REFORM: REFACTORIZED ELECTRONIC WEB FORMS - LARGE SCALE SURVEY DATA CAPTURE AND WORKFLOW CONTROL FRAMEWORK

by

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REForm: Refactorized Electronic Web Forms - Large Scale Survey Data Capture And Workflow Control Framework

Abstract

by

NINGZHOU ZENG

High-quality data capture plays a key role in interventional studies. However, capturing high-quality survey data is an arduous process for large-scale and longitudinal interventional studies. There are some challenges from the aspect of survey takers and the survey givers. From the perspective of survey takers, it is difficult to navigate back and forth in an efficient way as longitudinal studies usually consist of surveys that will be 10 pages or longer. In the other hand, it is critical for survey giver to keep track of progress for each survey participants during a longitudinal interventional study. Unlike the one-time survey, interventional studies consist of particular workflow and are highly related to the progress of participants in such studies. Flexible workflow design and reliable participants’ progress tracking functionality are required. The main contribution of this thesis is an interface-driven system called REForm: Refactorized Electronic Web Forms. REForm provides researchers the capability to design and manage surveys and to organize them in a customizable workflow. REForm also provides a powerful participants management
system for adding, deleting or emailing participants in batches. In order to support large-scale interventional studies, a team managing system is also implemented, which enables researchers to assign privileges to other system users as team members to help with management of studies. Furthermore, a flexible and efficient navigation system is designed to enhance survey takers’ user experience. An NCI-funded interventional study called IMPACT has been designed, pilot-tested and deployed utilizing REForm. REForm provides IMPACT the capability to build a baseline survey with 95 questions and 662 options, a post-intervention survey with 82 questions and 574 options, six Ecological Momentary Assessment (EMA) surveys while each one consists of four questions with 26 options, and a follow-up survey containing 15 questions along with 125 options. To evaluate our system, we also embed feedback questions as a part of the post-intervention survey. More than 94 percent of IMPACT participants highly endorse the design and usability of REForm.
Chapter 1

Introduction

1.1 Motivation

Capturing high-quality data is critical in interventional studies. To perform comparative analysis, researchers usually author online surveys to collect information about participants before and after interventions. In nowadays scientific studies, online surveys emerged from the 1980s [1] as a research tool has been widely used shown by studies [2–5]. As an important research method, there are many products such as Google Form [6], Survey Monkey [7], Qualtrics [8], and Research Electronic Data Capture (REDCap) [9] available for researchers to author online surveys.

Even with rich products available for building online surveys, researchers still need to use online surveys as separate toolkit [10–12] from intervention materials. The situation of such separation often leads to unnecessary data integration and cumbersome management work like redundant study participants information storage, manual randomization of study subjects, and mapping between survey takers and intervention takers. Such problem will become more noticeable when interventions assignment are based on answers to specific
questions for personalized interventional studies. Besides, another shortcoming of the system aforementioned is the lack of the workflow control. In current settings, surveys are independent from each other even they are highly related logically, which is opposite with the integrity of the interventional studies. Situation could be worse when it comes to large-scale of interventional studies. A typical large-scale of interventional studies can have more than ten surveys with hundreds of questions, thousands of study participants and lasting for years, which will cost large amount of human effort to integrate and manage data in such studies. A workflow control can help researchers keeping track of each study participants status and assign corresponding intervention materials. From the perspective of studies participants, efficient navigation in a large-scale surveys is important if they want to find and modify previous answered questions. In addition, real-time data storage, and intuitive progress indicator are also important as insufficient support for these features compromises user experience and discourages them from continuing the future steps in the study.

To address the limitations and challenges in current survey systems, we introduce Refactorized Electronic Web Forms (REForm) in this thesis, a web-based application for data capture of large-scale interventional studies with online surveys builder, workflow control, participants management, and research team management. We test our system on IMPACT, an online educational program aimed to improve oncology nurse engagement in patient attitude towards clinical trials. Utilzing REForm, IMPACT build, deliver surveys to participants, perform automatic randomization and assign tailored interventions. 390 oncology nurses have enrolled and participated in the IMPACT program after the launching
of IMPACT since July 30 2016, which produces 510 answered surveys accompanied with positive feedback on REForm.

1.2 Features of REForm

In this thesis, we introduce an interface-driven web-based application called Refactorized Electronic Web Forms (REForm) with the following unique features:

1. Interface-driven — REForm is an online interventional platform, which interacts with end users through interface. We use interface-driven development to guarantee a nice and user-friendly interface;

2. Survey builder — We build a survey builder widget with rich functions for Researchers to design surveys with abundant question types and customize surveys layouts.

3. Workflow Control — We build a visualized and interactively workflow control widget, which provide a powerful widget for Researchers to integrate each separate survey into a complete interventional study workflow.

4. Role based Access Control — Different roles of end users including system administrator, project manager, survey builder, and team members are defined in REForm. All these roles cooperatively access and finish their assigned tasks.

5. Web-based — REForm is a web-based system such that it can be accessed easily from different locations and platforms.
1.3 Organization of This Thesis

REForm aims to address the challenges of designing and managing surveys and organizing them in a customizable workflow for large-scale longitudinal interventional studies. Using interface-driven method, it proposes a survey builder and workflow control system. Matching study participants to tailored interventional materials based on their answers and keeping track of these participants specific progress in the study. REForm has been piloted with IMPACT since July 2016 and the results demonstrate it is functional, user friendly, and improve the probability that patient participates into clinical trials. This thesis presents the design, implementation, and pilot deployment results of Refactorized Electronic Web Forms (REForm). The rest of the thesis are organized as follows:

1. Chapter 2 reviews the background knowledge about IMPACT and the challenges to control the whole study. It also introduces some resources we rely on to build REForm;

2. Chapter 3 focuses on the design of core concepts of REForm models;

3. In Chapter 4 we go over the system design about REForm;

4. Chapter 5 gives the implementation details for the designs in Chapter 3 and 4;

5. Chapter 6 evaluates the results of a pilot testing IMPACT with REForm;

6. Chapter 7 we conclude the work of this thesis, compare it with other existing online survey system, and discuss the future work we can do to improve REForm.
Chapter 2

Background

To better understand the work of this thesis, in this chapter, we describe the background knowledge of clinical trials and nurse engagement roles in clinical trials target recruitment. We also review the information of two resources that we rely on to develop REForm system: IMPACT from National Cancer Institute (NCI), and Refactorized Electronic Web Forms (REForm) system. IMPACT originally aims to improve the oncology nurse engagement in patience decision making about clinical trials. In later chapters, we will talk about one core concept of REForm called interventional studies, which defines the schema of an eligibility criterion of a clinical trial. We use IMPACT as one sample project to implement one instance of REForm; REForm is the prototype interface we adapt from IMPACT. It originally proposes the idea to integrate surveys with interventions.

2.1 Nurse Impact

IMPACT is an NCI-funded online educational program about clinical trials developed by Case Western Reserve University in consultation with the Oncology Nursing Society (ONS). Clinical trials are important and necessary to develop new cancer prevention and
treatment strategies. Participating rate of patients in clinical research studies remains low despite the encouragement from government and organizations. Less than 10% of cancer patients take part in a clinical trial [13–15]. Oncology nurses share a therapeutic relationship with their patients and are estimated to have twice as much contact with patients as their physician [16, 17]. Given the close involvement of oncology nurses in supporting patient decision making about care and treatment [18], and potential barriers to discussing clinical trials with patients [28], IMPACT is proposed to be developed, implemented, and evaluated as a theory-driven, interactive, web-based, tailored educational program to improve oncology nurse engagement in patient decision making about clinical trials.

2.1.1 Interventional Studies

IMAPCT is an interventional study. Intervention study, also called experimental study design, are those where researchers intervenes at certain point during the study and are often conducted in laboratories and clinical studies [19]. In current day, the most common and effective interventional study design is a randomized controlled trial. Besides, there are also some other interventional studies such as pre-post study design, non-randomized controlled trials, and quasi-experiments [20–22].

As we mentioned above, randomized controlled trials are the most common and widely used interventional study and there are many modifications [23–25]. A randomized controlled trials usually separated a group of homogeneous study participants into two groups randomly. If the randomization is successful and effective, these two groups should be
the same in all aspects. Then the intervention would be applied to one of the group. The remaining group will be treated as control group. The only difference between these two groups is the intervention.

### 2.1.2 Workflow of Nurse Impact

![Workflow of Nurse Impact](image)

**Figure 2.1 Workflow of Nurse Impact**

IMPACT is the primary use case of REForm, which is a large-scale interventional study with the goal to recruit thousands of participants who will following procedure (illustrated in Figure 1) including nine surveys. First of all, all participants need to register in REForm system and answer the screening questions. Participants who pass the screening will proceed to take the baseline survey. Based on answers that they provided in screening questions and some question in baseline survey, these participants are randomized into two groups: experimental group and control group. This is the randomization step in interventional studies. IMPACT utilized stratified randomization, a randomization scheme where
strata are constructed based on user characteristics and randomization is performed separately within each stratum. By utilizing stratified randomization, we can ensure the balance of group assignment on the various combination of the characteristics. There are two types of educational interventions in IMPACT: one is video and the other one is reading materials. Besides, participants in experimental group are assigned to specific videos based on their answers to the baseline survey and the total length of all videos for each participant is about thirty minutes. Each participant takes post-intervention survey. After they complete the post-intervention survey, six optional Ecological momentary assessment (EMA) surveys are provided to participants who are willing to take. Finally, a follow-up survey will be delivered to each participant three months after the completion of post-intervention survey. The entire procedure is a complex workflow. Therefore a flexible workflow design and control system is critical for REForm.
Chapter 3

Modeling of REFORM

In this chapter, we propose the modeling of core concepts in REForm: interventional studies, survey ontology, workflow, intervention library, participant management and responses of participants. Despite the various forms of survey available in current days, the major components of a survey remains the same. Therefore, it is a big challenge to support the variability and flexibility of survey authoring while maintaining a fixed core components at the same time. We propose the survey ontology to achieve our goal. A formal representation of survey ontology in REForm consists of 3 critical components: hierarchy of survey concepts, survey building widget and survey data modeling. In REForm, we build survey ontology for building surveys reusing terms from existing terminological system; construct surveys using interactive web-based user interface and store them in database; and model survey data in JSON format. Hence, we can save and retrieve survey data to automate the authoring process of various surveys.
3.1 Modeling of Interventional Studies

A complete interventional study consists of workflow design, survey authoring, interventional process, participants recruiting, and responses of participants. To integrate all these components, we model each study in REForm as a project.

![Model of Interventional Studies in REForm](image)

**Figure 3.1 Model of Interventional Studies in REForm**

Figure 3.1 demonstrates the complete model of a project in REForm. As shown in the figure, one project will have a workflow, a set of surveys, interventional materials, and participants. Some major attributes of a project are listed down below:

1. **Project Name** — the name of this project.

2. **Description** — complete description of the project.
3. Requirement — is used to show to participants in the process of recruiting.

4. Reward — the reward for participating and completing the studies.

### 3.2 Survey Ontology

To formally capture the common fields of survey and allow our survey building system to reuse existing terminology system, we build an Survey Ontology (SO) for survey authoring.

#### 3.2.1 Attributes of Survey

1. Name — Full name of the survey, e.g. Baseline survey

2. Description — Description of the survey, e.g. Please provide the following information about yourself is the description for baseline survey.

3. Status — Two status to categorize all surveys: active and inactive. When the survey status is active, it will be available for participants. Otherwise, the survey will not be accessed by participants.

4. Page — Page is the container to manage questions and options.

5. Question — Specify question content for survey. In REForm, we categorize questions into three groups: closed, semi-closed and open question. For closed question, all the answers available for such question are fixed; Semi-closed question, such question usually provide fixed options along with a free text option for survey takers.
to fill in their own answers; Open question, such question does not provide any fixed answers and all answers are from participants’ own input. Besides, we built in the following question types in terms of question selections:

(a) Single choice — For each question, selection is exclusive. Only one option can be selected.

(b) Multiple choice — For each question, multiple selections are allowed.

(c) Text Single — A single text input for participants to fill in.

(d) Text Multiple — Multiple text input for participants to fill in.

(e) Group Single — In such question, options are grouped into multiple groups. In each of the group, only one option can be selected.

(f) Group Multiple — In each group of options, multiple selections are allowed.

(g) Matrix — A special question type with multiple questions aligning row by row and same options aligning column by column for each question.

6. Option — Specify options content associated with each question.
Figure 3.2 Combined sample of multiple types question

Figure 3.2 demonstrates an example of combined multiple question types. The figure shows the typical questions of various types in the order mentioned above. Question 7 is an example of question with matrix type.

### 3.2.2 Modeling of Survey in REForm

The model of survey in REForm basically follows the attributes mentioned above. But in actual implementation, the survey model data are stored as key-value in the database. Furthermore, a survey may also have predefined correct answers which are used to assign participants to corresponding interventional materials.
3.3 Modeling of Workflow

Workflow design is critical in REForm. To support customize workflow design system, we model the workflow in a sequential way such that study participants will follow the order defined by the survey author.

![Diagram of Workflow in REForm](image)

Figure 3.3 Model of Workflow in REForm

Figure 3.3 demonstrates our model for workflow. As we can see, workflow consists of steps, each step can have “pre-message” and “post-message” which will be showed to participants before and after current step. Besides, survey author can add reminders to each step. The reminder will be triggered in conditions specified by the survey author.

3.4 Modeling of Interventions

The model for interventions is straightforward. Each study has one unique library to contain all interventional materials. These materials will be categorized into different types
with a unique category name. Under each category, each entry consists of its filename and path in the system for future retrieval.

Figure 3.4 Model of intervention in REForm

Figure 3.4 demonstrates an example of interventional materials. There two categories of interventional materials which are video and text. Each category has multiple entries with their detail information.

3.5 Modeling of Participants

Figure 3.5 down below illustrates the model of a single participant.

1. Status — is used to indicate the status of participants.
(a) Pending — This participant has not accept the invitation to participate current study.

(b) Active — This participant has not finished current study.

(c) Completed — This participant has completed current study.

2. username — username of this participant in REForm system.

3. email — email information of this participant.

### 3.6 Modeling of Responses of Participants

The modeling of responses are also straightforward. We need to keep track of which survey is answered and the corresponding participant. Additional information such as page number, question number, and responses to current question will also be stored.

### 3.7 Matching participants with Interventional Materials

With the modeling survey data and responses of participants, the matching process is straightforward. As demonstrated in Figure 3.6, Matching between participants and interventional materials is transformed to be matching between responses of participants and survey correct answers.
Figure 3.6 Match patient data to a clinical trial

A participant will be assigned to interventional materials according to their answers to the study surveys.
Chapter 4

System Design

In this chapter, we review the architecture from system perspective of REForm, participants randomization, interventional materials assignment, and large-scale survey support.

4.1 System Architecture

Figure 4.1 illustrates the architecture of REForm system.
4.2 Role-based access control (RBAC)

Role-based access control (RBAC) is non-discretionary approach to restrict system access to authorized users and is more central than Discretionary Access Control (DAC) to non-military systems’ needs for secure processing. [26] [27]. Every individual member can be assigned to a role and each role can have a corresponding set of individual members. Therefore the relationships between individuals and privileges are many-to-many [26].
which means users could have many roles and roles could assign to many users. In RE-Form, we deploys RBAC in team manager, which will be mentioned in later chapter.

4.3 Randomization

Using stratified randomization, our randomization algorithm can categorize participants into different groups based on customize settings. To make the randomization work, researchers need to provide two parameters: randomization questions and group assignment radio. By setting up the randomization questions, our algorithm can combine the characteristics of participants while the group assignment radio can be used to precompute the group assignment table. The group assignment table consists of the group name: intervention or control and user id of the assigned participants. Algorithm 1 pre-computes the group assignment tables. Each table has the same name as the stratum. We demonstrate an example of utilize Race and Gender as characteristics to build stratum and ratio of participants in interventional group and control group is one. We have: Male (M), Female (F) for Gender and White (W), Non-White (N) for Race. Therefore, we will have four strata: MW (Male and White), MN (Male and Non-White), FW (Female and White), FN (Female and Non-White). By input these four strata and the expected max participants in each stratum, we then obtain four group assignment tables. Once the group assignment tables are created, group assignment should be simple: we can find the stratum for new participant and append the new participant to that group assignment table.
Input : Strata S: [MW, MN, FW, FN], Maximum number of participants Max;
Output: Group Assignment Tables;

for s ∈ S do

Create group assignment table t;

while count < Max do

    a = [1, 2].random;
    insert a rows into t with group name as intervention and participant id as empty;
    insert a rows into t with group name as control and participant id as empty;
    t = t + a * 2;
end
end

Algorithm 1: Precompute Group Assignment Tables for Stratified Randomization

4.4 Personalized Interventions Assignment

Personalized interventions or tailored interventions are selected from the entire intervention library based on the information of participants acquired from the baseline survey. To generate the corresponding tailored interventions for each participant in the intervention group, we use the intervention assignment algorithm.

Let us assume a intervention library \( L \), which consists of a set of videos. Each single item in the library is denoted as \( i \). The mapping relation between questions answers and
intervention items is denoted as $R$. In the following video assigning algorithm, we take the answers of one participant and the mapping relationship as input and output a subset of interventions assigned to the participant.

```
1 Input: Baseline Survey Answers $A$, Intervention Library $L$, and Mapping Relationship between $A$ and $L$;
2 Output: A set of interventions $S$;
3 Create an empty set $S$;
4 for $a \in A$ do
5    Find related mapping rules $r$ from $R$;
6      for $r' \in r$ do
7          $a = [1, 2].random$;
8          $i = r'.getIntervention()$ addi into $S$
9      end
10 end
```

**Algorithm 2:** Intervention Assigning Algorithm

4.5 Large-scale Survey Support

To better support large-scale or long survey, REForm provides three critical features: real-time data storage, page-wise indicator, and swift page navigation. For large-scale or long survey, it requires more time for participants to complete. Therefore, real-time data storage can prevent data losing from unexpected events such as power outage, crash of web browser for a long period of time. Besides, participants are likely to encounter unsure
questions that they would like to skip and come back later in a large-scale survey. In such situation, the survey system should be capable to indicates the skip pages and allow participants go back to specific pages instantly, e.g., with one mouse click. We describe how REForm addresses these challenges.

1. Real-time Data Storage. REForm utilize AJAX (Asynchronous JavaScript And XML) technique to save survey answers in real time without reloading the webpage. User interactive actions like mouse click or keyboard stroke will be detected and corresponding requests will be sent to server. After processing requests, the server will send back two responses: one is to update the progress bar status if needed, and the other is to show hidden questions if their displaying conditions are satisfied.

2. Page-wise Progress Indicator. Figure 4.2 desmonstrate the progress bar used in REForm survey system. Each page in the survey is represented by a circle. There are three possible colors for each circle: white, yellow, and green. With a white color, none of the questions is answered on the page represented by this circle. Yellow means questions on the page are partially answered. Green represents that all questions in the page are answered. This progress bar is also real-time updated as we implements the real-time data storage in REForm.

![Figure 4.2 Progressbar with three colors](image-url)
3. Fast Page Navigation. The progress bar not only serves as a progress indicator, but also as a fast navigator. Each circle in the bar is a hyperlink that links to the related page. In such way, a participant will be able to navigate to specific page quickly instead of using the next or previous button to navigate one page after another.
Chapter 5

Implementation results of REForm

In this Chapter, we focus on the details of REForm implementation, including the development environment we use, building of workflow, interactive survey builder, participants recruiting and matching algorithm between patients and interventional materials.

5.1 Development Environment

Table 5.1 illustrates the system environment chosen to develop REForm.
Table 5.1 REForm Development Environment

<table>
<thead>
<tr>
<th>Name</th>
<th>Requirement</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ruby</td>
<td>2.2.0</td>
</tr>
<tr>
<td>Rails</td>
<td>4.2.0</td>
</tr>
<tr>
<td>MongoDB</td>
<td>3.4.4</td>
</tr>
<tr>
<td>D3.js</td>
<td>4.8.0</td>
</tr>
<tr>
<td>React</td>
<td>15.5.4</td>
</tr>
<tr>
<td>Bootstrap</td>
<td>3.3.7</td>
</tr>
</tbody>
</table>

5.1.1 Ruby on Rails

Ruby on Rails is an outstanding open-source web framework with the goal to allow developer to develop web application efficiently and sustainable productive. It provides everything that is needed for REForm to build database-backed web application following the MVC (Model-View-Controller) pattern.

5.1.2 MongoDB

MongoDB is a free, open source and cross-platform NoSQL database. It is a mature document-oriented NoSQL database with well-written documentation and large-scale commercial use. MongoDB also has a broad support for different programming langauges with rich drivers.
5.1.3 D3.js - Data-Driven Documents

D3.js - Data-Driven Documents [29] is a powerful Javascript library for building interactive and dynamic data visualizations using web browser. D3 utilize the widely used web technology like HTML, CSS and SVG to render data.

5.1.4 ReactJS

React [30] is an open-source Javascript library for building interactive user interface. React allows web developer to build large-scale web application with frequently data changing over time. In the MVC template, it corresponds to View. Two major features of React are:

1. **One-way data flow.** React constructs interface using the concept of component. Properties are a set of immutable values passed to children component’s renderer in its HTML tag. The children components can not modify the properties passed to them directly. But they can use callback functions to modify the values in parent component. The principal idea is that properties flow down and actions flow up.

2. **Virtual DOM.** React creates an in-memory data structure cache, computes the difference, and then updates the rendering efficiently as React libraries only re-render subcomponents that actually change.
Besides, the data format for properties in React is JSON, which is the same with MongoDB. Therefore, we are able to match the front-end and back-end perfectly, which is extremely convenient for developers.

### 5.1.5 Bootstrap

Bootstrap is a powerful integrated front-end framework for web user interface development. It provides us with nice and clean user interface styles and interactive Javascript widget which can greatly save the time of web developer.

### 5.2 Intervention Study

Researchers are required to create user accounts using the signup interface (Figure 5.1) before proceeding to build intervention studies.
After they create their own user accounts, they will be able to create a new project. Figure 5.2 shows the dashboard for a sample project. There are five major widgets in REForm dashboard: Survey Builder, Workflow Design, Intervention, Team Manager, and Participant Manager. These widgets provide a strong support for building and managing intervention studies.

Figure 5.1  Signup Interface of REForm
5.3 Survey Builder

Survey builder in REForm is a powerful and flexible survey building system. It is the core component in REForm. In the following subsections, we will explore more details of our survey builder widget.

5.3.1 Survey Meta Data

To create a new survey, researchers need to click on the new survey button shown in Figure 5.2. Then a pop-up window will show up for researchers to fill in meta information for a survey. See Figure 5.3. Here, they are required to fill in the basic information about the survey: survey title, description, and status. If the status of a survey is set to inactive, then it will not be accessible to participants. Once the meta information is saved, the new created survey will be shown in the survey builder widget in dashboard and researchers can click the action button to proceed to survey authoring.
5.3.2 Survey Authoring

The survey authoring interface is shown in Figure 5.4. The top banner of the web page will show current survey title and users can navigate back to dashboard. Down below the banner, there are three sections:

1. Data & Analysis — to show the survey responses statistics

2. Search — provide search function for users to search specific question

3. Preview Survey — for users to preview their surveys
In REForm, a survey consists of multiple pages and each page can have multiple questions. To add a new question in one page, users only need to click the add question button and the question builder will show up.

Figure 5.4 Survey Authoring Interface

Figure 5.5 is the interface of question builder where users can specify question types, fill in question content and add options. There are totally eight pre-build question types: single choice, multiple choice, plain text, text single, text multiple, group single, group multiple, and matrix. Users can select question type in the left corner of the widget. They can fill in the question and add new option using add option button or add other button. Besides, there is also a side widget along with our question builder which can provide advanced functions while building survey.
Figure 5.5  Add a new question in Survey Builder

1. Sections — Group different surveys into sections by setting the same section name; but be default, it will be blank

2. Variable Name — Set a customize variable name for current question so that this question can be referred by the variable name. It is useful in data importing.

3. Answer Score — To set answer scores if this question is correctly answered.

4. Set Correct Answer — Set the correct answer for current question.

5. Required — Set current question as mandatory question.

6. Position — To align the options horizontally or vertically.

7. Validation — Customize data input format

8. Actions — Additional actions for survey internal logic
(a) Add Display Logic — Display or hide specific question if certain dependencies are satisfied.

(b) Add Skip Logic — Skip certain part of the survey if conditions are satisfied.

5.3.3 Survey Preview

REForm survey builder provides survey preview function so that users can preview their survey any time even the survey is not completed. Figure 5.6 demonstrates an example of unfinished survey with only 2 questions.

![Baseline Survey](image)

Figure 5.6 Preview of the survey
5.3.4 Survey Responses Report and Visualization

To better support data analysis, REForm also provides detail statistics of responses collected from all participants and visualize these results into charts using D3. See Figure 5.7.

Figure 5.7 Responses Report and Visualization
5.4 Workflow Design

For an intervention study, workflow is critical as it determines the process of the study. REForm implements an interactive interface for survey authors to design and customize a workflow as shown in Figure 5.8. Each step will be a built survey or prepared intervention. Survey authors can deliver welcome messages or instructions to participants by input the “Pre-Message” before each step. Similarly, survey authors can also provide summary information about user’s current status or brief introduction about next step using “Post-Message”. Besides, REForm workflow system also support reminders. Survey authors can add one or multiple reminders before next step as shown in Figure 5.9.

![Design Workflow](image)

Figure 5.8 Workflow Design Interface in REForm
In this example, we show a reminder for baseline survey. We can interpret the message as follow: A reminding message (detail see screenshot) will be sent to user who does not finish the baseline survey 7 days after it is started.

Figure 5.9 Workflow Reminder in REForm

5.5 Intervention Library

To support intervention studies, REForm implements a folder based intervention management system shown in Figure 5.10. Survey authors can create a new library by clicking the Create Library button. Each library will be displayed as a folder. In Figure 5.10, there are two libraries: videos and text.
If survey authors double click the folder, the system will open the folder and show all current interventions in the folder. To add new file to current folder, survey authors can use the new button to select file from local computer and upload it to the server. All these operations can be done using our interface. Besides, survey authors can also use actions to delete files.

5.5.1 Matching between Intervention and Participants

In chapter 4, we mention the intervention assigning algorithm. One critical input for that algorithm is the mapping relationship between surveys answers and intervention library. REForm offers an interactive and web-based methodology for users to built their own unique mapping relationship.
As shown in Figure 5.11, there is a setting widget for each intervention. If the survey author clicks the setting widget, a pop-up window will show as Figure 5.12. The setting widget consists of several components:

1. Displayname — specify the name displayed to participants
2. Description — description about current intervention
3. Rank — ranking of current intervention
4. Add dependencies — set up the dependent questions for the current intervention. As illustrated in Figure 5.12, survey authors can select specific questions from built surveys to build a relation between question and current intervention. Once the question is selected (done button is clicked), a dependency widget will allow survey authors to define the responded status of the selected question. In the example shown in Figure 5.13, current intervention will be assigned to participants who do not answer the selected question.
Figure 5.12 File Setting Widget

Figure 5.13 Dependency setting for selected question
5.6 Team Manager

A large-scale intervention study often requires a group of researchers to collaborate with each other. Therefore, a sophisticated team management system is of great value. To overcome this challenge, we employ the team manager system in REForm. It is a management system that allows project owners to invite other users to help with managing or building their studies shown in Figure 5.14. If the invited users do not have REForm account, they will need to create their accounts before joining the team. To distinguish different roles in an intervention study, REForm employs the role-based access control mechanism.

Figure 5.14 Invite new team member

Figure 5.15 demonstrates an example of role-based access control implementation in REForm. There are two team members in this example. The first team member will have the privilege to build survey and workflow design, while the other one can manage team members and participants. We can see that team members are only allowed to do things within their privileges.
5.7 Participants Manager

Participants management is also important in large-scale intervention studies. To reduce the burden for survey authors, participants invitation can be done in batch mode using REForm. Demonstrated in Figure 5.16, REForm are capable to send invitation emails in batch mode as long as these email addresses are separated by semicolon. These invitation emails contain the description of the study and provide direct links for participants to sign up or login in REForm.
Chapter 6

Pilot Results of REForm

Utilizing REForm for IMPACT, we built one baseline survey with 95 questions and 662 options, a post intervention survey of 82 questions and 574 options, six EMA surveys of 4 questions and 26 options, and one follow up survey consisting of 15 questions and 125 options. Besides, we also design a workflow consisting of these steps: 1). baseline survey, 2). intervention, 3). post-intervention survey, 4). six EMA surveys, 5). follow-up survey. There are also “pre-message” and “post-message” for each step along with two consecutive reminders which will be sent at user customized time interval. Participants will receive their surveys and interventions following the workflow.

Figure 6.1 summarizes the statistics of IMPACT participants up to date since the launching of REForm in July 2016. We can see from the figure that there are total 2,159 participants registered in REForm. 1,999 of the registered participants participate in IMPACT. 1,758 of these participants pass the screening and 1,583 of them finished the baseline survey. 1,146 of participants who finished the baseline survey completed their interventions.
Furthermore, there are 1,072 participants completed their post-intervention survey. Besides, there are 198, 203, 213, 208, 202, and 211 participants completed EMA1, EMA2, EMA3, EMA4, EMA5, and EMA6 surveys respectively.

![Figure 6.1 Statistics of participants in the REForm system up to date](image)

**6.1 Evaluation**

We perform the evaluation of REForm from two prospectives: 1). usability for study designer to build surveys and design workflow 2). support for large-scale intervention studies from the view of participants.
6.1.1 Usability Evaluation

To evaluate the usability of REForm, we conduct a comparative experiment between REForm and REDCap within three data scientists. All the data scientists have not used REForm system and REDCap before.

Table 6.1 Comparative evaluation between REForm and REDCap

<table>
<thead>
<tr>
<th>Name</th>
<th>Question Type</th>
<th>Number of Questions</th>
<th>Number of Options</th>
</tr>
</thead>
<tbody>
<tr>
<td>Test 1</td>
<td>Single Choice</td>
<td>5</td>
<td>4</td>
</tr>
<tr>
<td>Test 2</td>
<td>Multiple Choice</td>
<td>5</td>
<td>4</td>
</tr>
<tr>
<td>Test 3</td>
<td>Text Field</td>
<td>5</td>
<td>1</td>
</tr>
<tr>
<td>Test 4</td>
<td>True/False</td>
<td>5</td>
<td>2</td>
</tr>
<tr>
<td>Test 5</td>
<td>Matrix</td>
<td>8</td>
<td>8</td>
</tr>
<tr>
<td>Test 6</td>
<td>All above</td>
<td>22</td>
<td>1 to 11 (in each question)</td>
</tr>
</tbody>
</table>

Table 6.1 shows all six tests in this evaluation. We measure the performance by the time requiring to complete the tests. We select five common types of questions in REForm and REDCap. For each test from 1 to 5, only a single type of question is implemented to evaluate the capability to build specific types of questions. These short tests are aimed to get the evaluators familiar with the two survey systems. For test 6, evaluators are required to construct the whole demographic section of baseline survey in IMPACT from the plain text files provided.
The detail feedback from all evaluators are illustrated in Figure 6.2. For test 1 and 4, both REForm and REDCap share the same performance. REDCap demonstrates a better performance in constructing matrix question in test 5. Despite of some advantages in building matrix question, two evaluators out of three reported a better performance using REForm than REDCap. According to the evaluators, REDCap has better support for building single type of questions as previous question’s information are inherited when adding a new question. But, in test 6 question type is not single and this kind of inheritance of question information actually produces extra work when the question type is different. Besides, evaluators also reported some features below that is unique in REForm:

1. REForm provides more flexibility, e.g. REForm provides an “other” option with a text field for participants to fill in more information.

2. REForm supports group question type while in REDCap users have to separate one group question into two questions.

3. REForm provides inline style for question building and REDCap does not.

Evaluators found that REForm provides more intuitive and lightweight interface. As a sofishticated survey tool, REDCap demonstrates its completeness from the aspect of function.
6.1.2 Support for large-scale surveys

To evaluate support for large-scale surveys, we embedded two questions in the IMPACT post-intervention survey.

(a) How satisfied are you with the information presented to you?


5. Extremely satisfied
(b) The web site is easy to navigate? 1. Not at all; 2. Very little; 3. Some what; 4. Quite a bit; 5. A great deal

We received 1,072 responses from post-intervention survey for these two questions shown in Figure 6.3. For question (a), 1,047 out of 1,072 participants (97.7%) felt moderately satisfied or better (answer 3, 4 and 5). Considering question (b), 1,006 out of 1,072 (93.9%) participants think REForm is very easy to navigate (answer 4 and 5).

Figure 6.3 Answers to evaluation questions (a) and (b) from IMPACT participants
Chapter 7

Conclusion

We create a web application called REForm to solve the data capture challenges of large-scale interventional studies, which provides an interactive survey authoring interface with inner-question logic, branching logic and workflow design. Besides, REForm also enables researchers to integrate surveys with interventions. REForm innovates a set of features to address the challenges in large-scale interventional studies.

7.1 Contributions

REForm enhances the current survey system in the following aspects:

1. REForm integrates interventions with surveys and keep the survey data in one single data repository, which eliminates unnecessary data integration tasks.

2. Comprehensive workflow can automate the process for building surveys and intervention delivery including “Pre-message”, “Post-message” and reminders.

3. Specially designed widgets to help participants with navigation and completing large surveys which require less effort and encourage participants to complete their study procedure.
4. REForm can automate research procedures like randomization and personalized intervention assignment with user customize rules.

5. Role based access control for team management.

REForm is a live and evolving system. With the increasing number of question types and participants, it will be able to handle large-scale intervention studies.

In summary, this thesis introduces REForm, a web application created to solve the data capture challenges of large-scale interventional studies. REForm provides survey authoring interface and supports integration of online surveys with interventions in a comprehensive workflow. REForm also provides sufficient support for large-scale surveys by implementing features such as real-time storage, page-wise progress indication, and fast page navigation. REForm has been deployed for IMAPCT study since July 2016 and initial user feedback shows that it has been successful in meeting its design objectives.

7.2 Future work

There are many aspects that REForm can improve. More question types could add to survey builder. Currently, we only implement eight types of questions which it is not enough. Besides, we organize workflow in a consecutive steps. A better implementation is to design an interactive interface which enables drag and drop function in a svg format. Furthurmore, we can implement online chat function which can enable users to communicate with each other. Continued effort is under way to improve the functionalities of the system, such as customization for layouts of surveys.
APPENDIX
Ruby on Rails Code

A.1 Project Controller

```ruby
require 'json'
require 'mongo'
class SurveysController < ApplicationController
  before_action :set_survey, only: [:show, :edit, :update, :destroy, :
  survey_builder, :build, :fetch, :delete_question, :preview, :
  save_answer, :responses, :setting, :setting_save, :
  save_correct_answer]
  include Mongo

  # GET /surveys
  # GET /surveys.json
  def fetch
    @surveys = Survey.where(id: params[:id])
    respond_to do |format|
      format.html {
        render 'index'
      }
      format.json {
        pageData = []
        if @survey.pages.present?
          @survey.pages.each do |key, value|
            pageData << value
          end
          pageData.to_json
        end
        # puts pageData
        render json: {
          pageData: pageData
        }
      }
    end
  end

  def build
    respond_to do |format|
```
```javascript
format.html
format.js {
  # Check questionNumber number
  if params[:edit].present?
    questionNumberNew = params[:hashKey]
    p "come here"
  else
    if @survey.pages.present?
      if @survey.pages["#{params[:page]}"].present?
        questionNumberNew = @survey.pages["#{params[:page]}"]['questions'].size + 1
      else
        questionNumberNew = 1
      end
    else
      questionNumberNew = 1
    end
    puts questionNumberNew
  end
  # check if options are empty
  optionCount = 0
  if params[:questionType] == "plain_text" or "group_single" or "group_multiple" or "text_single" or "text_multiple" or "matrix"
    optionCount = 1
  else
    params[:options].each do |option|
      if option.present?
        optionCount = optionCount + 1
      end
    end
  end
  # Saving question begin
  if (params[:question].present? and optionCount > 0) or params[:questionType] == "matrix"
    optionHash = {}
    groupHash = {}
    labelHash = {}
    rowHash = {}
    columnHash = {}
    if params[:options].present?
      # Save group questions hash
      if params[:questionType] == "group_single" or params[:questionType] == "group_multiple"
        params[:groupsName].each do |groupId, groupName|
          groupOptionHash = {}
          params[:options][groupId].each_with_index do |option, index|
            if option.present?
              singleOptionHash = { "#{index}": option }
              groupOptionHash.merge!(singleOptionHash)
            end
          end
        end
      end
      optionHash.merge!(groupOptionHash)
    end
  end
```
groupHash .merge!("#{groupName}" => groupOptionHash)

questionHash = Hash[
  "#{questionNumberNew}" => {
    "questionNumber": params[:questionNumber],
    "questionType": params[:questionType],
    "question": params[:question],
    "groups": groupHash
  }
]

else
  # other type question with options
  params[:options].each_with_index do |option, index|
    if option.present?
      singleOptionHash = { "#{index}": option }
      optionHash .merge!(singleOptionHash)
    end
  end

  questionHash = Hash[
    "#{questionNumberNew}" => {
      "questionNumber": params[:questionNumber],
      "questionType": params[:questionType],
      "question": params[:question],
      "options": optionHash
    }
  ]
end

else
  # For plain text or text single, multiple and matrix
  if params[:questionType] == ("text_single" or "text_multiple")
    puts "why it 's here"
    params[:pre_label].each_with_index do |label, index|
      singleLabelHash = Hash[
        "#{index}" => {
          "pre_label": label,
          "post_label": params[:post_label][index]
        }
      ]
      labelHash .merge!(singleLabelHash)
    end
  end

  questionHash = Hash[
    "#{questionNumberNew}" => {
      "questionNumber": params[:questionNumber],
      "questionType": params[:questionType],
      "question": params[:question],
      "labels": labelHash
    }
  ]
else if params[:questionType] == "matrix"
  puts "come here"
  params[:rows].each_with_index do |row, index|
    singleRowHash = Hash[ "#{index}" => row]
    rowHash.merge!(singleRowHash)
  end
  params[:columns].each_with_index do |column, index|
    singleColumnHash = Hash[ "#{index}" => column]
    columnHash.merge!(singleColumnHash)
  end
  questionHash = Hash[
    "#{questionNumberNew}" => {
      "questionNumber": params[:questionNumber],
      "questionType": params[:questionType],
      "rows": rowHash,
      "columns": columnHash
    }
  ]
else
  questionHash = Hash[
    "#{questionNumberNew}" => {
      "questionNumber": params[:questionNumber],
      "questionType": params[:questionType],
      "question": params[:question]
    }
  ]
end
end
end
# puts questionHash
pageHash = {
  "#{params[:page]}": {
    "pageNumber": params[:page],
    "questions": questionHash
  }
}
if @survey.pages.present?
  if @survey.pages["#{params[:page]}"].present?
    if @survey.pages["#{params[:page]}"]["questions"]["#{questionNumberNew}"].present?
      # update existing question
      @survey.pages["#{params[:page]}"]["questions"]["#{questionNumberNew}"] = questionHash["#{questionNumberNew}"]
      puts "update question"
    else
      # add new question
      @survey.pages["#{params[:page]}"]["questions"].merge!(questionHash)
      puts "new question"
    end
  end
end
else
    # add question first time
    @survey.pages.merge!(pageHash)
    puts "first name"
end
else
    # add new question in new page
    @survey.pages = pageHash
    puts "new page new question"
end
    @survey.save
    render json: nil, status: :ok
end
end

def delete_question
questionsHash = @survey.pages[params[:pageNum]]['questions'].tap { h | h.delete(params[:hashKey]) }
plainTextNum = 0
questionsHash.keys.each_with_index do |key, index|
    new_key = index.to_i + 1
    if questionsHash[key]['questionType'] == "plain_text"
        plainTextNum += 1
        puts plainTextNum
    else
        questionsHash[key]['questionNumber'] = (new_key - plainTextNum).to_s
    end
    questionsHash[new_key] = questionsHash.delete(key)
end
    @survey.save
    render json: nil, status: :ok
end

A.2 Survey Model

class Survey
    include Mongoid::Document
    include Mongoid::Attributes::Dynamic
    include Mongoid::Timestamps
    field :name, type: String
    field :description, type: String
    field :pages, type: Hash

### A.3 Survey Builder View

#### A.3.1 survey_build.html.erb

```html
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```
A.3.2 _form.html.erb

<%= form_for(survey) do |f| %>
  <% if survey.errors.any? %>
    <div id="errorExplanation">
      <h2><%= pluralize(survey.errors.count, "error") %> prohibited this survey from being saved:</h2>
      <!-- Error list goes here -->
    </div>
  <% end %>
</form>
<ul>
  <% survey.errors.full_messages.each do |message| %>
    <li><%= message %></li>
  <% end %>
</ul>

<% if project.present? %>
  <%= f.hidden_field :project_id, value: project.id %>
<% end %>

<div class="field">
  <%= f.label :title %><br>
  <%= f.text_field :name, class: 'form-control' %>
</div>

<br/>

<div class="field">
  <%= f.label :description %><br>
  <%= f.trix_editor :description %>
</div>

<br/>

<div class="field">
  <%= f.label :status %><br>
  <div class='border-style' style='padding: 20px 0 15px 20px'>
    <%= f.radio_button :status, 'inactive', :checked => true %>
    <%= label :inactive, 'Inactive', style: 'color: grey;font-size: 1.6rem;' %>
    &nbsp;&nbsp;&nbsp;&nbsp;&nbsp;&nbsp;
    <%= f.radio_button :status, 'active' %>
    <%= label :active, 'Active', style: 'color: green;font-size: 1.6rem;' %>
  </div>
  &lt;p style="color: grey;"&gt;While inactive, the Survey will not be accessible.&lt;/p&gt;
</div>

</div>

<div class="modal-footer">
  <%= f.submit 'Save', class: 'btn btn-success' %>
  &lt;button type="button" class="btn btn-default" data-dismiss="modal"&gt;Close&lt;/button&gt;
</div>
<% end %>
LIST OF REFERENCES


[26] David F. Ferraiolo, D. Richard Kuhn. “Role-Based Access Controls”.


