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Development and Use of a Tablet-Based Resuscitation Sheet for Improving Outcomes During Intensive Patient Care

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ABSTRACT
Data documentation from resuscitation events in hospitals, termed 'code blue' events, utilizes a paper form, which is institution-specific. Problems with data capture and transcription exists, due to the challenges of dynamic documentation of patient, event and outcome variables as the code blue event unfolds. We hypothesize that an electronic version of code blue real-time data capture would lead to improved resuscitation data transcription, and enable clinicians to address deficiencies in quality of care. To this effect, we present the design of a tablet-based application and its use by 20 nurses at the Mayo Clinic hospital. The results showed that the nurses preferred the tablet application over the paper based form. Furthermore, a qualitative survey showed the clinicians perceived the electronic version to be more accurate and efficient than paper-based documentation, both of which are essential for an emergency code blue resuscitation procedure.

Categories and Subject Descriptors
D.2.2 [**Software Engineering**]: Design Tools and Techniques – *decision tables, state diagrams, and user interfaces.*

General Terms
Design, Human Factors, Verification.

Keywords
Tablet applications, Resuscitation, Intensive Care.

1. INTRODUCTION
The American Heart Association recommended in 1997 the data elements that should be collected from resuscitations in hospitals [1]. Currently, data abstraction from resuscitation events in hospitals, termed 'code blue' events, utilizes a paper form, which is institution-specific. Problems with data capture and transcription exists, due to the challenges of dynamic documentation of patient, event and outcome variables as the code blue event unfolds. Often key tasks performed or commands given are missed/ entered in error. Oversight may be sub-optimal. This may lead to poor quality metrics, putting patients and providers at risk and provide potentially misleading picture of resuscitation outcomes due to methodological shortcomings.

We hypothesize that an electronic version of code blue real-time data capture would lead to improved resuscitation data transcription, and enable clinicians to address deficiencies in quality of care. The goal of this research is to create an iOS based application, primarily designed for iPads, for code blue events at the Mayo Clinic Hospital. The application layout and functionality is explained with the help of screenshots later in this the design section following the related work section that describes other efforts in this area. Next, the paper elaborates the development procedures, followed by an explanation of how these methods are reproducible for other paper to electronic conversions. Usability testing of the interface along with the clickstream analysis is included next section. Finally, the results of the evaluation of the application with respect to user interface are presented, followed by the discussion of results.

The paper concludes that the developed application is preferable to the current paper-based form being used at Mayo Clinic and it is likely be used at Mayo Clinic in the near future.

2. RELATED WORK AND BACKGROUND
There has been considerable work done in building mobile applications that provide better form and function than paper based documentation procedures. In [2], it was found that nurses lacked quality and precision while recording critical events during fast paced code-blue resuscitations. A code blue is an emergency code that indicates a patient facing cardiac arrest. Figure 1 shows the correlation between time delay and chances of survival from cardiac arrest [3]. A study [4] conducted by the Pritzker School of Medicine found that tablet applications were easier to use than paper document. In that study the average ease of use for tablet applications was greater than 20% over paper based procedures. Another study [5] by the North Shore University Health Research Center, found that it was easier to predict the occurrence of code-blue events when there was proper documentation through electronic medical records (EMR). A tablet application would be

able to naturally integrate into an EMR system as compared to a paper based procedure.

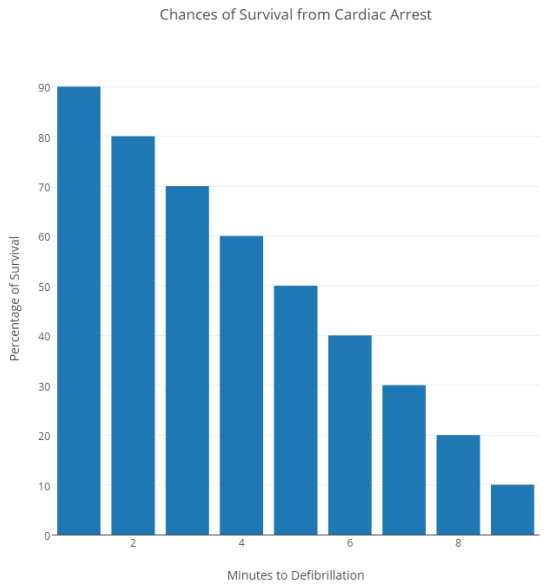

Figure 1. Chances of survival decreases with delay

There are two main applications that are commercially available in the market for resuscitation. Both these applications have several short comings and our approach aims to provide solutions to these.

1. Full Code Pro: The application has a limited set of tasks, there is no place to document prior events, has difficulty to switch between screens, does not cover non code-blue events and has multiple clocks that can make recording confusing

2. Resuscitate! CPR AED & Choking: The application doesn't have note taking ability and is more of a health care assistant rather than document recording process.

There is the option to use paper to electronic conversion tools such as Iron Mountain, Shoeboxed or Form Wizard, however these tools do not easily integrate with EMR and there are several disadvantages in terms of privacy, visibility, cost and compatibility. There is a need to have a proper digital documentation application for resuscitation and this forms the motivation behind this research.

The application has been designed taking into account the Nielson Usability Heuristic Metrics. These metrics are general principles for interaction design [6]. A detailed heuristic evaluation is presented in [7], and the Nielsen's Metrics have been elaborated for better understanding of the design. Moreover, screenshots that illustrate the design and screen flow of the application are also included in this section. The aim of the application is to enable resuscitation processes to be documented in a timely and accurate way. Furthermore, we show how the design can be represented as an effective choice from the Human Computer Interaction (HCI) perspective. This approach is selected with the aim of creating a responsive design that will allow nurses to accurately record data in a timely manner for a code blue emergency procedure. The tablet application is designed with the aim of reducing clinicians' cognitive load, the amount of mental effort required to process presented information, by automating common tasks that have to be frequently accessed in a paper based documentation system.

3. METHODS

3.1 Design

The goal of the application is to replace the paper based form that is being currently used at The Mayo Clinic to document code blue events. A part of the actual paper based form is shown in Figure 2.

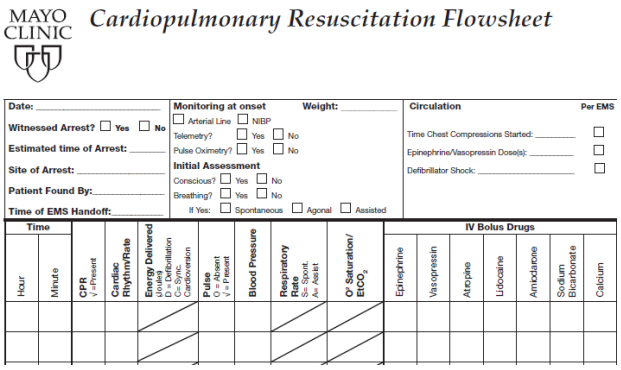

Figure 2. Mayo Clinic paper resuscitation document

As seen above, there is very little white space and overcrowding of documentation, as all information has to be recorded on a single sheet. Resuscitation central [8] identified four main problems with using this document: incomplete recording of data, illegibile recording of data, absent of team member names, use of different clocks to enter times.

The application was designed using an iterative heuristic evalutation process. The application was initially developed with minimal input, heuristic evaluation was conducted with three doctoral students in HCI, the changes were implemented and the process was reported until it was deemed suitable for use by the nurses. The three students uses all ten Neilson's metrics and assesed the application by providing the appropriate indicators. The feedback was compiled into a set of software requirements at each iterative cycle and the programming team performed the necessary changes. The major design considerations with respect to the ten usability metrics are illustrated below:

1. Visibility of system status: All tabs that are used for documentation are always visible to the user and the current tab is highlighted.

2. Match between system and real world: To give familiarity to the application and improve acceptability with the target users (nurses in cardiac arrests) the application UI and graphic style was indicative of use in the cardiac emergency department.

3. User control and freedom: The application was designed to keep data persistent and allowed users to switch between tabs without loss of data.

4. Consistency and standards: The entire application has a standard look and feel and all tabs have same design templates with same contrast, font and color schemes.

5. Error prevention and recovery: The application allowed only one input item to be active at any given point of time. Dependencies between single choice answers was programmed into the application, thereby reducing time and input error.

6. Minimizing memory load: All possible selections are provided as a dropdown list and users do not need to recall the right choice, rather recognize it from the list.
7. Flexibility and efficiency: The application didn't address this metric and several ideas such as adding a search option for specific information or tabs and a cheat menu for all actions possible on a tab are being proposed for future work.
8. Aesthetic and minimalist design: The application tries to keep only the necessary information on the tabs and the information is provided in a simplistic white backroad that stays true to the paper based look.
9. Help option: Help is available at any time during the application by clicking a button and an email is sent to the developer with the current state of the application and the tab of origin.
10. Documentation: Complete user manuals and interaction flows were created for the target users.

Figure 3 shows an example screen highlighting the team members tab of this application.

Figure 3. Tablet application showing the highlighted team members tab.

3.2 Overcoming paper based shortcomings

The major challenges in paper based procedures as listed in [8] were overcome by the design of the tablet application in the following manner:

1. Overload of information: Multiple tabs provide an elegant way to divide the information and remove clutter.
2. Illegible handwritten data: Data is typed or selected and is always legible.
3. Incomplete data: Application checks if all input boxes have been completed and alerts the user.
4. Names of team members: Using a drop down list it is easy to select the team members for the event.
5. Multiple clocks: Since the clocks are all synchronized between the tablets, the issue of multiple times and inconsistency is automatically prevented.
6. Slow pace: Since majority of information is via drop down selection the nurses are able to keep pace with the resuscitation.
7. Inaccurate: Accuracy is improved by have all the above factors/impediments corrected via the tablet application.

3.3 Usability testing

Two rounds of usability testing was performed with a dyad of nurse and physician at the Mayo clinic. Real life resuscitation was followed for a simulated (dummy) patient to test the documentation process. The physician gave the nurse specific resuscitation orders as they would give during an actual event. The nurse performed the documentation using a tablet instead of the paper form. Audio recordings of the process were analyzed by creating transcripts. Major changes during usability testing were performed to look and feel of the application and are listed below:

1. The background color was changed from blue to white as it was less pleasing
2. The stopwatch icon that showed the time lapsed was made larger and bolder.
3. Comments were made available as a drop down list, instead of being typed as the most comments that users made ended up being part of a similar set of entries.

After these above changes were incorporated, twenty nurses were asked to use the application under simulated situations. Nurses with vary level of competency and experience were recruited for the testing. A survey was given to the nurses at the end of the test to record their experience with the tablet application. The survey followed guidelines from the software usability scale [9] and adapted to the use in cardiac emergency with additional guidelines provided by the Mayo clinic physician. The survey consisted of ten questions that followed a Likert scale that varied between strongly agree (SA), agree (A), neutral (N), disagree (D) and strongly disagree (SD). Table 1 below shows the results of the survey.

Table 1. Results from the survey conducted with 20 nurses using the tablet application.

ID	Question	SA	A	N	D	SD
1	The materials presented in iPad form was intuitive	5 (25 %)	15 (75 %)	0 (0 %)	0 (0 %)	0 (0 %)
2	I understand the messages and prompts displayed by the tool	7 (35 %)	13 (65 %)	0 (0 %)	0 (0 %)	0 (0 %)
3	It's easy to move back and forth between screens	3 (15 %)	14 (70 %)	2 (10 %)	1 (5 %)	0 (0 %)

4	Tasks took longer to execute using iPad than expected	1 (5 %)	2 (10 %)	7 (35 %)	9 (45 %)	1 (5 %)
5	The tool crashed or throws up error messages when attempting to use it	0 (0 %)	0 (0 %)	0 (0 %)	7 (35 %)	13 (65 %)
6	Compared to paper, the iPad was easier to navigate	5 (25 %)	6 (30 %)	8 (40 %)	1 (5 %)	0 (0 %)
7	Compared to paper, critical events were easier to document using iPad	2 (10 %)	11 (55 %)	6 (30 %)	1 (5 %)	0 (0 %)
8	It was easy to look at the timestamps of different interventions post hoc/post data entry	7 (35 %)	10 (50 %)	3 (15 %)	0 (0 %)	0 (0 %)
9	There are too many data points on one screen	1 (5 %)	7 (35 %)	2 (10 %)	9 (45 %)	1 (5 %)
10	Overall, I prefer using this tool compared to paper based documentation	7 (35 %)	8 (40 %)	3 (15 %)	2 (10 %)	0 (0 %)

4. DISCUSSION

The results from the survey also shows the percentage of users who selected a given option. The total number of users was twenty and 5 percent implies one tester. All the testers were nurses who are the end users of the application when released.

For the first two questions in the survey, all the testers agreed that the materials presented in the tablet were intuitive and the messages and prompts displayed by the tool were understandable. Only 1 out of 20 nurses disagreed in the third question as she felt that it is not easy to move between screens. Interestingly, she was the only who had never used a tablet before which might have led to her judgement. 3 (15 Percent) of the testers felt that tasks took longer to execute using tablet than expected. When probed further, these subjects had very high expectations, which are not realistic for an application that has to store data dynamically. They were expecting all features on one screen, which is not possible for this application as there considerable content and limited screen size. Question 5 from the survey had a 100% positive response as no user reported the tool crashing.

For questions 6 and 7, nineteen out of twenty users felt that the tablet was easier to navigate and also to document critical events compared to the paper-based version. This overwhelmingly positive response from the testers augurs well for the future of the application, as these two features are critical part of the resuscitation process. The one person who disagreed to these questions was the same tester who had never used a tablet before. This brings out an interesting development that some basic tablet or smartphone experience is needed to make best use of the application. Alternatively, some form of training on using the application and tablet can be provided for users with no prior experience.

However, not even a single user disagreed for question 8 which stated, “It was easy to look at the timestamps of different interventions post hoc/post data entry”. This is also an essential part of the application. Users do not have to manage different clocks, as the clock built into the application is handling everything. Question 9 was a point of concern as 8 (40 Percent) of the testers felt that there are too many data points on one screen. This screen was identified as the hemodynamics tab and a cheat menu was proposed which will further divide that screen into sub sections. This has been included in future work as it is not a critical issue for the current iteration.

The final question asked whether the users preferred the tablet application over paper-based for the documentation. 15 (75 Percent) of the users agreed whereas 3 (15 Percent) remained neutral. Two users disagreed, as they still preferred the paper-based documentation. These results show that an overwhelming majority of the participating nurses preferred the electronic version. To make this result more meaningful, it should be noted that the testers have been using the paper-based version for years whereas it was the first time they were using the developed application. Despite this, a good majority preferred the tablet application, showing a great future for the application.

To provide quantitative depth to the results as well as providing additional measures from a usability standpoint, clickstream analysis was performed. Clickstream analysis [10] is the process of collecting, analyzing, and reporting aggregate data about which pages users visit in what order - which are the result of the succession of mouse clicks each user makes.

As part of their usability testing, the actions that the twenty nurses performed on the tablet were logged into the database. Once the nurses completed their survey, the logs were sent to a database. The logs contain every click that the nurses performed with time stamps. Using this data, the screen flow of the application can be emulated, which provides the ordering of clicks that the users performed. This data mainly provides a representation of the user’s navigation through the application, and also demonstrates their path before they abandoned a particular task. Furthermore,

after careful consultation with the emergency care physician at Mayo Clinic, the team identified certain tasks as 'critical' for the success of the application. These particular 'critical' tasks have been listed in table 4 below. The completion rate, also given in the table, shows the percentage of nurses who were able to complete the task successfully. Using this data, the team came up with the following click-stream analysis presented in Table 2 below.

Table 2. Clickstream Analysis

Task	**Completion Rate (%)**
Logging Patient Information	100%
CPR Start and Pause clock automatically	95%
Logging Respiratory Rates and Airway Types	95%
Logging Medication Dosages	100%
Logging Pre and Post Resuscitation Events	100%
Entering Comments	90%
Submitting Report and Activity Log	70%

The results show a high percentage of completion rate, which indicates that most of the users were able to complete the task assigned to them. Moreover, a 100% completion rate also implies that all twenty nurses were able to complete the task without navigating to the wrong screen, or clicking the wrong buttons. Additionally, the only task that has a completion rate of less than 90% is the submission of final report and the activity log. The reason for the lower completion rate for this task is that users usually navigate to the earlier tabs before they submit the report. The users want to be sure that all the required information has been filled out. Therefore, they navigate away from the 'submit' screen, which in turn leads to a lower completion rate.

Overall, the clickstream analysis provides quantitative depth to the earlier usability testing by depicting that most of the critical tasks were completed by majority of users with a high success rate.

5. CONCLUSION AND FUTURE WORK

This tablet application was developed specifically for use at Mayo Clinic. However, this application can be used in hospitals across the world to document the resuscitation process. Another benefit of this application is that it covers processes that are not code-blue as well, which gives it greater generalizability for large-scale use. Moreover, at present, there is no generalizable code-blue application that is in large-scale use.

The methods described in this paper can be used to develop more electronic applications from paper-based documentations. Furthermore, this process could have potentially massive implications for the future as there are numerous paper-based documentations existing in the medical field at present and converting these documents into electric form could prove to be vastly beneficial for the users. The methods discovered in this paper can potentially be used for most of these conversions. In addition to that, these overall methods can be applied to the non-medical world as well. Basically, any paper-based form that needs to be converted to an electronic form can benefit from this research.

This paper addresses the problems with data capture, as it exists during code blue events during emergency care. The team developed a tablet application primarily designed for iPads that improves transcription of resuscitation variables for patients who undergo a code blue event. This application aims to replace the conventional, paper-based resuscitation transcripts that nurses currently use to an electronic form. It was observed that a high quality electronic application was noted to be preferable to a paper-based version. Usability testing of the electronic resuscitation documentation application done at Mayo Clinic corroborated that physicians and nurses strongly prefer the electronic version of code blue resuscitation sheet.

The iPad application developed as part of this research meets the basic standards required as it was tested based on the usability principles covered in a heuristic evaluation. Moreover, a number of healthcare providers at the Mayo Clinic indicated a strong desire to use this application, and support the future work that would involve synchronizing the application based-data with Mayo Clinic's patient database (electronic medical record) as well as adding more functionality to the application.

6. ACKNOWLEDGMENTS

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