Design and deployment of eHealth interventions using behavior change techniques, BPMN2 and OpenEHR

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Case study: Diabetes

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***Abstract*—Healthcare Systems are transforming from acute care to managing chronic conditions. In this process they are becoming highly distributed and specialized. Innovative approaches are needed to fully support the design and deployment of new eHealth interventions. We present a method for designing new eHealth interventions and an ICT platform that supports the deployment phase. The method is grounded in using behavior change techniques in order to make eHealth interventions more effective and the platform is based on enabling interoperability and reusability by focusing on open standards, open data, open source technology and different modeling approaches, namely BPMN2 and OpenEHR.**

Keywords—eCare; interoperability; interventions; behavior change; sustainability

I. Introduction

Due to ongoing transformation of healthcare systems from acute care to managing chronic conditions, they are becoming highly distributed and specialized with a goal to increase the quality and safety of care. [1].

Healthcare systems can be described as complex adaptive systems[2] (CAS) where a group of independent agents work in a nondeterministic way and at the same time, the agents are linked together in a way that actions of one agent influence the change of context of other agents (e.g. primary healthcare). Healthcare systems have, historically speaking, never been designed properly. They have grown in a natural way. As a consequence, it is impossible to define the boundaries of the system and also all the possible processes of a typical healthcare system. Different agents exchange information by means of orchestration (with the help of a central coordinator) or choreography (peer to peer). In order to support these agents, we need to focus on the homogeneity of architecture of the agents that enables interoperability between the agents in the sense of mutual understanding of exchanged information. Furthermore, this architecture of agents should align with organizational and legal perspectives.

Information-communication technology (ICT) systems are used to support healthcare systems as complex adaptive systems. These lead to innovative care models that are based on personalizing care which includes prevention, home care, services for the elderly and lifestyle support services [1]. Interventions are designed and deployed with a purpose to support health related behavior change. By anchoring the design phase of new interventions into theory and existing evidence that is available, we can achieve greater health related outcomes for patients.

In addition, there has been a rapid growth in the focus of eHealth and more recently, mHealth interventions. Both concepts describe the usage of ICT in Healthcare. It is important to stress that both eHealth and mHealth solutions should be designed by informing the design phase with information from relevant behavior change theories and existing evidence of what has been shown to work. In this way we can increase the cost efficiency due to less trial and error iterations and also increase the effectiveness of achieving the desired outcomes.

Arguably, there is a real need to develop new interventions based on theory and evidence, whilst simultaneously deploying them on an ICT platform that enables different interoperable communication patterns. This requires a method for designing new interventions and also a platform that would support the deployment phase. In order to support interoperability as the basis for sustainability of new interventions, the design should be based on theory and existing evidence, and the deployment should not form new siloed systems but should be based on **open standards** and **open data**. The ICT platform should support different intervention modeling approaches and a multilayered architecture with loose coupling as a main property. Furthermore, the ICT platform should support both eHealth and mHealth solutions as sets of interventions, and involve a **common architecture** that would be used on different devices as described in [3].

II. METHODS

The goals of our work was to (1) test a method of designing new interventions by grounding it in theory and evidence namely with behavior change techniques (BCTs) that are defined as the **active ingredients** in an intervention that are both **observable** and **replicable** and directly bring about change in the target behavior [4], and (2) to support the deployment phase by a common ICT platform that can be used for different interventions in different domains.

Before focusing on using BCTs, we identified several existing approaches to grounding intervention design in theory. These included several existing influence frameworks that organize multiple factors believed to modify human psychology and/or behavior.

After the design phase, we modeled the intervention for ICT deployment by using different ICT modeling approaches. We used BPMN2 [5] to model the intervention business processes (e.g. care processes). To model the clinical knowledge that was used in the intervention and to map it to different existing terminologies (e.g. LOINC, ICD-10, SNOMED-CT, etc.), we chose OpenEHR [6] multi-level modeling approach. We also used object oriented models that at the end formed the execution environment of the ICT platform which was based on open source technology.

In order to be able to include our interventions into an existing eHealth infrastructure in Slovenia, we cooperated with the Ministry of Health of Republic of Slovenia. Consequently, by using OpenEHR as the basis for modeling clinical data, we were able to exchange data with the healthcare system of Slovenia seamlessly.

A. Influence Frameworks

Influence describes any approach aiming to change psychological faculties (e.g. attitudes), behaviors or both [7]. An **influence framework** is any system that organizes multiple factors believed to modify people's psychology and/or behavior.

Cugelman[7] has identified five different influence frameworks, namely: Evidence-based behavioral medicine, Cialdinis general system to describe influence, captology, the stages of change model, and social marketing. Each of these influence systems organizes influence techniques differently based on psychological principals, how people use technology, intervention planning process etc. Also, the use of theories varies between all the influence frameworks. The Stages of change is both a theory and a set of techniques. Behavioral medicine draws on approaches that have been empirically shown to work and places less emphasis on theory. Other influence frameworks use multiple theories to explain phenomena.

In practice, when designing real interventions, practitioners are not confined to a given set of theoretical frameworks but blend theoretical constructs with practical considerations [7].

Common to all theories is the basic model of behavior change that consists of influencers which influence behavioral determinants which support behavioral outcomes. Influencers and behavioral determinants are components – namely **influence components**. But these are always combined together [7].

Gamification is closely tied to influence components. It represents a combination of ingredients to make a product fun and engaging [8].

Intervention designers use gamification as a design pattern. It ultimately means that you will have on screen elements that support the gamification ingredients (e.g. giving rewards, showing progress, etc.). Despite the attractiveness of gamification, one should always be aware of the full range of psychological and design components that will be dependent upon the target audience and the context. Evidence-based behavioral medicine combines theory and evidence and one of the approaches that fit into this category is the Behavior Change Wheel [9] which utilizes the BCT taxonomy (V1)[10]. An example of using the Behavior Change Wheel is presented in [11] where authors use this approach to inform the intervention design phase.

We have decided to focus on the use of BCTs since this behavioral science tool was available at the time of our intervention design phase. We already had experience with designing an intervention on a previous project, where we focused on supporting an intervention for patients with depression [12]. In addition we performed a literature review which revealed the existence of taxonomy of BCTs [13] that formed the basis of our grounding of intervention design in theory and evidence.

B. Modeling Interventions for ICT deployment

In order to model interventions for ICT deployment, a clear mapping from conceptual level to ICT level was needed. An example of such mapping from conceptual level to technological level is presented in [14]. There are also other approaches like intervention mapping [15] and in [11] the authors use the Behavior Change Wheel framework [9] that is eventually mapped to a set of application features. Since all these approaches were not published during our phase of work on such mapping, we give a description of our mapping in terms of a set of behavior change techniques (BCTs) that have been used in our diabetes intervention.

C. Modeling intervention processess with BPMN2

The set of behavior change techniques that was used in our diabetes intervention was supported by different functionalities of the platform. The intervention processes were modeled by using BPMN2 thus some BCTs are directly supported by these models; some BCTs are supported at the user interface level. This means that BCTs are eventually mapped into technological elements that are representing functionalities of the system. BPMN2 was the chosen modeling approach due to being a well-established way of modeling and visualizing the models for both orchestration and choreography communication patterns. We used BPMN2 to model intervention business processes which represent orchestrations of different roles (doctors, nurses, patients, family members, etc.) performing different steps of interventions and may include different ICT systems. In this way intervention business processes are modeled and deployed separately to the platform and can in turn have separate development and deployment cycles and most importantly are not hard coded into a technology specific programming language.

D. Modeling clinical concepts with OpenEHR

Data and information that is captured and managed by ICT systems in healthcare are of three types: patient data, concepts (terminology) and guidelines (decision support)[16]. There are thus at least three types of models that a typical ICT system in Healthcare know and use. In order to be able share data, we need either a combined model that includes all the other models or we can define a new model that would act as an interface to other models. A more feasible approach is the later and OpenEHR is one such approach that has disrupted [17] the way of handling data sharing and semantic interoperability.

The openEHR technical approach is **multi-level modeling** within a service-oriented software architecture, in which models built by domain experts are in their own layer. This allows domain experts - clinicians, allied health workers, and other experts - to be directly involved in defining the semantics of clinical information systems, and it also makes using terminology much easier. OpenEHR greatly enables new business models in healthcare that are not based on lock-in but on open standards and open data and therefore support the long-term goal of interoperability and sustainability.

E. Using open source technology for ICT support

Open source technology represents an important innovation also in the field of healthcare. Recently, one of the most prominent healthcare systems in the world, the British National Healthcare System (NHS), has devoted great effort towards using open source technology as the basis for ICT solutions in healthcare. Many other governments and healthcare institutions are also taking part in this global movement. Therefore, we have also decided to support it in our project since it supports the concepts of open standards and open data and also, similarly to OpenEHR, supports different business models that are not based on lock-in. In this regard it adds one more positive argument towards sustainable interventions.

F. Interfaces towards national eHealth

In order to achieve the goal of having an interoperable solution for deployment of new interventions, the platform should interface towards the national eHealth infrastructure of Slovenia which is based on IHE [18] and OpenEHR. Therefore, all the data from our interventions can easily be exchanged on the national level without additional integrations.

III. RESULTS

Our method of designing interventions was based on theory and evidence by using BCTs. We developed an ICT platform that supports the mapping of interventions from a conceptual level to the technological ICT level. Since the platform was developed through iterating the method five times – for five different interventions, we were able to identify common ICT platform elements that represented the mappings of BCTs.

The method was executed in eight steps and started with the conceptual design phase of designing new interventions towards the deployment phase were the intervention was supported by a running ICT system.

Step 1: Defining the ideal intervention

If doctors and other medical personnel were permitted to define the intervention "without limits" – what would the ideal intervention look like to them? The result of this step was a document that described how the intervention worked and what the expected outcomes were. These outcomes were clinical (e.g. level of blood sugar) and organizational (e.g. number of visits) in nature. Doctors were given the opportunity to use their explicit and tacit knowledge together with their experience as medical doctors in the Slovene Healthcare System. The intervention had to include the concept of home care. We then reviewed such an intervention proposition and specified questions in order to additionally set the scope and also to clarify which behavior change techniques should be used. The language we used was not the one from the field of behavior change but from the ICT field – namely describing different features the final ICT system was to support.

Step 2: We analyzed the document from step 1 in order to (1) define behavior change elements that we were going to use and (2) design the intervention by using BPMN2. This involved modeling business processes or better said intervention processes or care processes in the case of the Diabetes intervention. The result of this phase was one large BPMN2 model that linked to BCTs elements.

Step 3: Intervention BPMN2 model evaluation with the doctors: they quickly grasped the information due to the notation part of the standard. We used a common tool for modeling and presenting the model. The model already contained the elements of behavior change that were selected as useful on the basis of previous experience and gathered evidence.

Step 4: After Step 3, we had an agreement with the medical domain experts on the intervention. The agreement is very structured and already includes a number of BCTs. However, it provides limited information about the interaction design in the sense of the final look-and-feel of the web interface or any other visual elements on the web page that can potentially influence usage. In this step, the intervention models were reviewed again – this time from the perspective of deployment to the ICT platform. The models were enriched with additional attributes which link the models to the underlying ICT components. This includes e.g. implementation class names that are in charge of supporting a particular step of the processes.

Step 5: Implementation of the supporting Java classes – the logic which connects the BPMN2 model to executable elements of the platform. This includes also a mapping of particular BPMN2 tasks to OpenEHR archetypes for the purpose of validating and capturing clinical data.

Step 6: Deployment of the BPMN2 processes and the supporting Java implementations to the Process Engine. This included packaging the BPMN2 models separately and deploying them to the Process Engine, and also packaging the Java code separately and deploying it to the Application Server.

Step 7: Now the BPMN2 models that orchestrate the intervention elements were accessible through a REST API. By using this API we were able to work on the web application which is the main tool through which the end user interacts with the ICT supported intervention. The web interface was a generic Groovy/Grails web application which supported the main BCT app features (e.g. tasks, education, chat, etc.). In addition, it included visual elements from gamification that promise better engagement (e.g. disease status in form of a traffic lights, etc.).

Step 8: Deployment of the web application separately from the processes on a separate application server. The web application was accessed by all the roles identified in an intervention. Each role had a different set of features available.

The results of Step 2 of our method were: (1) a set of BCTs that were identified and used, and (2) mapping of

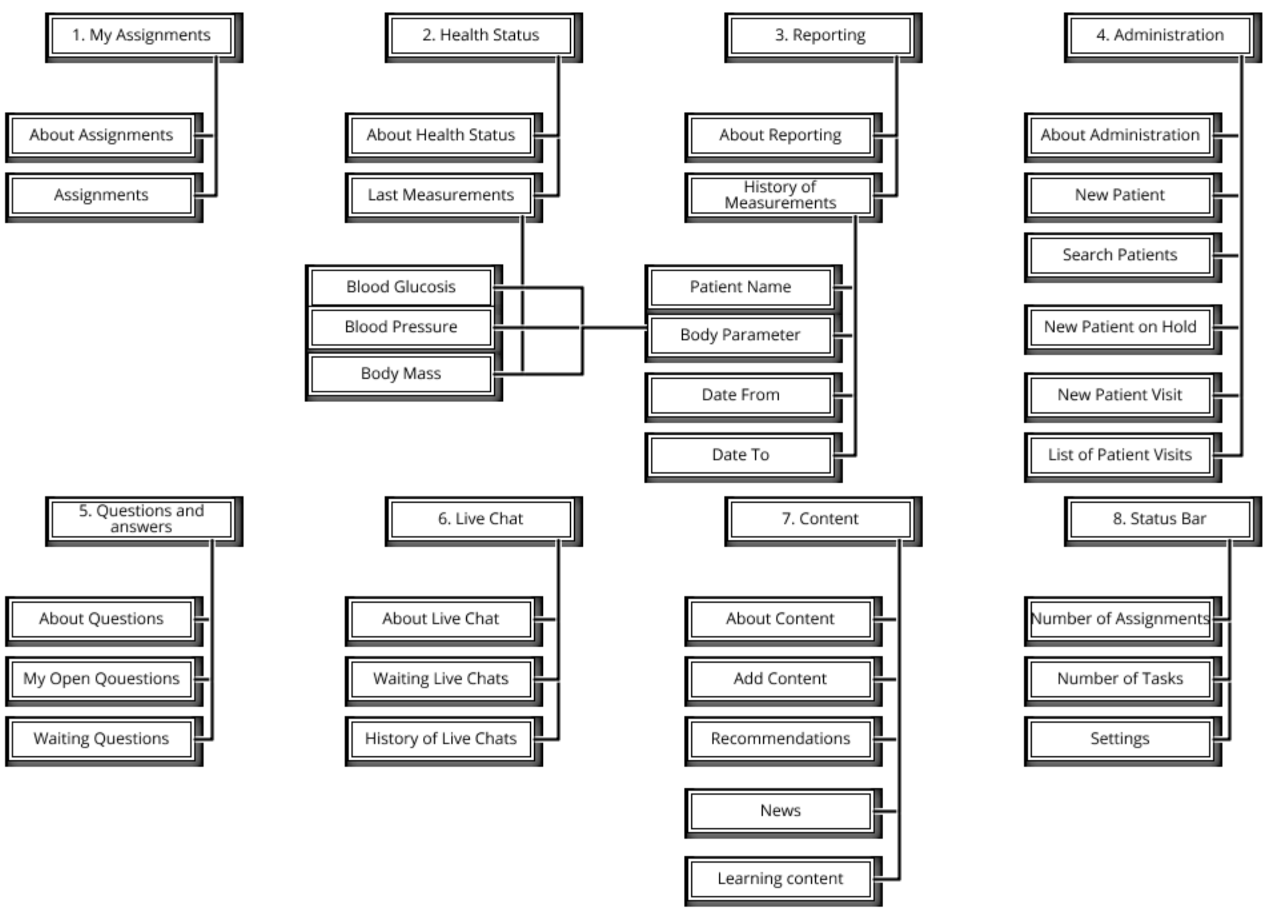

Figure 1 Web Application Functionalities with main parameters

identified BCTs to BPMN2. The BCTs represent a subset of the taxonomy of behavior change techniques [13] and are the following:

1. Set behavioral goals: a patient had to keep his blood sugar value within defined limits and had to perform tasks while at home;
2. Target standard of behavior: the patient had to keep their main parameters in the green field (in addition to orange and red meaning two levels of worsening of parameter levels);
3. Monitoring: a patient was able to track their data where medical staff could see it and receive notifications in the case of bad parameter values;

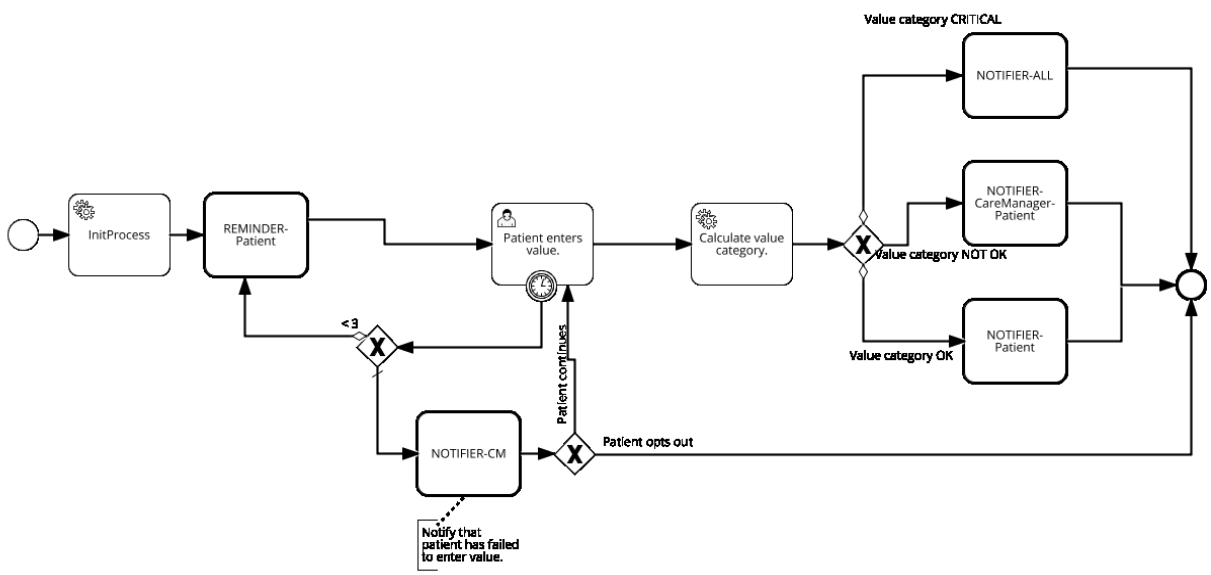

Figure 2 Generic process for patient entering new values

4. Feedback of monitored behavior: a patient was always informed on how well they were managing their diabetes by means of the simple traffic light like status or by means of different reports;
5. Comparison (history data): a patient could always visually see all their data; the medical staff could also see patients history data;
6. Planning: was incorporated in the intervention and was valid for all patients. It was done in the intervention design phase.
7. Coping planning: the intervention was designed to handle coping. If a problematic behavior was identified (e.g. not entering measurements) a patient was called by a nurse for further support. Then a new visit to the office could have been planned if necessary.
8. Goal review: A nurse/doctor was able to see visual reports on how well the patient was achieving the goal of managed diabetes. If this was not the case, we was reviewed and given more support to follow through.
9. Prompts: many types were used namely: sms, email, phone, and web application tasks.
10. Rewards: positive feedback from the system and positive encouragement from the medical staff.
11. Punishment: a call from the care manager in case of bad behavior, concerned feedback by the system.
12. Instruction: patients were given instructions on how to successfully achieve the target behavior. Also, they were given additional info by means of the educational content.
13. Relapse prevention: If the patient did not enter measurements they were notified and called by a nurse on the phone. He also got his status colored red in the web application. The medical staff also saw a red colored patient in the main patient list. This was the trigger to call the patient in for a earlier visit to the doctor's office.
14. Information on the consequences of the behavior: A patient was given information on the consequences of not managing their diabetes properly.
15. Personalized messages: Tailored messages for each patient, care manager or doctor.
16. Set homework tasks: Besides the need to input measurements from home, patients were getting additional tasks in their Calendar functionality. These tasks could have been just about anything that they themselves entered or a nurse/doctor has entered for them.

Out of these behavior change techniques, we identified the following main intervention elements:

- Measurements: patients performed measurements and entered them into the web application. They could visually track them in the reporting section of the web application.
- Reminders: sms, email or phone reminders were used to remind patients about their tasks in the intervention.
- Notifications: after entering a measurement the system would inform the patient of how good the value was. In case of bad values, nurses and doctors would be notified also.
- Tasks: these could be simple forms for measurement input or a questionnaire or educational content etc.
- Education: besides being delivered as a task, some static educational content was always available on the web application. It was published by the nurses and doctors. In addition, the system also supported news and recommendations for patients. Also, patients were able to ask questions in a form of discrete questions and answers or by using live chat.

These elements form the core object model of the intervention that was used on the business process level and on the user interface level. The functionalities that were implemented on the use interface level are shown on Figure 1. In addition to using the web based user interface, users also used mobile phones for sms messages and email accounts for receiving personalized emails.

The mapping from BCTs to BPMN2 or to ICT functionalities in general is simple for some BCTs like reminders, prompts; personalized feedback etc. In general, BCTs can be implicitly supported by a combination of functionalities or cannot be supported at all due to being on higher conceptual level in comparison to the ICT level. Our identified common BCTs set were chosen in a way that could be supported by ICT also for the purpose of reusing them in different interventions.

In Figure 2 we show a process model that describes a generic process that includes reminding patients of a new task for entering a value (max 3 reminders), calculating the value category and based on the category notifying either the patient, care manager and patient or all roles in case of a critical value. Such a model includes the mechanics of certain BCTs. We have modeled all the processes of the Diabetes intervention in a similar way and In Figure 3 we show a hierarchy of processes that has evolved from modeling the intervention and gave as a reusable set of process models that support different BCTs and can be reused on different interventions. We have obtained a library of BCTs mapped to process models.

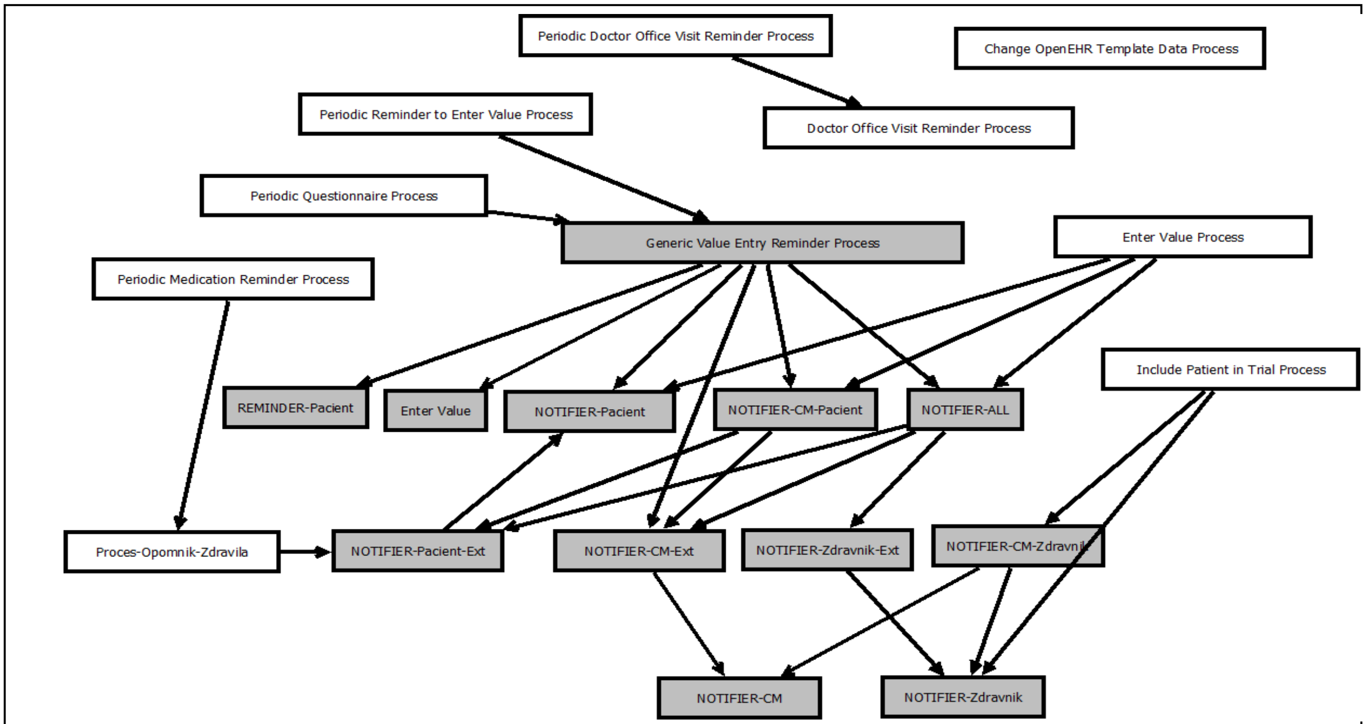

Figure 3 Process dependency hierarchy

The gray colored processes on Figure 3 are the basic elements that are used as functions from higher order processes. We used this core library of elements in all our interventions supporting also the following domains: asthma, obesity, and sports activity. The process depicted in Figure 2 is named *Generic Value Entry Reminder Process* in Figure 3. The process parameter values were injected from intervention specific configuration in runtime. In Figure 2 we can see a manual task named *Patient enters value.* This task is generic.

In specific intervention we inject the name of the web form that the patient sees in his *My Tasks* section of the web application. If the form is used to capture clinical data, it can be generated from the OpenEHR Template that exists for this form. The patient then enters the values and submits. The form data is posted to the application server where the web application is deployed. The intervention logic inside the web application receives the form data and communicates with the process engine. The process engine that is running our *Generic Value Entry Reminder Process*, receives the form data as input to the *Patient Enters Value* step of the process. The Java Delegate code is then ran by the process engine which uses the OpenEHR reference implementation to validate the form data and to perform some additional business logic that is connected to the current data (e.g. aggregate values). This form data is then stored in the XML based database as serialized OpenEHR xml document that represents an OpenEHR Template. In this way, we can query clinical data by using existing XQUERY and XPATH mechanisms or other means like XML-DB API.

Since Diabetes was only one of the overall five interventions we developed, one can quickly see that by having such reusable elements on the business process level and then also on the OpenEHR archetype level, we can achieve high level of reusability for new interventions that reuse many of the existing available models. In addition, since all these models are not hard coded into Java code, we can deploy these models separately from the Java execution code and thus achieve high level of decoupling. In Figure 4 we show the architecture of our platform as viewed from the perspective of supporting the Diabetes intervention.

The web application is deployed on a separate application server, namely, Tomcat 5.0. It was developed using Groovy language and Grails MVC framework. It called the Process Engine by using a REST API. All the forms for entering values and business logic were part of the process based platform. In this sense it is a very generic web application. The platform or the back-end was all Java and based on open source. The process engine was deployed on a Tomcat 5.0. It was an open source process engine Activiti [19]. The OpenEHR Execution Environment was the open source reference implementation of the OpenEHR reference model. The OpenEHR models were stored on the file system and loaded into working memory when the application server started. The process repository is depicted separately and the reason is that each process can be deployed by itself. The Electronic Medical Record depicts the logically separate repository of clinical data that is created by the nurses and doctors during patient visits. The Personal Health Record depicts the data entered by patients at home.

In order to successfully include the Diabetes intervention into the national eHealth infrastructure in Slovenia we had to define a new type of document in the national IHE XDS national repository. The Diabetes intervention would provide a new type of document in a form of a structured data set to the Slovenian healthcare system. The document was a HL7 CDA R2 xml standard document that had archetypes based structured OpenEHR xml data as the body of the document. In this way the data can be recognized by the national OpenEHR repository and can be available for querying immediately. Patients and the healthcare personnel can also view this new data during patients visit.

DISCUSSION

We have successfully tested a method for designing new eHealth and mHealth interventions that is grounded in theory and evidence by using BCTs to inform the design phase. The method included a mapping from BCTs to BPMN2 models, user interface functionalities and object models. All these models form a library of reusable ICT elements that support different BCTs and can be reused on different interventions. The intervention ICT elements were deployed on a common ICT platform that was based on BPMN2, OpenEHR and Java open source technology. In addition, BPMN2 has enabled us to bridge the semantic gap that is usually present between how business processes are seen by a business analyst and how they are seen by a software developer. Traditionally, these two views on business processes are captured by using

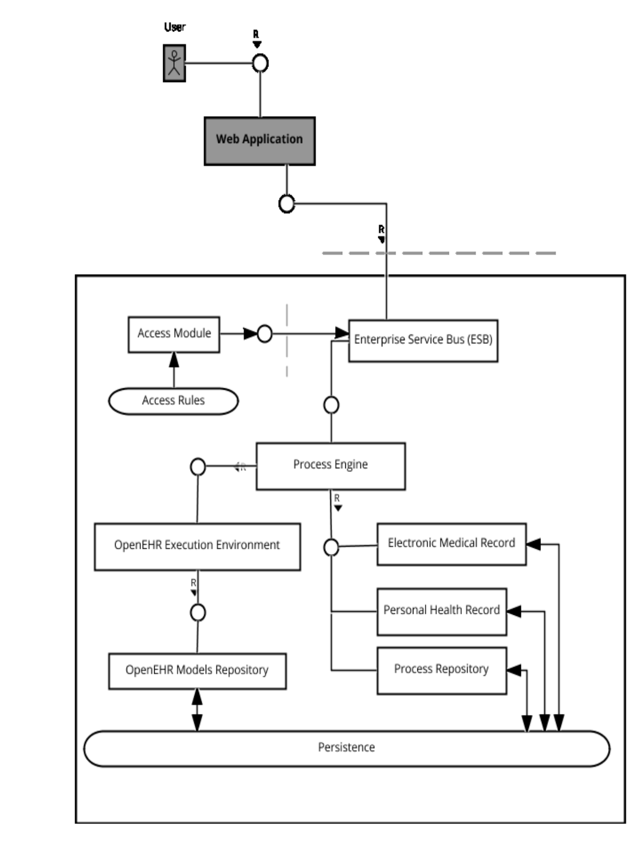

Figure 4 Architecture of the platform as a FMC

different modeling approaches that require another mapping between the two modeling approaches (namely from BPMN to BPEL).

By using OpenEHR to model clinical data, we have enabled greater interoperability due to open standards and open data concepts that the OpenEHR approach supports. We have easily integrated into existing national eHealth infrastructure of Slovenia that is based on IHE and OpenEHR. In this way the patient data can easily be transferred to whatever part of the Slovenian Healthcare System when needed.

LIMITATIONS

The intervention design only incorporated BCTs and mapped these to ICT elements. However, there are other important theoretical components and design features to consider in intervention design. For example, using a behavior change intervention development framework such as the BCW would help to link theoretical determinants (based on the COM-B model[20]) to intervention functions and BCTs as shown in other work [11]. Furthermore, there is also a need to incorporate design elements such as engagement attributes, which are important for the uptake and sustained use of digital interventions. These limitations provide fruitful avenues for future research linking evidenced based and theory driven intervention components to ICT features, resulting in the deployment of sustainable behavior change interventions.

CONCLUSSION

The OpenEHR clinical models are freely available as are also all the other models that support the Diabetes intervention. Due to being available on the national and international level, the OpenEHR models enable new business models that are not based on the traditional data lock-in where data is taken hostage by the Software Companies. In addition, by using our method of designing new interventions, and by using the supporting freely available ICT platform, more sustainable interventions can be supported in the long run while increasing quality of care delivery.

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