Supporting the Adaptive Generation of Learning Game Scenarios with a Model-Driven Engineering Framework

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Abstract. Learning games are promising methods for autism therapy. In this context, our research project aims to propose an "escape-room" game for helping children with Autistic Syndrome Disorder (ASD) to learn visual performance skills. Given the specific needs of the intended players, the generation of learning scenarios has to be adaptive. For that, our proposal relies on Model Driven Engineering techniques to deal with dynamic scenarization instead of implementing fixed configurations of scenarios. Our approach proposes to express the game description components and child profiles as models from which adapted scenarios can be automatically generated by means of model transformations. In addition, an iterative co-design process based on rapid prototyping is introduced. It allows ASD experts to take part in the design activity and get fast feedback.

Keywords: Serious game · Autism · Learning scenarios
Adaptation · Model Driven Engineering

1 Introduction

The use of serious games [3] in Autistic Syndrome Disorder (ASD) interventions has become increasingly popular during the last decade [4]. They are considered as effective new methods in the treatment of ASD and efficient means of transferring knowledge [4,18,19]. Computerized interventions for individuals with autism may be much more successful if motivation can be improved and learning can be personalized. In fact, game adaptivity (i.e. customize the game according to each learner individuality) is very important particularly for learner with specific needs.

This research work is conducted in the context of the *Escape it*! project. The objective is to develop a serious game to train visual skills of children with ASD. This serious game will borrow mechanics from "escape-room" games (i.e. the player has to solve a puzzle in order to open a locked door to escape the room). The current paper tackles the challenge of generating adapted learning sessions

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to autistic children. For that, it was crucial to involve ASD experts in the first development stage. The aim is to guarantee that the proposed game fits to ASD characteristics while to be individually adaptive to each child.

We propose a model-driven design process that allows domain experts to take part in the design activity and guide the development of the game (i.e. the focus is on adaptation and the game scenes set-up). Hence, we provide experts with means to determine the game components and the way game sessions have to be constructed and adapted. Besides, our proposal includes a rapid prototyping support so that the experts can immediately test a playable version of the game and give relevant feedback about the adaptation and generation rules.

The remainder of this paper is organized as follows. In Sect. 2, we present the context of this research work. Section 3 provides a review of adaptation challenges and mechanisms for generating adapted scenarios. Then, Sect. 4 gives a global overview of our proposal followed by an application case in Sect. 5. Finally, Sect. 6 concludes this paper and presents future work.

2 The *Escape It!* Project

The project aims to develop a mobile *learning game* (i.e. a serious game with learning purposes) dedicated to children with ASD (Autistic Syndrome Disorder). The game intends to support the learning of visual skills derived from a curriculum guide [13]. It will be used both to reinforce and generalize the learning skills. These skills will be initiated by "classic" working sessions with tangible objects.

2.1 General Overview of the Serious Game

The serious game is based on a minimalist "escape-room" gameplay. The child (player) has to drag objects, sometimes hidden, to their correct locations in order to unlock the room's door and get to the next level. The drag and drop gameplay for matching/sorting/categorizing pictures is already implemented in several mobile games targeting children with ASD. As for the "escape-room" orientation, it has been proposed by the autism experts involved in the project.

The involved experts consider that the proposed game can be an intermediate support for learning generalization between therapy structured setting and generalization in a child's natural environment as fostered by the Pivotal Response Treatment (i.e. PRT is an intervention that focuses on the generalization of learned skills in the child's natural environment [8]). The game propose to deal with "responding to multiple cues" and "self-management" which are among the four pivotal areas of PRT.

The game design relies on best practices founded in the literature [4,19] and recommendations/requirements expressed by the ASD experts. The main concerns are listed below:

- Targeted skills: a subset of the visual performance skills derived from [13] that can be adapted for a mobile gameplay (e.g. matching an object to an identical

object, sorting similar objects, categorizing objects with same functions or characteristics...).
– Variable game sessions: the game proposes from 3 to 6 levels at the convenience of the pairing adult or the child.
– Scenes as meaningful living places grouped into themes: for example, the *bedroom, kitchen* and *living room* are related to the *home* theme. Whereas, *classroom* and *gymnasium* belong to the *school* theme.
– Adapted difficulty: the difficulty level is set according to the current child's progress in the targeted skill. Basically, three successful activities for a same skill (along one or several game sessions) raise the difficulty level for this skill.
– Generalizing the acquired skills: it is the process of taking a skill learned in one setting and applying it in other settings or different ways [9]. To this end, scenes have to be changed in accordance with previous difficulty levels. Hence, the game proposes non-identical challenges for the same skill. We quote variation examples: (i) changing the background and elements of a scene; (ii) adding background elements to disrupt visual reading; (iii) changing the objects to find and handle; (iv) adding other objects that are not useful for the resolution; (v) hiding objects behind or into others.

Figure 1 depicts an example of a scene which targets the B8 skill (i.e. sort non-identical items) in the '*Expert*' difficulty level. Trucks and balls have to be found and moved into the appropriate storage boxes before the door opens. Interactive hiding places, like the closet and its drawer, can be opened showing hidden objects.

Fig. 1. An example of the *bedroom* scene

2.2 Components of a Game Scene and Design Issues

Whichever scenes are selected for the learning scenario, they share common features:

– A background image that depicts a familiar scene for children with recognizable objects.
– Several empty slots where objects to find can be placed.
– Additional decors to impair visual reading with respect to the difficulty level. Each one can:
  • Appear in different locations.
  • Create new slots for other game objects.
– Interactive hiding objects that provide new slots to hide objects and reveal them when touched.
– Solution objects where game objects have to be placed in/on. One or several places can be proposed to place a solution object or the different instances required to solve the level (e.g. for sorting objects two or more storage boxes can be used).

A game scenario is an ordered sequence of scenes with precise descriptions of their setups. All the related information (e.g. number of scenes, selected scenes, order, scenes components and locations...) has to be adapted to the child's profile when starting a new game session. There are various profile variables (e.g. current progress in learning skills, preferences/dislikes, difficulty level of each skill...) and a lot of combinations of elements to set-up a scene. It will be time-consuming and costly to design and develop all the combinations of settings. Therefore, we need to generate dynamically game sessions adapted to each child's profile. The following sections detail our proposal to address this issue.

3 Background and Positioning

The motivation for steering adaptivity in serious games is to improve the effectiveness of the knowledge transfer between the game and its players. Several studies tackled the adaptation issue in order to find a balance between the player's skills and the game challenge level. The learning goals to achieve are usually strongly coupled with the gradual personal improvement of a skill set. Generally, adaptive serious games have specialized *ad hoc* approaches where game components are adjusted in order to encourage training of a specific skill.

Research work dealing with adaptivity have different targets (game worlds and its objects, gameplay mechanics, nonplaying characters and AI, game narratives, game scenarios/quests...) [2,7,15]. Game scenarios are generally defined as *the global progression within a game level, its initial settings and the logical flow of events and actions that follow* [5], whereas game worlds are *the virtual environments within which gameplay occurs.* In our context, we are focusing on learning game scenarios because each scene to achieve targets a specific skill. Besides, we disregard the flow of events or actions because our game will not embed script-oriented events. The resolution of a scene only requires that the learners find and move objects to their appropriate target locations. Our context partially maps the game world and its object definition in the way that the available objects of scenes can have zero or more instances according to the generation process.

Research work adressing game adaptivity also rely on various methods [2,7,15] (e.g. Bayesian networks, ontologies, neuronal networks, rules-based systems, procedural algorithms…). The model-driven approach we propose is not currently widespread. Nevertheless, it has been used in instructional design contexts to deal with learning scenarios specification and implementation issues [10].

Reaching beyond skill-driven adaptivity and integrating scenario with world adaptation/generation while the game is running remains a research challenge [11]. There are two approaches to tackle it: (1) during the loading stage of a game session by considering player-dependent information; and (2) in real-time during game playing. Our concern relies on the first approach.

In [1], the authors have proposed a system for generating content highlights the involvement of domain experts (i.e. teachers) to control the content generation. Teachers can select pre-created game objects, add new learning content to them and create relationships between objects. Knowledge about objects and their relationships seems a basis for solving and generating all the appropriate content. It could be a valuable contribution to control the generation of our learning game scenarios by using knowledge on the objects of each scene and their relationships. Such game knowledge should be specified at a high semantic level in order to involve domain experts.

Closer to our concerns, the work presented in [14] proposes a generic architecture for personalizing a serious game scenario according to learners' competencies and interaction traces [6]. The architecture has been evaluated with the objective to develop a serious game for evaluating and rehabilitating cognitive disorders. It is organized in three layers: domain concepts, pedagogical resources and serious game resources. In addition, this proposal allows the generation of three successive scenarios (conceptual, pedagogical and serious game scenarios) according to the three presented layers. As for the validation of the generated scenarios, the authors used an evaluation protocol. For that, experts were involved at first to validate the domain rules, *a priori* of the generator implementation, and then to produce scenarios for specific contexts. These scenarios are compared to the generated ones. Hence, experts guide the requirements specification and validation activities, but they are not directly involved in the generation process.

4 A Model-Driven Co-design Process for the Serious Game

Our general concern is the generation of learning scenarios adapted to children profiles while considering the game knowledge. More precisely, we have derived three related challenges:

1. How to make explicit and well defined the domain components (skills, game knowledge, learner model elements...), as well as the mapping and generation rules.
2. How to use these information to drive the generation of adapted learning scenarios.
3. How to involve domain experts in the design and the validation of our serious game.

Model Driven Engineering (MDE) is a research domain promoting an active use of models throughout the software development process, leading to an automatic generation of the final solution. In our case, MDE allows expressing the game description, the learner profile, and the learning scenarios as active models. Hence, adapted scenarios can be dynamically generated by means of model transformations (challenges 1 and 2). These models are expressed in a high level of abstraction so that the participation of domain experts in the design/development activities does not require a technical background (challenge 3). Also, model transformations make it possible to automatically propagate changes of these models to the generated scenarios. Therefore, we can achieve quick feedback from domain experts (challenge 3).

4.1 A 3×3 (Meta-)modeling Architecture

We propose a 3×3 metamodel-based architecture: 3-dimensions specification of domain elements to be managed, and 3-incremental perspectives on the resulting scenarios.

The generic domain concepts and relations, required for the generation of scenarios, are defined by three inter-related metamodels (see the top part of Fig. 2): *Learner* metamodel, *Game Description* metamodel and *Scenario* metamodel. The *Game Description* metamodel plays a central role because it describes static game knowledge and relations including those referencing the supported skills. Thus, the *Learner* and *Scenario* metamodels include references to it.

Different models that conform to the presented metamodels are managed (bottom part of Fig. 2). The game description model describes all the real game elements (skills, resources or exercisers, in-game objects...). As for the profile model, it represents a player's (child's) profile. These models are transformed into three target scenarios (objective, structural and feature) that conform to the *Scenario* metamodel. Indeed, we have followed the generation principle from [14] where the final learning game scenario is built after three steps.

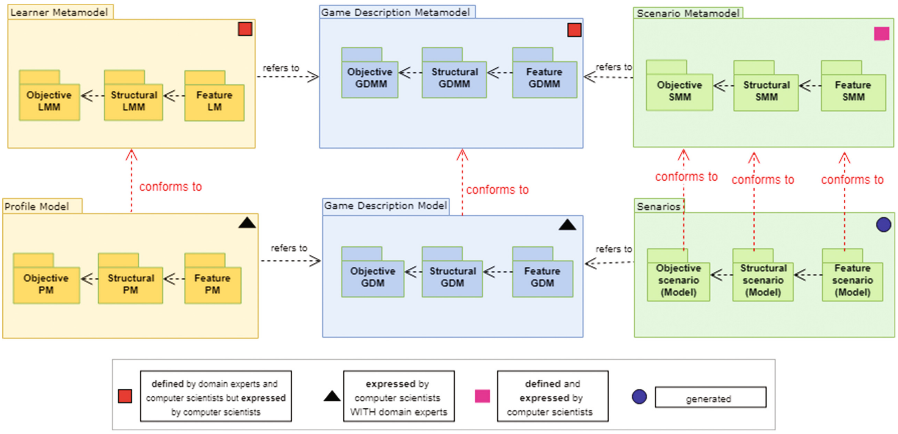

Fig. 2. The proposed 3×3 metamodel-based architecture

- *Objective scenario*: it refers to the selection of targeted learning objectives according to the user's profile. In the *Escape it!* project, this is related to the elicitation of the visual performance skills in accordance with the number of levels to generate, the considered skills and the child's progression.
- *Structural scenario*: it refers to the selection of learning game exercises or large game components. In our project, we focus on the various scenes where game levels will take place. This scenario specifies correspondences between the selected pedagogical large-grained resources (i.e. scenes) and their targeted skills.
- *Feature scenario*: it refers to the selection of additional inner-resources/fine-grained elements. In the *Escape it!* project, this concerns all objects of a scene. The feature scenario specifies the overall information required by a game engine to drive the set-up of a learning game session.

As illustrated in Fig. 2, each scenario's perspective has been considered when defining the implied metamodels and expressing models. For example, the generation of an objective scenario considers a relevant subsets of the profile elements (e.g. skills and their levels for a specific child) and the game description elements (the ones representing the skills that are tackled by the game).

4.2 An MDE Based Process to Co-design the Serious Game

Figure 3 depicts the co-design process of the proposed serious game. This process involves domain experts and computer scientists to conjointly design and validate the domain elements and rules that are relevant for the generation of adapted scenarios. The *meta-modeling* and *transformation specification* activities are performed by computer scientists because of the required expertise. The remaining activities involve both ASD experts (i.e. with no technical background) and computer scientists.

- *Game analysis*: this activity aims at identifying and expressing the various domain elements, properties, relations and domain rules that are involved in the adaptive generation of scenarios. An application case and other explicit designs (e.g mock-ups, sound effects...) can also be expressed.
- *Meta-modeling*: this activity consists in specifying the metamodels that define the static domain elements according to the metamodeling architecture presented in Sect. 4.1.
- *Modeling profiles and game description*: domain experts and computer scientists express together the relevant models by using a dedicated editor.
- *Transformation specification*: this activity is related to the development of the model transformation(s) [12] that allows producing adapted scenarios from a profile and game description source models.
- *Scenarios generation*: this activity applies the aforementioned transformation to the profile and game description source models in order to generate the target inter-related scenarios (i.e. the objective, structural and feature scenarios). After that, the produced scenarios can be integrated into the execution engine with a view to producing a playable prototype of the game.
- *Test and validation*: during this activity, ASD experts and computer scientists make use of the generated prototype in order to verify the relevance, coherence and completeness of the generated scenarios. Besides, this activity deals with the validation of domain rules that drive the generation. Consequently, domain experts can approve these rules or suggest alterations.

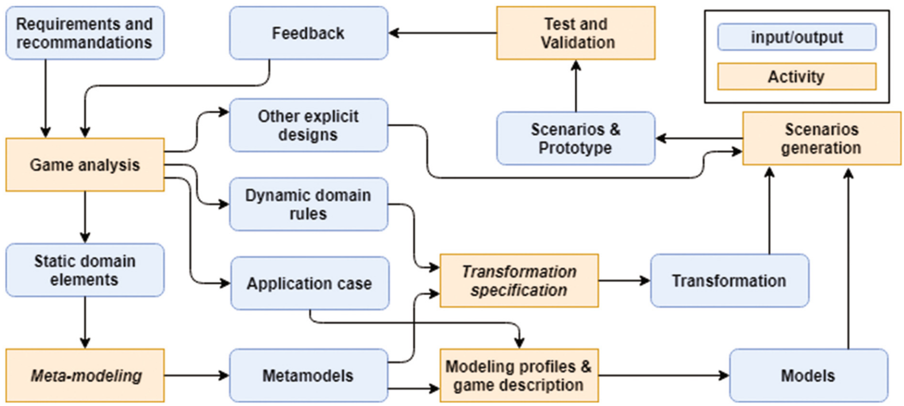

Fig. 3. The co-design process involving domain experts

These activities are part of an iterative process. One can consider at least three iterations focusing respectively on the three incremental scenarios: objective scenario, then structural scenario, and finally the feature scenario. Nevertheless, other iterations may be required for a same scenario's perspective according to the feedback from "*Test and validation*" activity. Indeed, gaps between experts predictions and the generated scenarios can occur. Generally, the analysis of the generated scenarios can highlight some misunderstandings within the interdisciplinary team, or some misconceptions about the generation rules. Therefore, re-engineering iterations have to be completed.

5 Application

In this section, we describe the application of the proposed co-design process to the presented serious game. This section is structured according to the aforementioned design activities and concerns one design iteration. It is worth noting that the focus here is on the global co-design process rather than on how the model transformations are implemented.

5.1 Game Analysis

Collaborative sessions with autism experts led us to identify the detailed description of each supported scene. This includes the various objects to place, hiding elements and solution objects. Furthermore, domain rules to apply when generating a scenario have been specified. Table 1 gives an overview of the main generation rules as well as the elements from the profile and game description models in relation with them.

Table 1. The different domain rules and relevant elements according to our 3×3-dimensions metamodeling architecture

	Game description	User profile	Generation rules for scenarios
Objective scenario	–visual skills to acquire –*dependency* relations between skills	–acquired or in progress skills –their difficulty level –number of levels to generate	–only skills with *parents* at '*Intermediate*' level or higher are eligible –80% of targeted skills with a difficulty level less than '*Intermediate*'
Structural scenario	–themes and associated scenes – skills targeted by each scene	**–themes/scenes to exclude/favor according to child's preferences/dislikes** **–history of proposed scenes**	–generate different scenes from the same theme
Feature scenario	–background elements, hiding objects, available object places of each scene	**–scene objects to exclude/favor according to child's preferences/dislikes** **–objects involved in previous sessions**	–mappings between each difficulty level and the objects to select and place into the scene

Some mapping rules have been established to guide scenes construction according to the difficulty level. Five difficulty levels have been defined (i.e. Beginner, Elementary, Intermediate, Advanced and Expert). For example, mappings for the '*Intermediate*' level are given below:

– Background elements can appear.
– Hiding objects can appear with 0 or several hidden objects according to their available slots.
– All selectable objects are tied to the problem resolution (no objects for disturbing purposes).

5.2 Metamodeling

Recalling from Sect. 4.1, the domain elements and relations required for the adaptive generation of scenarios are structured according to three metamodels (i.e. the *Profile*, *Game Description*, and *Scenario* metamodels). By playing the role of computer scientists and relying on the identified static domain elements, we have used the EMF platform[1] to express the relevant metamodels (see Fig. 4). We have to notice that Fig. 4 depicts all related constructs as one metamodel for better comprehending the inter-metamodels references.

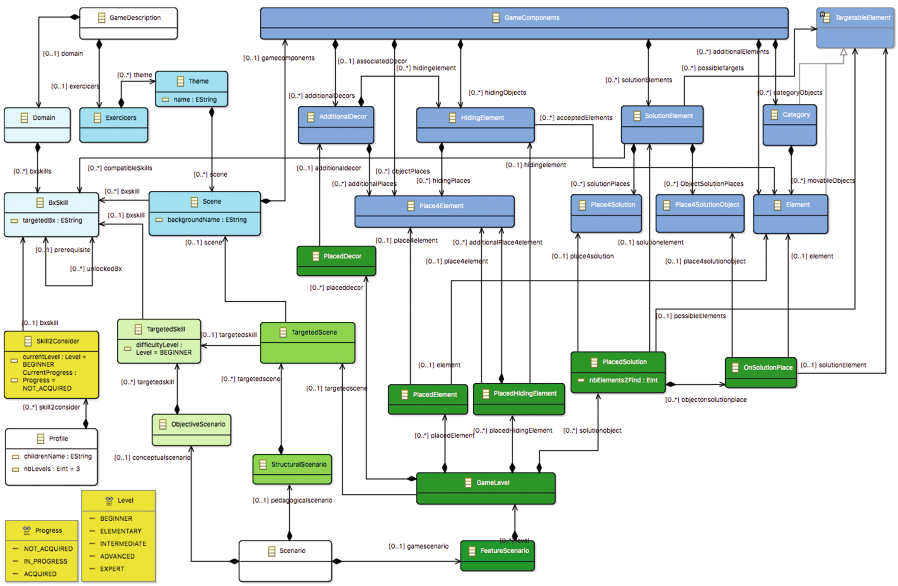

Fig. 4. Complete view of the metamodels with variations of colors to discern the different dimensions/perspectives

[1] http://www.eclipse.org/modeling/emf/.

A *Scenario* instance contains three inter-related elements: objective, structural and feature scenarios. By following the same decomposition approach, the *Game Description* constructs are decomposed into three subsets that match the scenario's perspectives: the skills elements (visual skills), the exercises elements (scenes and themes) and the game components associated with a concrete exercise (background, objects, locations...). Some elements from *Exercises* and *Game Components* parts will refer to specific skills elements (e.g. scenes must specify which targeted skills they can deal with). As for the *Profile* constructs, they are limited to elements required for generating the objective scenario. The remaining perspectives are not yet handled by our proposal (they are highlighted with gray color in Table 1).

5.3 Modeling Profiles and Game Description

The game description is the first required input model. It has been expressed using a tree-based editor proposed by EMF tooling. Figure 5 shows three different extracts. The root element is a *Game Description* instance. The containment references are naturally represented within the tree-based representation, whereas properties and other references are detailed in the *Properties view* depending on the element being selected.

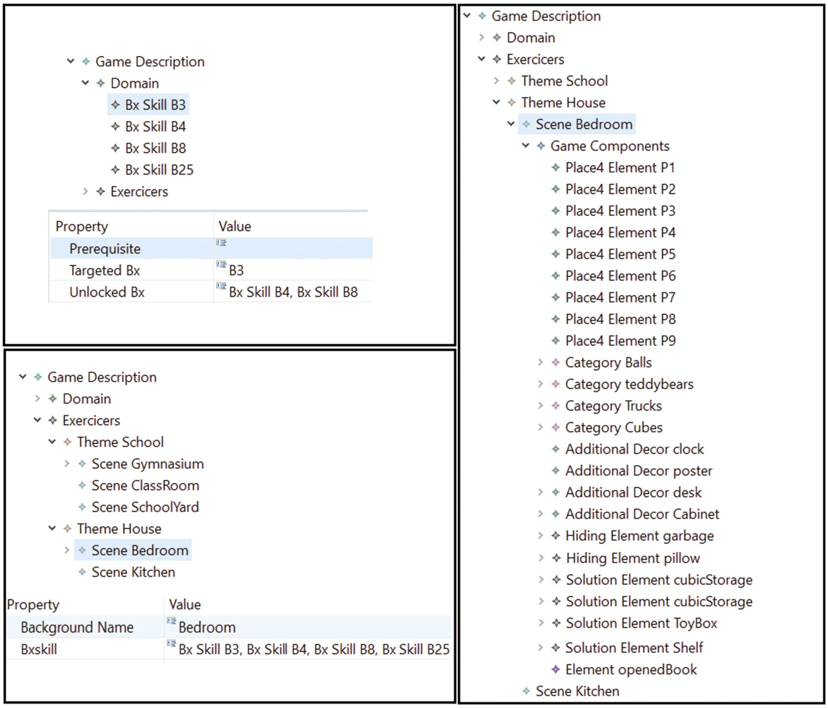

Fig. 5. Partial views of the game description input model

The top left part of Fig. 5 depicts four visual performance skills: B3, B4, B8 and B25 (respectively matching object to image, matching object to object, sorting categories of objects, making a seriation) and their dependency relations. For example, the B3 skill unlocks the B4 and B8 skills (i.e. completing B3 at its highest difficulty allows to progress independently with the learning of the B4 and B8 skills). The bottom left part depicts the description of the game scenes and their container themes. Finally, the right part details the elements involved in the *BedRoom* scene.

In opposition to a unique game description model, several child profiles have been expressed as input models. For that, ASD experts have proposed various fictive profiles but realistic according to them.

5.4 Transformation Specification

The generation of scenarios adapted to child profiles is implemented as a model transformation written in Java/EMF [16]. This transformation is applied to the profile and game description models to allow the successive generation of the three perspectives of an adapted scenario. It is worth noting that the experts requirements related to dynamic domain rules are not easy to implement. In fact, the implemented model transformation uses an external constraints solving library to tackle some very specific generation steps.

By considering an existing procedural context generation taxonomy [17], our proposal to generate scenarios could be regarded as *online* (i.e. during the runtime), *necessary* (i.e. the content has to be correct), *parameterized* (i.e. it takes as an input the game description model), *stochastic* (i.e. randomness is used when several combinations are possible) and *constructive* (i.e. it never produces broken content).

5.5 Transformation Execution

Employing the transformation presented above performs the generation of adapted scenarios. However, interpreting the generated models using basic EMF editors is not appropriate to perform domain rules validation. As a solution, we have implemented a support for integrating the generated scenarios in the Unity-based[2] game engine. This concerns the low level scenario (i.e feature scenario) and makes it possible to play the related game session. By this mean, ASD experts can carry out effective tests of the game. It is worth noting that the scene depicted in Fig. 1 was generated using the proposed integration support.

5.6 Test and Validation

We have conducted a collective validation session with two ASD experts. We have exploited the generated scenarios (each one corresponds to a specific profile) and then analyzed them by using the game prototype integration support. As a

[2] https://unity3d.com/.

feedback, the experts decided to disregard the 80/20 generation rule. This rule stipulates that 80% of the skills referenced by the generated scenario must be at a difficulty level less than '*Intermediate*' against 20% at higher level. Indeed, the experts realized that this rule cannot be satisfied in all possible cases (basically for children not familiar with the game and those at an advanced stage).

On the other hand, the experts have proposed new rules concerning the selection of candidate scenes. The base principle is to diversify the scenes offered to the child while trying to use the same theme. Accordingly, the experts have expressed the rules below. They are cited in order of priority:

- All scenes must be different and belong to the same theme.
- All scenes must belong to the same theme. In addition, two successive scenes must be different.
- All scenes must be different (no constraints on themes).
- Two successive scenes must be different (no constraints on themes).

This design iteration confirms the need to involve experts in a co-design process ranging from requirements elicitation to test and validation. Indeed, relying on the expert's knowledge is crucial for this type of project whose end users have specific needs. Moreover, the limitation to the requirements and recommendations of ASD experts cannot guarantee a good adequacy of the game with children. Indeed, the experts only become aware of the consistency of their choices through playing the game.

6 Conclusion

This paper focuses on the development of a serious game for helping young children with Autistic Syndrome Disorder to learn and generalize visual performance skills. It presents a co-design process that allows ASD experts and computer scientists to express and validate the domain elements and rules involved in the generation/adaptation of learning scenarios. Essentially, the proposed process is iterative and relies on MDE and rapid prototyping.

MDE provides support for adaptive generation of scenarios and allows varying situations proposed to domain experts without significant effort. Indeed, it is possible to express several profiles and apply the same transformation to automatically generate the consequent scenarios. As for rapid prototyping (based on the integration of scenarios in Unity), it allows simulating a real exploitation of the game under-development. Therefore, ASD experts can express more relevant feedback that can be considered in the following iteration.

A perspective of this work relies on change impact analysis to support a rapid generation of the new prototype related to the expressed feedback. This involves managing traceability links between the experts recommendations/requirements and the prototype generation mechanisms. In the same perspective, we intend to re-specify the model transformation responsible for generating adapted scenarios in a more structural and modular manner with a view to determining precisely the fragments impacted by an expressed change.

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