and practices
	Is comfortable with technology such as smartphones and computers
Quote	‘I’m interested in any tools that improve my productivity and are novel’

7.3 Paper Prototype

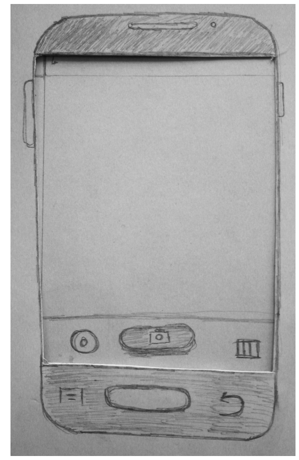
(a) Welcome



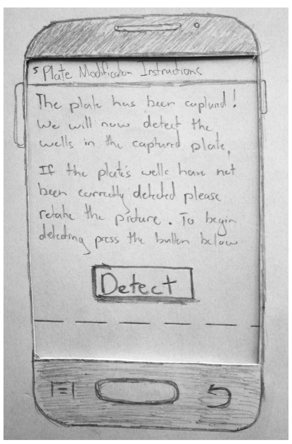
(b) Input Screen



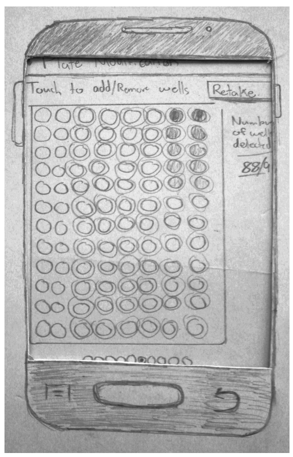
(c) Instruction Screen



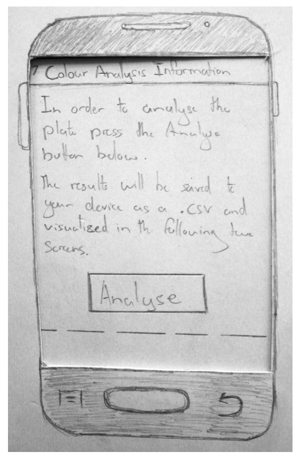
(d) Camera



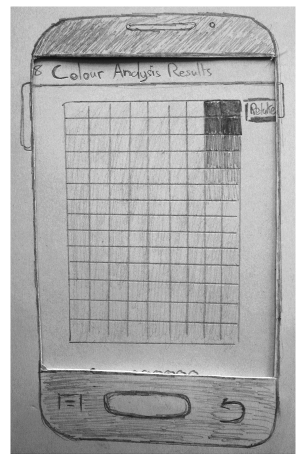
(a) Detect Screen



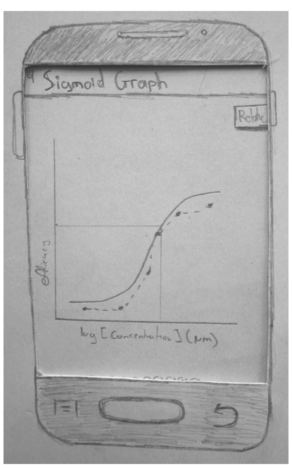
(b) Well Detection Screen



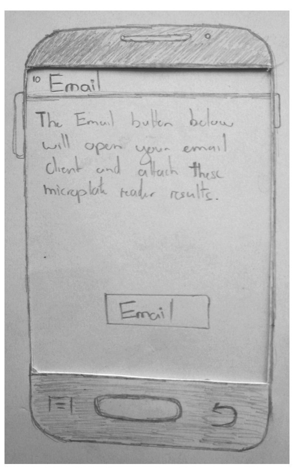
(c) Analyse Screen



(d) Conditional Table

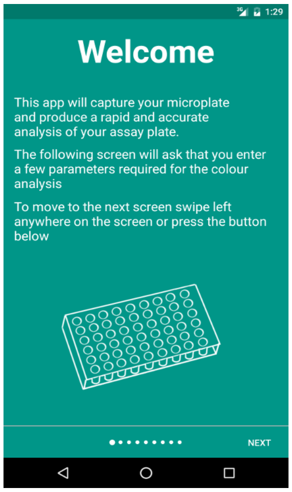


(a) Graph Visualisation

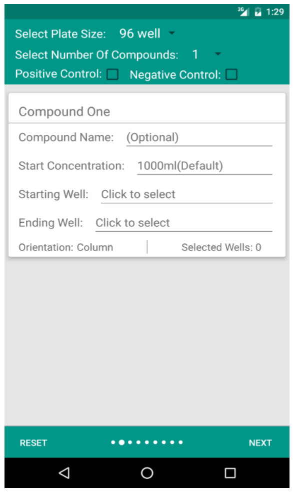


(b) Export Options

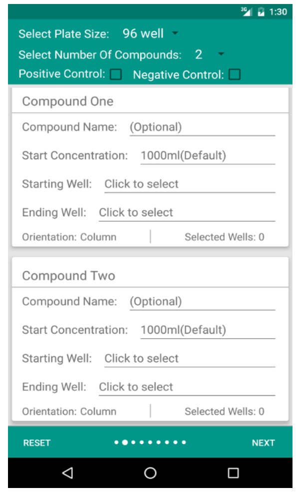
7.4 Final Application



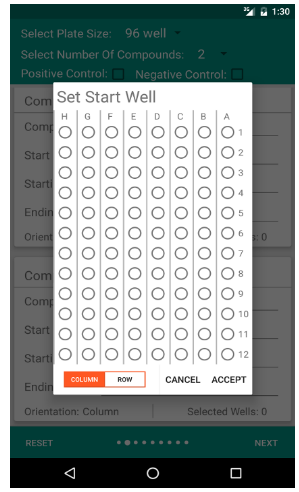
(a) Welcome



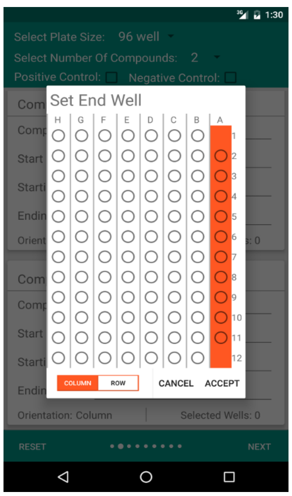
(b) Input Screen



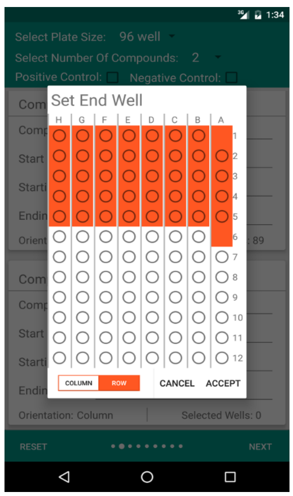
(c) Multiple Compounds



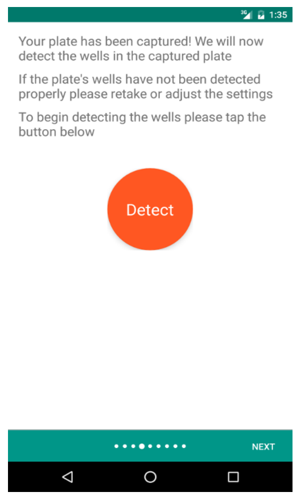
(d) Input Plate



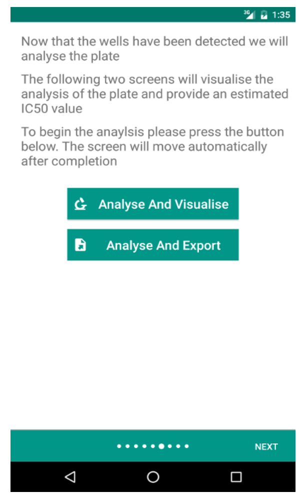
(a) Compound Selected



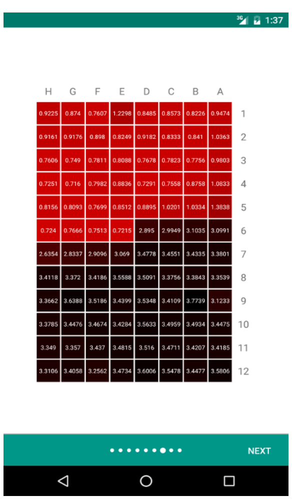
(b) Row Option Selected



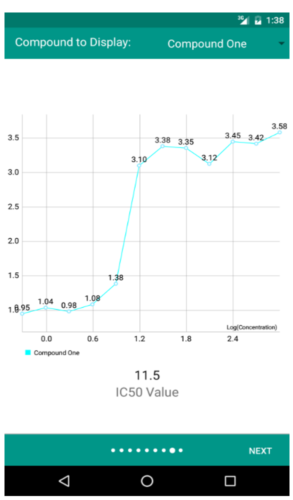
(c) Detect Screen



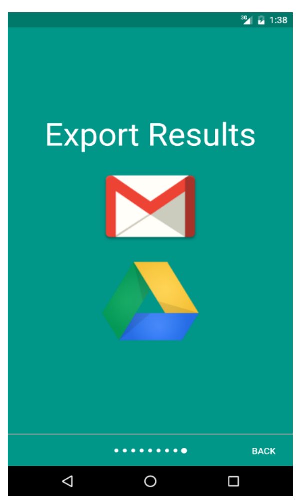
(d) Analysis Options



(a) Plate Visualisation



(b) IC50 Graph



(c) Export Options