MobileCoach: A Novel Open Source Platform for the Design of Evidence-based, Scalable and Low-Cost Behavioral Health Interventions

Overview and Preliminary Evaluation in the Public Health Context

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Abstract—**Effective and efficient behavioral interventions are important and of high interest today. Due to shortcomings of related approaches, we introduce MobileCoach (mobile-coach.eu) as novel open source behavioral intervention platform. With its modular architecture, its rule-based engine that monitors behavioral states and triggers state transitions, we assume MobileCoach to lay a fruitful ground for evidence-based, scalable and low-cost behavioral interventions in various application domains. The code basis is made open source and thus, MobileCoach can be used and revised not only by interdisciplinary research teams but also by public bodies or business organizations without any legal constraints. Technical details of the platform are presented as well as preliminary empirical findings regarding the acceptance of one particular intervention in the public health context. Future work will integrate Internet of Things services that sense and process data streams in a way that MobileCoach interventions can be further tailored to the needs and characteristics of individual participants.**

Keywords—open source platform; behavioral intervention; empirical study, public health; addiction

I. Introduction

The reader may be familiar with statements like “I will stop smoking!”, “I want to lose 10 kilos!”, “I want to get healthy”, “I must drive more safely!” or “I would like to cut 10% of my energy costs!” These among various other intentions and underlying behaviors are the concern of many people. As a consequence, the design of effective and efficient behavioral interventions based upon theories on behavior change has been investigated for several decades in various application domains such as health [1], education [2], criminology [3] or energy [4].

One of the most significant and serious challenges today is the global lack of resources and capacity to provide health interventions related to non-communicable diseases (NCDs) [5] such as heart diseases, asthma, diabetes or chronic kidney disease as they “impose the greatest burden on global health.” [6, p. 2] Therefore the current work will focus on the field of behavioral health interventions henceforth.

In this regard and among many other political and/or educational approaches, information and communication technologies (ICTs) have the potential to improve the effectiveness and efficiency of health interventions, reduce their costs and thus, can address the shortcomings in healthcare supply mentioned above [7]. However, there is still a lack of empirical support on how to design evidence-based, scalable and low-cost health interventions that are supported by ICT [8, 9]. Apart from that, the use of behavioral theories and techniques tends to improve the outcomes of these interventions [10].

Against this background, the current work introduces MobileCoach (mobile-coach.eu), a novel open source platform for behavioral interventions. From a health economic perspective, the overall objective of this platform is to give scientists, public and behavioral health experts a software platform that allows them to design evidence-based, scalable and low-cost health interventions. Based on its modular architecture, the rule-based engine for monitoring health states and triggering state transitions, we expect MobileCoach not only to help to improve the efficacy of behavioral interventions in general but to be able to address the shortcomings of healthcare supply worldwide, especially regarding a careful handling of NCDs. That is, according to WHO’s NCD global monitoring framework, many of these diseases are consequences of adverse health behaviors and exposures, for example, the harmful use of alcohol and tobacco, saturated fat intake, salt intake, physical inactivity or low fruit and vegetable intake [11].

The remainder of the current work is organized as follows. We first review existing behavioral intervention platforms and outline their strengths and shortcomings. We then introduce MobileCoach as a novel open source platform for behavioral interventions, provide an overview of its concep-

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tual design and describe the architecture and license model in more detail. Afterwards, we present a very first MobileCoach intervention in the public health context and report on the user acceptance based on preliminary empirical results. We conclude with a summary and an outlook on future work.

II. Behavioral Intervention Platforms

There exist innovative behavioral intervention platforms such as UBhave (ubhave.org) [12, 13], ginger.io [14-16], LifeGuide (lifeguideonline.org) [17-19], or Minddistrict (minddistrict.com). These platforms can not only be used for behavioral interventions in general but also for fully-automated health interventions in particular. However, there are several shortcomings that must be noted and which, in turn, represent design requirements for the MobileCoach platform.

First and foremost, the code basis of some of these platforms is not made open source, in particular, with an industry-friendly license such as an Apache-like license (e.g. ginger.io). As a consequence, the adoption, adaptation and continuous development of these platforms by research groups and (business) organizations is not only significantly limited but also restricted to pre-defined behavioral interventions and services for data collection purposes (e.g. restricted to sensor data of a smartphone). The development and reuse of common platform services that are similar in various behavioral interventions, for example, the intervention rules based on a common behavior change theory or the statistical analyses of repeated measures, is not possible and significantly increases customization effort.

Second, most of these platforms provide a passive monitoring of relevant behavioral data in combination with a direct presentation of those data. Tailored recommendations based on that monitoring is missing. For example, there are several physical activity trackers available on the market that measure and directly display the steps per day relative to a pre-defined goal (e.g. 10.000 steps per day). However, individual needs and characteristics of participants are not considered to tailor any data analyses, behavioral tips or recommendations and thus, reach and stabilize a particular target behavior. Thus IT-enabled precision medicine is not possible [20].

Third, health providers are often restricted to a given server or cloud infrastructure when it comes to the deployment of the behavioral platform. That is, health-related personal data is usually stored at the sites of the technology and / or platform providers. From a legal point of view, this is often not an option for healthcare providers that are bound to national law and which must access, store and backup health-related data up to several years.

Fourth, the development of evidence-based behavioral health interventions requires a flexible setup of sub-interventions tailored to intervention and control groups. Unfortunately, existing platforms are not designed to support these kinds of studies such as randomized controlled trials from scratch and often at least two almost redundant interventions have to be deployed.

Finally, several platforms provide anonymous diary services for data collection purposes [e.g. 21] and thus, lack personal communication which in turn is highly valued by patients [22] and related to increased effectiveness of interventions [23]. However, personal communication significantly limits the scalability of health interventions [24], in particular in regions where one physician is responsible for thousands of citizens. Fully-automated dialog-based communication is already utilized in health interventions [25] and represents the last design requirement of MobileCoach.

III. The MobileCoach Platform

In order to address the shortcomings outlined above, we now introduce the MobileCoach platform by outlining its conceptual design, the technical architecture and open source license.

A. Conceptual Design

Building on the foundations of automata theory [26], the technical design of the MobileCoach system follows the concepts of a state machine that uses intervention rules for state transitions, which can be referred to as a fully automated expert system. Here, the state is an aggregate of all relevant variables related to the intervention progress of a participant whereas state transitions triggered by intervention rules lead to a change in these variables and thus, to a state change in the state machine.

In particular, each participant is assigned to an initial state after filling out an online baseline assessment. The answers are stored in variables that can contain basic information about the participant (e.g. nickname, age, mobile number), psychological attributes (e.g. intentions) or other values that could be useful for the rule-based evaluation (e.g. individual preferences, experimental or control group). In response to the assessment, a web-based feedback is generated individually by the system for each participant. With rule-based constraints defined for each slide in the feedback, specific slides can be shown or hidden for participants based on their current variable values. Text blocks in the assessment as well as in the feedback can be personalized for each participant based on her actual state using variable placeholders, too.

After the baseline assessment, a fully automated dialog between the system and the participant starts to take place. For that purpose, a text message service is used in the first version of MobileCoach. That is, questions with pre-defined answer schemes are raised by the system (e.g. [Question… Please answer with Y (Yes) or N (No)]) and depending on the answers of the participants, rules trigger changes in states, fire state transitions and tailor the follow-up communication. Intervention rules are traversed on a regular basis (e.g. at least once a day, after replies, and, after no reply within a defined time frame) for each participant, and, as a result, update the state of the corresponding participant and continue the dialog with the participant in the form of a question, a feedback or a recommendation. The messages waiting to be sent to a participant, who can also contain variable-based placeholders, are grouped in message groups and are annotated with restriction rules to enable the intervention author to again filter also these based on the current intervention state of a participant, i.e. specific message based on several variables. Randomized message groups are possible as well as question answer paired groups.

The possibilities of personalization provided by the rule-based approach in combination with variable-based placeholders enable the intervention author to design a very flexible and personal message dialog. In case a participant does not answer a question, the author can design how the system reacts, i.e. which messages are sent in response. If answers cannot be interpreted automatically, then intervention author is informed and can manually interpret and answer the participant's message. The author can also start a personal dialog with a specific participant on its own at any time during an intervention. The system can furthermore be extended by additional modules to increase the direct dialog capabilities between the author and the participant in addition to the fully automated dialog, e.g. to provide a quiz or a message contest.

B. *Software Architecture*

The software architecture of MobileCoach is depicted in Fig. 1. The various functionalities of the platform result from an interplay of several Java-based modules. These modules are described in the following bottom up, from the persistence to the service layer:

Persistence Layer. As already mentioned, the MobileCoach platform needs to store not only the interventions itself, i.e., surveys, rules, media objects, but also information collected from a large number of expected participants, i.e., contact information, message dialog, variables, in a save and efficient way. Therefore the document-oriented database *mongoDB* (mongodb.org) has been used for this purpose for the MobileCoach platform in combination with the *Jongo* framework (jongo.org) to provide POJO access to the data objects for the further usage of the same in the other modules. The *Model Object-based Data Access and Modification Manager* enables the programmer to retrieve, filter and store data objects in the database in a failsafe and convenient way by providing an own model object interface for persistent objects. Beside that, the *Storage Manager* handles the persistent storage of media files, e.g. videos, audio files, that are stored in an automatically managed folder directly in the file system. Each media file has a media object representation in the database to be able to be referenced in messages, slides etc. To be able to exchange intervention as well as participant data between independent installations, the *Data Import/Export Manager* provides import and export capabilities using a ZIP file based exchange format. At last, the *Data Consistency Manager* ensures data consistency after version upgrades, unplanned system crashes or data restore, as well as the synchronization between media objects and their belonging media files.

Service layer. The service layer contains the core services of the MobileCoach platform. These services are split in four main services managing the administration and execution of surveys and the dialog-based interventions in the system:

The *Screening Survey Administration Service* provides all functions to define surveys as part of an intervention. Surveys can be created, designs selected, slides added, modified and deleted as well as access rules defined. In combination with rule-based constraints for each slide the intervention author can decide which slides will be shown in which order to the participant based on the variables already collected about the same. Different types of slides enable to create a big variety of slide layouts, e.g. single selection, multi selection, text input. Media objects can be added to the slides as well, to be able to present images, audio files or videos to the participants when doing a web-based survey. Beside assessment surveys also feedbacks can be created with the module. Compared to regular surveys, the feedbacks only contain slides presenting information, not collecting information. The advantage of the same is that feedbacks have unique URLs for each participant. These can be communicated to the same to allow them to see their current state during and after participating in the intervention. A link to the personalized feedback can also be provided to the participant after performing the assessment survey.

The counterpart of the aforementioned service is the *Screening Survey Execution Service*. When an intervention is set to be accessible by the public, the service cares for the creation and delivery of the survey slides as defined using the *Screening Survey Administration Service.* The participant can start the web-based survey using a regular browser on a tablet or desktop PC. The service delivers the websites to the participant and ensures access rights, correct slide order and validates inputs based on the validation rules provided by the intervention author. The *mustache.java* template engine (github.com/spullara/mustache.java) simplifies the creation of web-templates for the surveys and feedbacks for the administrator. No source code has to be written to use a

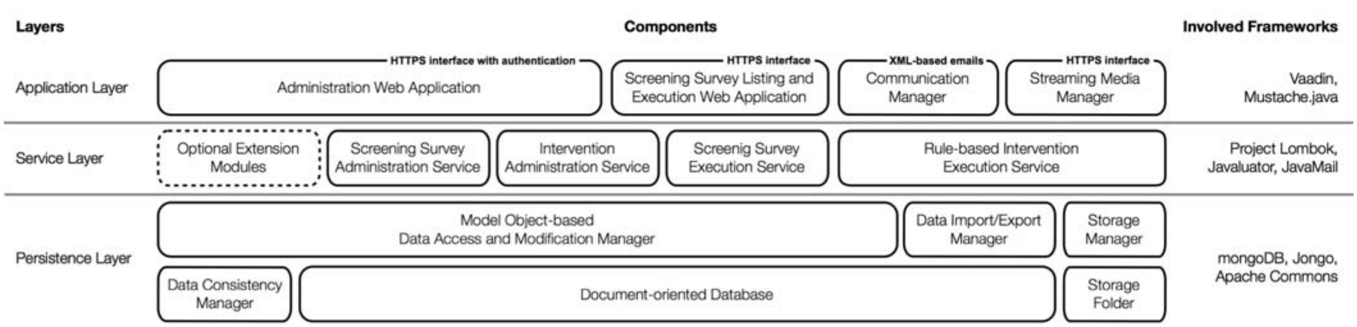

Fig. 1. Software architecture of the MobileCoach platform.

HTML/CSS template as a template for a MobileCoach based web-survey.

Similar to the *Screening Survey Administration Service* the *Intervention Administration Service* encompasses all functions to administrate an intervention. While the survey management is extracted in the aforementioned separate services to reduce the complexity of the particular services, all other functionalities that are required to administrate an intervention are provided by this service. Among these are: basic settings, access rights, participants management, messages management, monitoring rules management. The monitoring rules management, the functions to administrate the rules that define which message is sent under which circumstances, is the core part of the service. The author of an intervention can define hierarchical structures of rules, which will later be executed on the current state of variables of a specific participant. The system therefore provides the possibility to define calculation terms with placeholders for variables of the participant or several system variables, e.g. day of the week, week of participation, nickname of participant. These calculation terms can be combined with one of a group of available comparison rules, e.g., greater than, matches regular expression, time period in days. Using this combined approach the author can use rules to calculate new variable values (e.g., average values of last week) and to evaluate terms (e.g., one value is bigger than another). If a specific rule matches, the intervention author can decide to send a message to the participant by selecting an appropriate message group as source for the message to send. Within the monitoring rules management the author is also able to define how the system reacts if the participants answers a specific message on time or when it times out. This reaction can also be described the same way using rules.

The last major service is the *Rule-based Intervention Monitoring Execution Service*. Based on settings and rules defined in the former service, this service performs the rule execution for the participants when the monitoring has been activated for a specific intervention. Using the approach described in the former subsection the system automatically prepares the messages that will be send to a participant at a specific daytime on the following day. It also reacts on incoming messages and reacts according to the defined rules. Being the core part of the whole system, this service is designed with a strong focus on stability and validity. Therefore several functionalities are externalized in separate classes to be able to focus on the stable execution of the core tasks, the rule-based decision making.

Application layer. To enable intervention authors and participants to access and use the aforementioned functionalities, as well as to enable the system to send and receive messages, e.g., text messages, the application layer consists of four independent services.

The *Administration Web Application* is based on the *Vaadin* framework (vaadin.com) and provides an easy to use expert interface to administrate the whole systems involving interventions, surveys, participants and access rights. Since it is developed as web application as shown in Fig. 2, it combines the advantages of applications to provide complex functionality with the advantages of web pages to be simply accessible using a modern web browser. The web application is also the interface to supervise running interventions (e.g. in case of message replies that cannot be automatically processed) and to export intervention results in different text based formats (e.g. CSV for Excel or SPSS).

The *Screening Survey Listing and Execution Web Application* is the frontend part provided for the participants. A listing enables participants to select one of the currently available assessment surveys and start into it. A slide of an already implemented survey can be seen in Fig. 3. To ensure a high level of compatibility the surveys are provided as regular web pages.

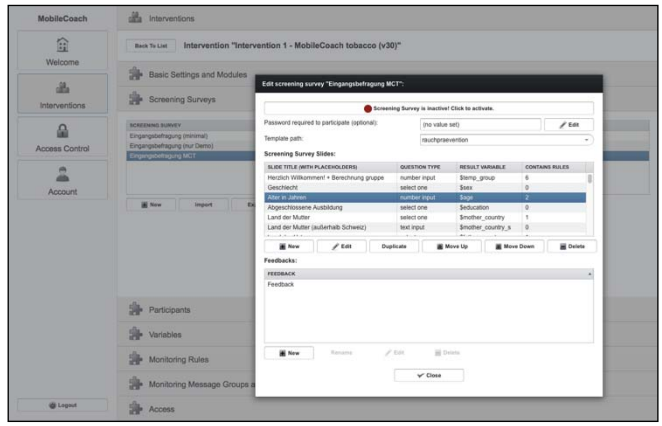

Fig. 2. Administration web application with survey editing window.

Fig. 3. Survey in browser slide prepared by MobileCoach.

The *Communication Manager* is responsible for the communication to external services required to provide the communication functionalities, i.e. the sending and receiving of text messages. In the current implementation a text message provider interface is implemented, but modules for several other APIs are planned.

At last, the *Streaming Media Manager* provides media streaming capabilities with a basic logging functionality: Based on the URL specifically created for each participant and media object the system cannot only send the appropriate media object to the same, but also log this action for the intervention author. By doing so, the intervention author can see which of the media objects have been viewed by the participant.

MobileCoach can be extended by optional modules of the service layer as indicated by the dotted box in Fig. 1. These modules can use the capabilities provided by the persistence layer and be configured on the application layer. After the first release of the platform, several extension are planned here, while three proprietary modules were already implemented as proof of concept for the first interventions described in section IV.

C. License and Open Source Code

The initiators of MobileCoach were eager to make this platform freely available to academia, public institutions and industry with the overall goal to promote further development resulting in useful evidence-based behavioral interventions. In this regard, all frameworks used in the development are published under the Apache 2.0 license. This enables the authors to publish the MobileCoach platform under the same license. Thus, the system can be used commercially without any legal constraints. The GIT-based source code repositories can be found on *mobile-coach.eu*. In the root folder of the main repository a ReadMe file can be found which explains the steps necessary to setup one's own MobileCoach platform installation on one's own server.

IV. Preliminary Evaluation

In order to evaluate the acceptance of the MobileCoach platform, a very first behavioral intervention was designed and is currently being evaluated in the public health context.

A. Background

Internet and mobile phones are extremely popular among adolescents and thus represent appropriate channels for behavioral health interventions [27]. As introduced above, various NCDs are affected by the misuse of alcohol and tobacco. Due to the fact that smoking prevalence rates among adolescents continues to be a serious problem [28] and alcohol consumption and tobacco smoking often co-occur, the goal of the first MobileCoach study is to evaluate the effectiveness of an integrated smoking cessation and alcohol intervention.

B. Method

A two-arm cluster-randomized trial is conducted to test the efficacy of MobileCoach *Tobacco*, a text messaging-based intervention for smoking cessation for adolescents compared to MobileCoach *Tobacco+*, a web- and text messaging-based integrated smoking cessation and alcohol intervention. Further details can be obtained from the study protocol [29].

C. Preliminary results on intervention acceptance

Since the beginning of recruitment in September 2014, until January 2015, a total of 880 students participated in the baseline survey. Out of these, 339 (39%) were current smokers and owned a mobile phone. From these students, who were eligible for participation, 233 (69%) registered for participation in the program and the study, respectively. Given that smokers were invited for program participation independent of their intention to quit, and only 38 (16%) of the 233 participants seriously intended to quit, this participation rate is very high and reflects the attractiveness of the intervention approach and its low-threshold access.

Until now 1277 text message prompts were sent to the participants that either assessed smoking-related target behaviors or encouraged participation in a quiz or a message contest. Of these, 853 (67%) were answered validly by the participants within one day, which shows that the majority of the participants are actively involved in the program.

The positive usage rates were additionally supported by findings of an online survey of a popular local newspaper. Within an online article about the MobileCoach project, the question was stated whether the readership would use MobileCoach as part of a smoking cecassion program. As of today, 239 readers have participated and 46% of them indicated that they would use MobileCoach to save time and money, 13% were undecided whereas 41% have declined to use it. It must be noted that both smokers and non-smokers have participated in that survey and thus, the results are promising.

V. Summary & Future Work

With MobileCoach, we provide a platform for the design of evidence-based, scalable and low-cost behavioral health interventions. MobileCoach offers an industry-friendly open source code basis, a modular and extendable architecture, and a flexible rule engine for the design of fully-automated intervention dialogs with tailored recommendations. It further supports the implementation of randomized controlled trials. Due to these characteristics, we expect high adoption rates by public institutions, business organizations and interdisciplinary research teams consisting of computer scientists and behavioral experts from all around the world. In this paper, we introduced the MobileCoach platform and provided first evidence on the acceptance of a particular MobileCoach intervention in the public health context.

In our future work, we will extend the MobileCoach platform with various services. First and foremost, statistical real time analyses on repeated measures will be made available not only for the intervention experts in form of an online dashboard service but also for the participants in the form of intervention rules that trigger novel tailored messages based on these analyses. In combination with machine learning algorithms that are used to identify individual thresholds on pre-defined measures, that statistical service will lay the ground for so-called early-warning health information systems [30]. Finally, interfaces to Internet of Things services that collect objective data continously (e.g. heart rate, skin conductance or physical activity) will be developed.

In summary, we expect MobileCoach to improve the quality and efficiency of behavioral interventions in general but especially, to help address the lack of resources in health supply with regard to the most significant burden on global health, i.e. careful handling of non-communicable diseases.

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