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A Model Driven Approach to the Development of Gamified Interactive Clinical Practice Guidelines

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Abstract: Clinical practice guidelines (CPGs) play a fundamental role in modern medical practice since they summarize the vast medical literature and provide distilled recommendations on care based on the current best evidence. However, there are barriers to CPG utilization such as lack of awareness and lack of familiarity of the CPGs by clinicians due to ineffective CPG dissemination and implementation. This calls for research into effective and scalable CPG dissemination strategies that will improve CPG awareness and familiarity. We describe a formal model-driven approach to design and implement a gamified e-learning system for clinical guidelines. We employ gamification to increase user motivation and engagement in the training of guideline content. Our approach involves the use of models for different aspects of the system, an entity model for the clinical domain, a workflow model for the clinical processes and a game model to manage the training sessions. A game engine instantiates a training session by coupling the workflow and entity models to automatically generate questions based on the data in the model instances. Our proposed approach is flexible and adaptive as it allows for easy updates of the guidelines, integration with different device interfaces and representation of any guideline.

1 Introduction

Medical knowledge is increasing at an exponential rate and it is difficult for clinicians to keep up with this quantity of knowledge production (Fervers et al., 2010). The development and use of clinical practice guidelines (CPGs) is a promising solution to this problem. CPGs are systematically developed statements that assist practitioners and patients to make decisions about appropriate health care for specific circumstances (Lohr et al., 1992). Guidelines are a comprehensive summary of the available evidence about medical conditions and provide recommendations for the management of those conditions (Goud et al., 2009). A well-developed guideline reduces variations in care, improves diagnostic accuracy, promotes effective therapy and discourages ineffective therapies all which contribute to improved quality of care (Shiffman et al., 2004). The mere availability of guidelines does not necessarily mean that the recommendations will be used in actual care. Indeed, there has been a reported gap between recommended care according to the evidence base and actual practice leading to preventable errors in practice (Donaldson et al., 2000; Baker, 2001). This gap can be attributed to several barriers to guideline dissemination and implementation which include: internal barriers (lack of awareness, lack of familiarity, lack of agreement with the guideline content, and the inability to overcome the inertia of previous practice) and external barriers (i.e., patient, environmental, and guideline related factors such as ease of use and complexity of the guideline) (Cabana et al., 1999).

The nature of guideline development means that published guidelines are well-researched, comprehensive documents that can be prohibitively voluminous. For example, the National Heart, Lung, and Blood Institute (NHLBI) 2007 Guidelines for the Diagnosis and Management of Asthma full report is 440 pages long (NHLBI, 2007) while the National Institute for Health and Care Excellence (NICE) guidelines for the diagnosis monitoring and management of chronic asthma (2017) report is 39 pages long (NICE, 2017). Such large texts are impractical for use at the point of care. Additionally, poor guideline presentation has been identified as a factor in the lack of physician familiarity as some of the guidelines have been described as being tedious, repetitive, confusing, and unclear (Cabana et al., 2000).

To mitigate some of the barriers to knowledge acquisition of guideline content, new dissemination strategies aimed at improving awareness and familiarity of guideline content are required. Active guideline dissemination strategies have been found to be more effective than passive strategies at improving the application of evidence based recommendations in patient care (Grimshaw et al., 2012). In particular, educational interventions (e.g. distribution of printed guidelines, educational meetings and outreaches) strengthen the effect of clinical educational material. Further, the more intensely the information is provided through these interventions, the greater its effect on the recipients (Marriott et al., 2000). Research into active strategies for clinical guideline dissemination are timely and relevant as they will potentially help to plug the gap between recommended and actual clinical practice.

One potentially useful active educational intervention is in the distribution of gamified guidelines. Gamification is the use of game design elements in non-game contexts (Deterding et al., 2011b; Deterding et al., 2011a). It uses game based mechanics, aesthetics and thinking to engage people, motivate action, promote learning and solve problems (Kapp, 2012). The concept of Gamification is relatively new and has been used to describe the use of game-based concepts and techniques, with the goal of increasing the motivation and engagement of the participants and improving the results.

The implementation of guideline summaries as interactive, gamified flowcharts on a mobile platform will potentially mitigate the problems of guideline complexity and presentation that plague the effective dissemination of guideline content. In this paper we present a formal model driven approach to gamification of clinical practical guidelines. To illustrate the approach, we present three models, an entity model of the clinical encounter domain, a workflow model for the clinical processes and a game model all of which will be integrated to create our gamified system. We also describe a prototype mobile-based guideline app that incorporates these models to present a gamified interactive guideline training tool.

The rest of the paper is organized as follows: In section 2 we give an introduction to the Diagram Predicate Framework (DPF) and show how it can be used for modelling CPGs workflows and entity models for the clinical domain. Moreover, we illustrate how the guideline workflow information is synchronized with the domain information. In section 3 we introduce our approach to gamification of workflows and discuss in further detail the use of the different models in our design. In section 4 we describe the implementation of our approach in the development of the prototype system. Finally in section 5 we compare our approach to other works before we conclude the paper and envision further work in section 6.

2 Background

In this work we use a formal diagrammatic approach to model driven software engineering (MDE), called Diagram Predicate Framework (DPF). MDE is a system development paradigm that promotes the use of models as the primary artefacts that drives the whole development process. In MDE models are specified using a modelling language whose syntax and semantics are defined by a metamodel (Rodrigues da Silva, 2015). This allows for the development of domain-specific modelling languages (DSLs) using notations and abstractions that are unique to a given domain. The use of DSLs allows for the development of more expressive models and ease of use by domain experts.

In this section we provide an overview of how diagrammatic models can be created using DPF. We chose to use DPF as it can be used to create custom domain specific modelling languages. Furthermore, we'll present a metamodel for representing a CPG workflow, a simple entity model for the medical domain, a model for the game engine and finally an integrated multi-metamodel that incorporates the entity and CPG workflow models. UML is another alternative approach for the modeling of various kinds such as UML entity model, sequence model. However, DPF allows us to do multilevel metamodeling and also visualizes constraints in the models.

2.1 Diagram Predicate Framework (DPF)

DPF formalizes software development activities such as metamodelling (Rutle et al., 2009) and model transformations (Rutle et al., 2012) based on category theory (Barr and Wells, 1990) and graph transformations (Löwe, 1993). By applying DPF we can formalize clinical guidelines and clinical domain models at different abstraction levels in form of diagrammatic specifications. The diagrammatic nature of DPF also

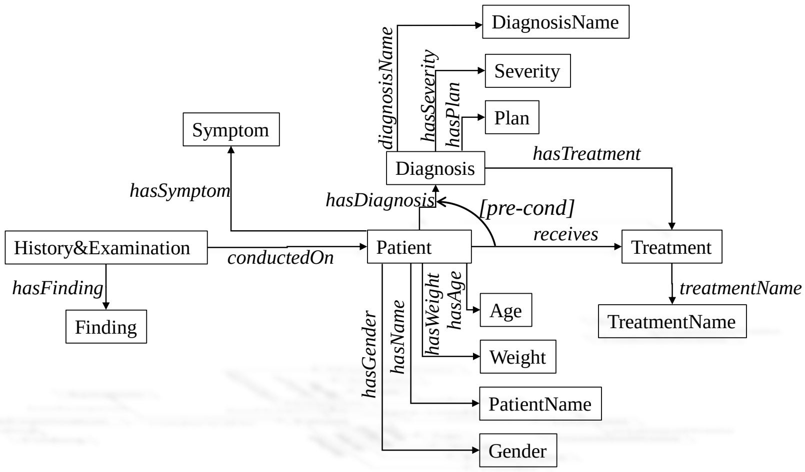

Figure 1: A simplified entity model of the clinical encounter domain

facilitates visual representations of guidelines that can be presented at different level of abstraction. A model in DPF is represented by a diagrammatic specification $\mathfrak{S} = (\mathcal{S}, C^{\mathfrak{S}} : \Sigma)$ which consists of a graph $\mathcal{S}$ and a set of constraints $C^{\mathfrak{S}}$ specified by a predicate signature Σ.

The predicate signature is composed of a collection of predicates, each having a name and an arity (shape graph). A constraint consists of a predicate from the signature together with a binding to the subgraph of the models underlying graph which is affected by the constraint. In order to apply DPF for the modeling of a game that operates over clinical practice guideline we need to formalize the concepts of a guideline using DPF and also model the gamification concepts with DPF. In the following subsection we present how DPF can be used to model different aspects of guidelines and representing the concepts for gamification.

2.2 Entity modelling

We will now present an entity model of the clinical domain. To do this we use a metamodel containing Concepts, Attributes and References. An actual model typed over this metamodel is shown in Figure 1. We have concepts and corresponding relations for domain entities such as Patients, Diagnosis, Treatments etc (see Figure 1). The model consists of a constraint modeled with a predicate named 'precondition' and visualized with symbol $[pre-cond]$. The constraint specifies that all the treatment instances must have a reference to a diagnosis instance.

2.3 Workflow modelling

Clinical practice guidelines often consist of a flow of information. Workflow models may be used to represent the flow of a guideline. In Figure 2 below we see an example metamodel (M_2) for behavioural models, where Tasks can be connected by Flow edges. On the next abstraction level (M_1) we see a generic treatment model that is typed by the flow model. The treatment model has three tasks Assessment and Diagnosis, Treatment and Evaluation. Finally, at (M_0) we see an instance of the treatment workflow of a severe asthma diagnosis.

2.4 Game modelling

At their core, games are goal-oriented activities with reward and progress tracking mechanisms. The design of gamified e-learning systems should be undertaken in the view of these core concepts. In our system, the training will be done through a series of questions based on the guideline content. The game engine in our model automatically generates questions from the entity and workflow models to instantiate a training module. The questions are categorized according to the learners skill level (beginner, intermediate, advanced) and each question has a reward in the form of points. A game model should also specify a learner profile that tracks the learners activities.

2.5 Integrating Models

The training model is built by the integration of the entity and workflow models based on the principles introduced by Rabbi et al (Rabbi et al., 2014a). The states of the training module TM are defined by a set

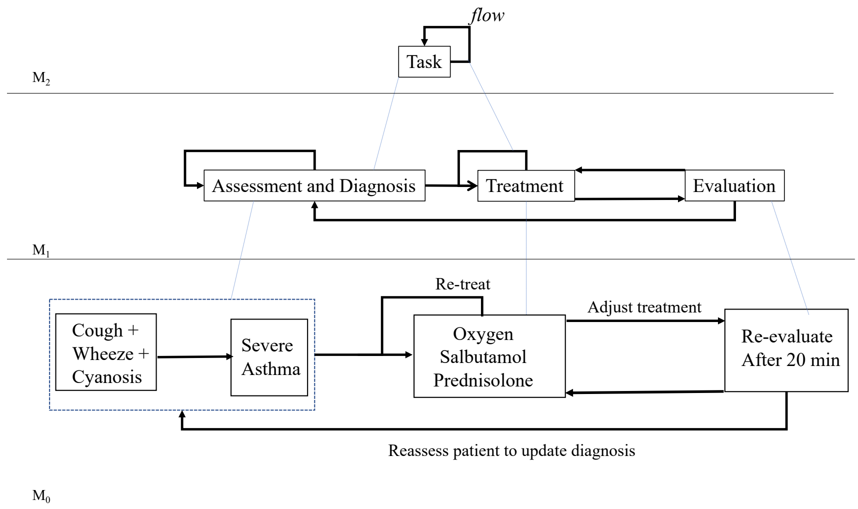

Figure 2: The workflow model with its metamodel

of elements that include a pair of workflow instance WI and an entity instance EI: $TM_i =< EI_i, WI_i >$ where i is a natural number. This integration of models is shown in Figure 3 and the concept is discussed in more details in section 3. In Figure 3, we show a section of the entity model with values from a given scenario where based on the *History & Examination findings*, a *Diagnosis* of Severe Asthma is made and its *Treatment* specified. The flow of how this process should happen is shown in the workflow model.

3 Proposed Method

3.1 Gamification elements

The core concepts of games that should inform the design of gamified e-learning systems are goal oriented activities with reward mechanisms and progress tracking (Strmečki et al., 2015). In the training of guideline content, the main goal is for the trainees to learn how to treat different aspects of a disease as described in the guideline. The reward mechanisms and progress tracking aid in increasing the users engagement and motivation (Bernik et al., 2018).

3.2 CPG modelling

In our approach, we separate two aspects from a clinical practice guideline (CPG). Medical conditions and clinical encounters of patients is one aspect which we model in an entity model; recommended clinical processes is another aspect which we model in a workflow diagram. A flow in a guideline often consist of medical conditions such as 'start giving oxygen if a child is convulsing for more than 5 minutes'. Typically a modeling approach specifies all the recommended processes in a workflow diagram. An instance of the diagram would then specify a concrete scenario representing the care processes executed for a patient.

In our approach, we skip modeling the general recommendations in a workflow diagram and directly specify concrete scenarios. For example, in our approach we model a scenario where a 2 year old boy who is convulsing for 7 minutes is admitted to a hospital and we start treatment by giving oxygen. We follow this approach as it allows us to model concrete scenario with less effort and we do not need to spend time on encoding the whole guideline. Since the purpose of modeling the guideline scenario is to generate questions using our approach, it is sufficient for us to model the scenario representing the recommended clinical processes according to the guidelines. To represent such scenarios we integrate a CPG workflow model with an entity model which is encoded as a DPF model. Typically, a CPG consist of a large number of pages with information from the clinical domain. There exists some approaches that allows us to design a visual model of a CPG.

In (Rabbi et al., 2014a; Rabbi et al., 2014b), the authors presented an approach where different aspects of a system were coordinated by means of multiple metamodels. The approach is based on the foundation of DPF.

In the multi-metamodeling approach, a workflow model is integrated with an entity model by means of metamodel coordination. A workflow metamodel is

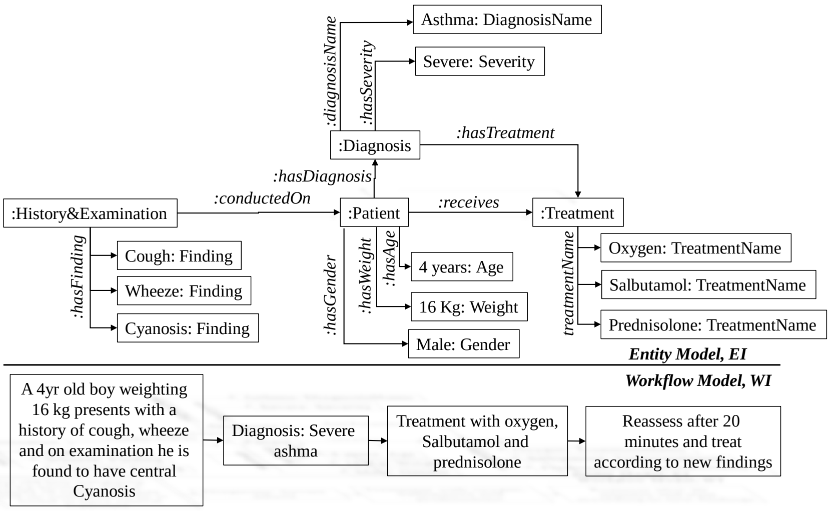

Figure 3: Integrated entity and workflow models

used to design the flow of a system and an entity metamodel used to design the entities and relationship of a domain. A workflow model can be used to represent an abstraction of a CPG but we need to incorporate the detailed domain knowledge in our modelling. In this paper we exploit the use of the multi-metamodeling approach to represent the domain knowledge of a clinical guideline and the clinical process and apply them to execute a training session. The idea of using the CPG workflow model is to control the flow of the game such that the user is interacting with the right gaming element at the right time.

In this section we explain a training module which consist of one or more CPG models and one or more entity models represented as DPF specifications. The states of the training module TM are defined by a set of elements that include a pair of CPG workflow instance and a DPF entity instance that represents the entities within a domain and relationships between them. Figure 4 illustrates an example of two states TM_1 and TM_2 of a training module. The state TM_1 consists of a set of elements that include a pair of workflow instances and DPF instances: $\{< WI_0, EI_0 >, < WI_1, EI_1 >, .. < WI_n, EI_n\}$ where $WI_1, WI_2, ..WI_n$ are workflow instances and $EI_0, EI_1, ..EI_n$ are DPF entity instances. Figure 4 shows a training session flow which consists of a sequence of states of training module i.e., $Training_{Flow1} :=< TM_1, TM_2, ...TM_k >$. Figure 3 shows an instance of a training session. In Figure 3 the game engine instantiates a training session by generating questions based on the DPF entity model and CPG workflow model. For example, it could initially generate a scenario based on the patient details and history and examination findings and ask what the diagnosis is. If answered correctly, it will move on to the next task and ask about the treatment. A training session is composed of a sequence of training modules and is evolved from the initial state of a training flow and progresses based on the answer provided by the user.

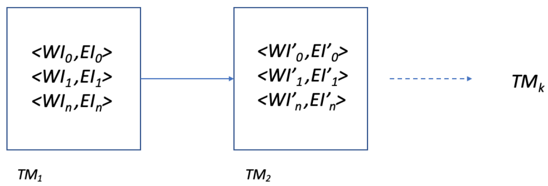

Figure 4: States of training module

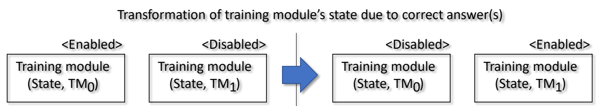

Figure 5: Progression of the states of training module

In our approach a training session is evolved from the initial state of a training flow and progresses based on the answer provided by the user. Figure 5 illustrates the idea of the progression of the states of training session. Depending on the answer given by the user, a game engine consults with the training flow and evolves the state of the training session. We use two DPF predicates $< Enabled >$, $< Disabled >$ to represent the current status of the training modules. A training module TM_0 when annotated with the $< Enabled >$ predicate indicates that the training

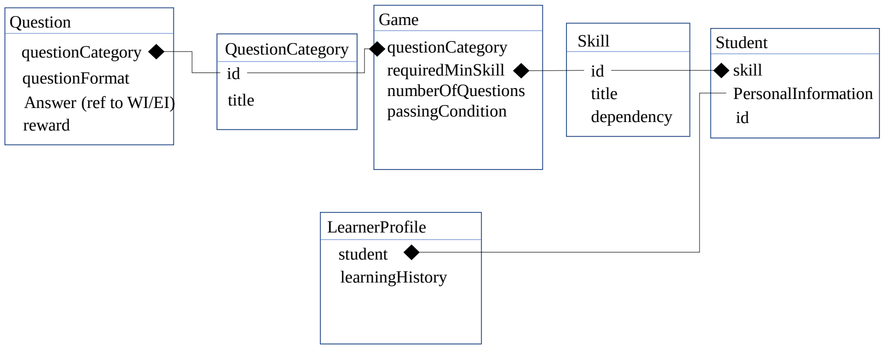

Figure 6: A conceptual model for the game elements

module is currently active and is being considered for training.

The answers are collected from the user in two different ways. We can ask the user to answer some questions about the domain ontology i.e., entities and their relationships; also the question can be based on the workflow instance. We utilize another DPF model to formulate the questions that can be asked to the user. Figure 6 shows the DPF model representing the concepts of an e-learning game. The model represents the game elements which include information about how the game engine should control the game. In our approach a game instance is associated with a training module. Using this DPF model we can specify the number of questions to be asked, passing condition and can include questions under some question category. We use references to the CPG instances and entity instances for specifying correct and wrong answers.

A general concern about this approach is the validation of the training flow. While constructing a training flow one might make mistake in two ways: (a) wrong composition of instances of CPG model and entity model; (b) wrong flow of CPG instances. To reduce the number of errors we apply inconsistency checking as described in the next section.

4 System Description

We propose to use a generic system based on the idea of multilevel-metamodeling and their coordination. Figure 7 shows an overview of the system. The responsibility of the 'Game Engine' is to control the training flow, maintain the status of the trainee, produce dialogues or control the visualization of the screen. The user should be able to interact with the game engine via 'Google Assistant' or 'Mobile application'.

We plan to support different types of devices for the training to facilitate training considering various learning style of the trainee.

Question Flow manager: The question flow manager selects the questions to be asked depending on the level of difficulty of a training session. It maintains the order of questions to be shown to the user. For example, user-A has skill-1 and chose to go through the beginning session. While randomly selecting questions that falls under the difficulty of 'Beginner', it also looks into the questions that has been used before for user-A. It puts more emphasize on the questions that the user has been struggling with.

Conversation manager: The conversation manager keeps track of the conversation and manages the context of the conversation. For example, if there are three questions to be asked that is related to a child who is 2 years old, then the conversation manager produces a context for three questions and starts the conversation saying "A 2 year old child comes to the emergency department with <some condition>, answer to the following questions:". Afterwards it asks the first question, followed by the 2nd and 3rd questions.

User management: The user management module keeps track of the trainees skill, progress and effort. The user management module is also used to produce visualization showing the performance of a population. If a group of trainee is particularly struggling with a set of questions or question category then the user management module will produce a report and the trainer will be able to monitor it.

4.1 Adaptiveness

There are two ways our system facilitates adaptiveness:

- Customizing the gamification process by means of model-driven-engineering approach.

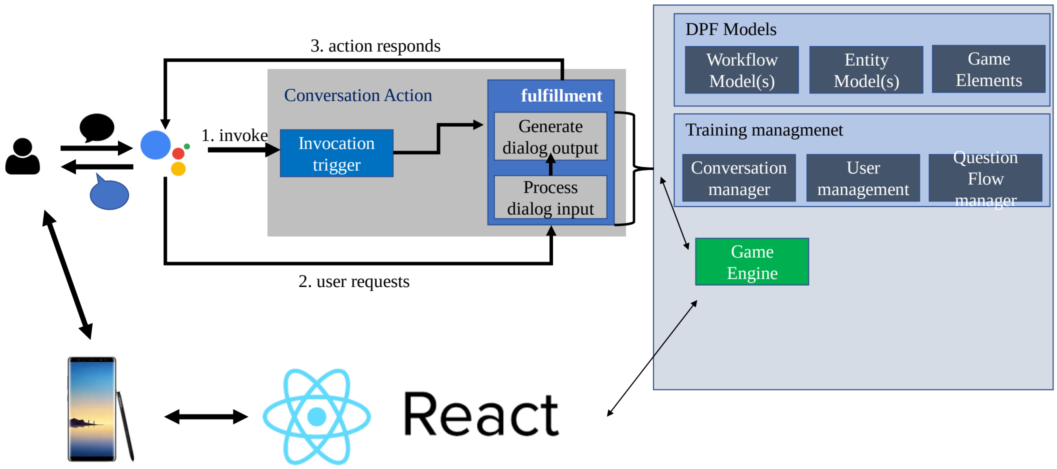

Figure 7: Overview of the proposed system architecture

- Capturing the learning behaviour of trainee and changing the model accordingly.

4.2 Methods

Our approach consists of modeling the entity which represents the concepts related to clinical information; the workflow which represents the flow of a guideline; and the structure of a game. We propose to use WebDPF tool for the modeling of these elements. The multilevel metamodeling supported by the WebDPF tool allows us to design domain specific modeling languages. The tool is also facilitated with a constraint checker which allows us to check if the models being constructed are valid or not. We persist our models using JSON format. Figure 8 shows an overview of the proposed system where the game engine reads the models using a model parser. The game engine executes the game by asking questions to the trainee and also stores the answer in a relational database. We have developed a report engine which retrieves data from the relational database and visualizes learning analytics to the trainer. The trainer can also interact with the report interface and can visualize the data from different perspective. The trainer can get an overview of the training modules and can select individual trainees usage statistics. In our current implementation we have not incorporated any machine learning algorithms. Therefore, adapting a training module according to the requirement of the trainee are done manually by the knowledge engineer.

We used this modeling architecture to develop a proof-of-concept game for the asthma guideline training. Figure 9 shows a sample conversation from the asthma guideline training. While the participant is using google assistant we use the google account for registering the participant to our system. It is planned to use OAuth 2.0 protocol for authenticating the user from the mobile application to the participants Google account. It will allow the user to switch from one device to another. While the participant is using the mobile application they get more feature such as browsing the guideline.

4.2.1 Implementation of the mobile application

The application is developed using React-Native and JavaScript. React-Native is based on the React framework, and is used to build mobile applications for Android and iPhone. The motivation for using such a framework is reuse of code when supporting both mobile platforms as well as the web.

The game consists of a collection of quizzes, where each quiz contains several questions. These questions are based around a scenario, where the student is presented with answer alternatives. Picking an answer alternative will give the student points for how close he was to the right action. The student is presented with the answer key, an explanation, as well as pointers to the evidence and the relevant guideline for further study.

The quiz will conclude with a summary, giving feedback and statistics on students performance. The quiz should have a passing condition to unlock quizzes at a higher difficulty level. This is illustrated in Figure 10.

4.2.2 Generating the scenarios

To generate questions, we will write small scenarios in the form of narrative templates where we use tags to refer to variables in the entity model. The tag refers

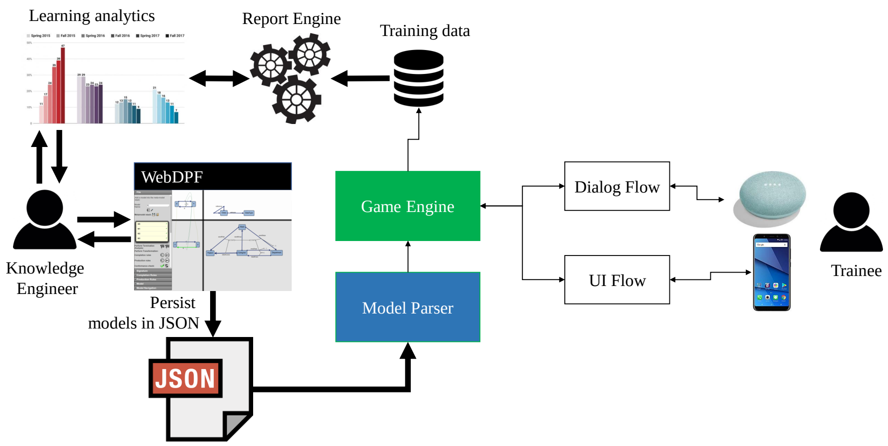

Figure 8: Proposed method of the system

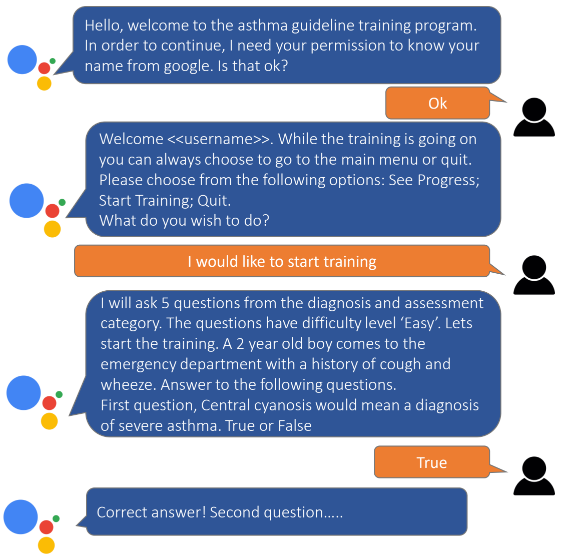

Figure 9: Sample flow of conversation from the asthma guideline training

to a path in the entity graph. The application will traverse through the graph and return the value of the given vertex.

A challenge with this method, is how to present the data returned by the graph in a text. The value from a measurement of the pulse-rate is just an integer. An observation that the patient has a breathing condition is a boolean, and an observation of the patients level of consciousness is an enumerate of the AVPU (Alert, Verbal, Pain, Unresponsive) scale. These values will have to be presented differently to make a good sentence in the scenario. How we solved this issue was by letting the vertex hold a string representation of its value. This is illustrated in Figure 11.

```
<%Ben.name%> arrives at the emergency
department.
He <%Ben.hasConsciousness.value.name%>.
```

translates to

```
Ben arrives at the emergency
department.
He is not alert and not verbal,
but responds to pain.
```

5 Related Work

In (Farkash et al., 2013) Farkash et al. presented a model-driven approach to formalize clinical practice guideline using natural rule language (NRL). Specifying the constraints of a guideline with English-like rule language reduces the gap of the representation and processing of guidelines. The authors presented a set of software components that support the representation, interpretation of CPGs using NRL and also can be applied directly to a patient's EHR data for analysis. Their approach is supported by a proof-of-concept implementation for a simple essential hypertension guideline directive. Our approach is different with their approach as we use a graph based modeling technique and the main contribution of our approach is to support the training of a guideline by means of gamification.

In (Kristensen et al., 2009) Kristensen et al. presented a conceptual model for e-learning where the learning materials are divided into atomic units and organized in several graph based models such as 'Knowledge map', 'Learning map' and 'Student map'. These conceptual models provide a better structure for representing an e-learning environment

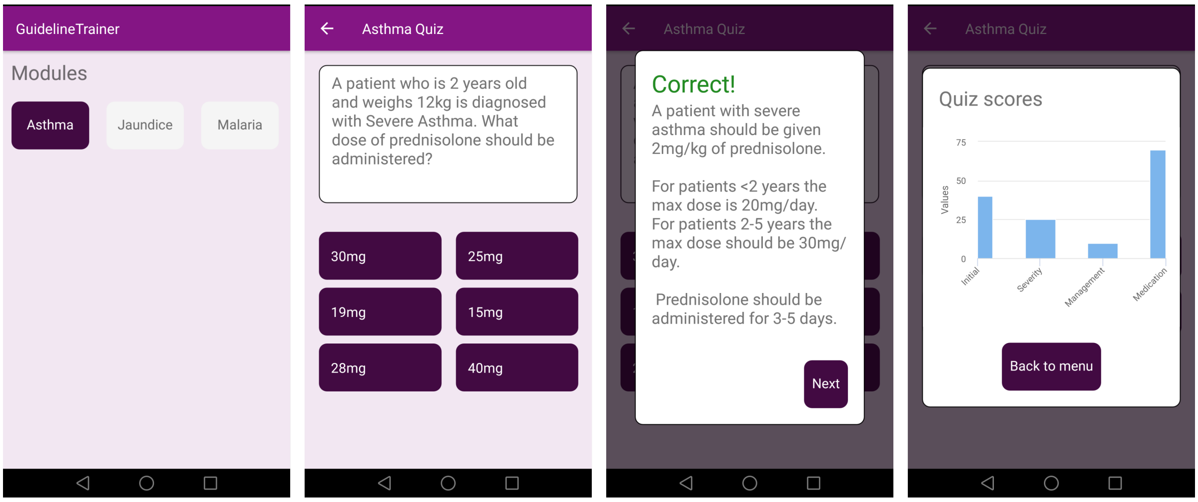

Figure 10: Flow of the mobile application

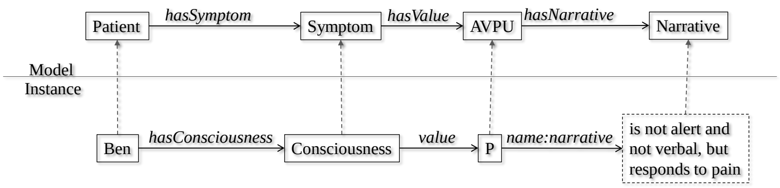

Figure 11: Importing variables from graph into scenario

and an easy-to-use navigation interface for existing learning materials. We borrowed concepts from this paper and adapted them for representing CPGs and game elements by means of Diagram Predicate Framework and multi-metamodelling approach.

A gamification approach was presented in (Akl et al., 2008) where the authors followed the format of TV game shows in which two teams of residents compete in answering questions that are based on the recommendations of guidelines. However, their approach is lacking formalization and does not support model based analysis. In our approach we emphasize on the modeling part and apply model driven engineering technique to interface with various platforms.

In (Del Cura-Gonzlez et al., 2016) the authors conducted a study to assess the effectiveness of a teaching strategy for the implementation of CPGs using educational games. They demonstrated the results for an e-learning game EDUCAGUIA to improve knowledge and skills related to clinical decision-making by residents in family medicine. The game consists of educational games with hypothetical clinical scenarios in a virtual environment. To identify the effectiveness of teaching strategies through e-learning, they proposed an average score comparison of hypothetical scenario questionnaires between the EDUCAGUIA intervention group and the control group. Such evaluation is very important and it reflects the usefulness of utilizing games in teaching guidelines. We plan to conduct similar evaluation of our gamification approach with healthcare professionals in future.

(Aouadi et al., 2016) uses Technology-Enhanced Learning standards to develop serious games which can be used in technological/professional/academic fields for learning. Their goal was to make a scenario-building approach, built upon a model driven architecture. The game includes a health course with demonstrative videos and evaluation quizzes with each course having a passing condition. The game is also demonstrated as a 3D game in a context of medical training. In their approach Aouadi et al., used a platform independent model for the development of game components which was transformed into a platform specific model by means of ATL transformation. While their approach is very close to our proposed method, they lack modularization and separation of concerns. In our approach we do not only apply multilevel metamodelling but also the integration of different modeling hierarchies which allows us to conveniently articulate various aspects of an e-learning system.

(Wyatt et al., 2013) presents OKWA (Okay with Asthma) which is a game targeted on children. They aim at educating children with asthma in self-management skill. This includes information about medications, how to avoid triggering the asthma, monitoring, when and how to get help from others. The game is an interactive animated movie-style narrative, where the actions the child chooses will have an effect on how the story develops. Our project differs from this one as our target group is adult health care workers. We will also focus more on evaluation of medical knowledge through tasks and quizzes rather than just story telling.

(Shegog et al., 2006) is similar to the OKWA project, as it targets self-management skills for children with asthma during a role playing game. The game uses the child's asthma profile, so the child can see the responses to his/hers health information in the game. To complete a scenario, the character in the game needs to be symptom free.

(Zolfo et al., 2010) describes an approach where they use mobile phones as a personal learning environment for health care workers in resource limited environments. They put an emphasize on the importance of avoiding health care workers being absent from the health station for training programs. They use didactic learning material (3d animations, video, presentations, sound) and evaluates learning through multiple choice questions. They also use Skype and Facebook to have clinical case discussions with a network of experts. The project differs to ours, as they have an emphasize on didactic distance-learning while we are learning through actively solving problems and tasks through gaming elements.

(Bartel et al., 2017) aims for a generic gaming platform for implementing gamified learning arrangements in engineering education. Their approach to implementation is based on the concept of domain-specific modeling, which is descirbed as an instance of model-driven software design. However both theirs and our projects are in the field of model driven development, Bartels work aims at engineering education, while we aim at education of health care workers. Their project is a work in progress, and have limited results to analyze and compare to.

(Pesare et al., 2016) presents both Edugame and Simulation of Clinical Cases. Edugame is aimed at patients and caregivers, to manage the disease and promote a healthy lifestyle to avoid critical situations and hospitalization. The game is a role-playing game, and the users mission is to answer correct on the problems posed on the character in the game. Simulation of Clinical Cases is a single player simulation game. The goal is to save the character in the game, by the user suggesting the right therapy, action and/or examination to solve the condition the patient in the game has. The game adapts to which role the clinician has, so the game will be different for a nurse and a physician. The game provides scores according to if the answer was correct, partially correct or wrong. Our project has a larger focus on model driven development and a data model to easier add new content and other types of games.

Septris (Evans et al., 2015) is an online training tool to help emergency clinicians to identify and differentiate between the different forms of the sepsis syndrome. Pick the right diagnostic tests and provide optimal management of the syndrome. Diagnose and treatment is a big part of our project as well, but it will be made general enough to make games for several different medical conditions.

6 Conclusion

In this work, we have presented a model-driven approach to the design and development of a gamified system for learning clinical guideline content. We also present a prototype mobile e-learning system that utilized our design approach in its development. In the near future we aim to test our system with clinicians to evaluate its usability, acceptability and effectiveness.

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