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Expressing Adaptations to Take into Account in Generator-based Exercisers: An Exploratory Study about Multiplication Facts

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Abstract: This paper intends to explore how the generation logic and the elements involved are expressed from the teachers' viewpoint, in the context of learning games. We present an interview-based exploratory study: preparation, realization, analysis, and findings. From the results we also propose a dedicated metamodel to capture these expressed elements and logic. We evaluate this metamodel by developing a high-level generator component about the practice of times tables.

1 INTRODUCTION

Serious games can be wearing for the users when activities are repetitive or redundant, or when the games present an imbalance of challenge relative to the skill level of the players (Streicher and Smeddinck, 2016). This is especially true when considering declarative knowledge (explicit knowledge of facts) that requires repetition for encouraging their memorization, generalizations, and retention (Kim et al., 2013). Serious games targeting such knowledge should then propose or generate a wide variety of adapted learning game activities. Designing a generator in charge of this need is a complex task involving different actors' viewpoints and different dimensions about the adaptation to take into account (didactic, pedagogical, gaming, motivational, . . .) (Laforcade, 2020).

This paper is about the design of generators of learning activities in the context of serious games dedicated to declarative knowledge. Our interest is about the complex adaptations that cannot be easily taken into account by the learning game at run-time, like the objective to consider or the specification of the game or learning components involved into the activity to propose. As a first step we intend to explore how the generation logic and the elements involved in the runtime generations are expressed from the teachers' viewpoint. Because we put aside the gaming dimension, one can consider the generated activities to study as adapted exercises for training declarative facts. This paper relates then the preparation, realization, analysis, and findings of an interview-based exploratory study we conducted, focusing on the multiplication tables as a case study. We also propose a first attempt to formalize the expressed elements and logic for an high-level generation.

This article is structured as follows: in Section II we briefly present some research works dealing with the design of generators for adaptation purposes. In Section III and IV, we present our exploratory study and analysis of the results, respectively. In Section V we propose a metamodeling approach to capture invariants and variants expressed by teachers. Finally, Section VI is about the application and evaluation of our proposed metamodel.

2 RELATED WORKS

As stated by (Streicher and Smeddinck, 2016), "despite remarkable progress in AI in recent years, adding adaptivity or personalization features to serious games in a fully automated manner [..] is not yet easily feasible". Past and current research works dealing with adaptivity focus on different *purposes* (recommandation, personalization, etc.), *targets* (content, learning objects, scenarios, etc.), and *methods / techniques* (Vandewaetere et al., 2011) (Streicher and

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Smeddinck, 2016). They also differ in focusing more on the learning dimension (Wilson and Scott, 2017) or the gamification dimension (Böckle et al., 2017). Research has already tackled the need for analysis frameworks helping identify and specify various involved models: learner models, domain models, game models, etc. Also, various approaches and techniques have been proposed to implement various adaptive systems. Nevertheless, the design of generators is barely considered (specify all involved models as well as the generation logic using them). Such formalized models (machine-readable models) can be used to drive the development of the generator component but can also be useful to evaluate, and validate the generation behavior as well as the involved elements before the development phase: changes at this step will be less expensive than changes occurring during the re-engineering of the overall serious game.

(Sehaba and Hussaan, 2013) proposed a generic architecture for personalizing a serious game scenario according to learners' competencies and interaction traces. The architecture is organized in three layers: domain concepts, pedagogical resources and game resources . Their proposal allows the generation of three successive scenarios (conceptual, pedagogical and serious game) according to the three presented layers. In past research works, from the *Escape It!* (Laforcade and Laghouaouta, 2019), we tackled the issue of generating adapted learning game scenarios. We proposed a specific modeling approach. It is based on a metamodel specifying at first the domain elements according to both a 3-incremental-perspective on the resulting scenario, and a 3-dimensions specification of domain elements. The approach proposes to model the game description and the learner's profile as input models for the generator that will produce the adapted scenario as an output model. Nevertheless, the generation rules and the mapping rules between the difficulty levels and the game objects involved within a scene resolution, are not explicit: they are hard-coded in the generator. These domain rules cannot be easily adjusted. Some studies have to be conducted to explore how making the generation logic more explicit and changeable.

3 EXPLORATORY STUDY

3.1 Overview

The objective is to collect and analyze information about how the generation of adapted exercises should be addressed according to the viewpoint of people interested in using such learning games with students: i.e. mainly teachers. We on purpose decided to restrict the adaptation to the learning dimension, i.e. putting aside for now the game dimension (indeed, teachers cannot be considered as game experts).

The analysis of the collected data will help us in identifying and characterizing how participants express the adaptations to take into account for the generation of adapted exercises. We are also interested in understanding how they proceed, what elements and rules they identify and how they express them.

The didactic context for this experiment is about the multiplication tables training. The fictive learning game to design aims at providing learners with adapted training sessions. The participants are people who could be involved in the design of this fictive TEL-system in order to represent the didactic and pedagogical viewpoints. Because of the exploratory context, we decided to conduct these first experiments with a single participant at a time (among the 11 participants), according to the following protocol.

3.2 Protocol

The protocol is illustrated in Figure 1. Because of the lockdown context occurring during this experiment (from May to June 2021) these steps have been designed for distant interviews.

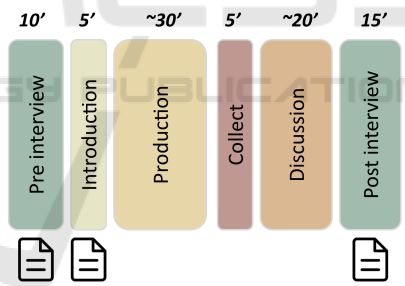

Figure 1: The different steps of the protocol with information about the average time and the use of documents.

Pre Interview. This first step is a semi-structured interview based on a list of subjects to question the participant. First questions are about the participants' identity, current or past teaching activities. Secondly, we guide them to present their own experiences about adaptation within their daily teaching activities.

Introduction. We introduce to them the didactic context about the training of multiplication tables. We present a fictive serious game based wherein the training occurs during multiple sessions, each one proposing students with an individualized session generated by the system to match their needs and preferences. The current focus on the 'learning' dimension is presented, explaining we put aside for now the 'gaming' dimension. This introduction step is supported by a slide-based document they can see during the presentation. This allows us to show examples of maths questions and answer modalities (Figure 2), defining what a question and an exercise are. Our objective is to give them a shared starting point about the generation target but no information about the sources to consider and how the generation should proceed.

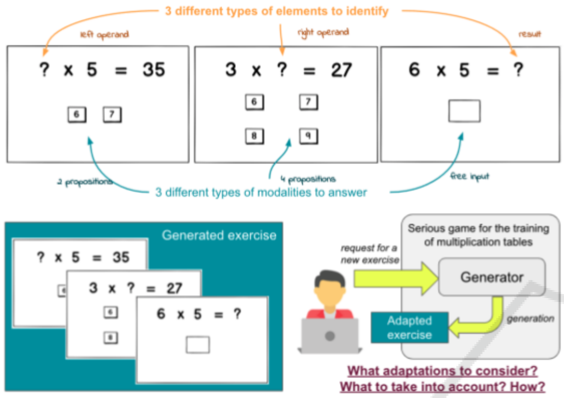

Figure 2: Information showed to participants during the introduction step (*assembly of translated parts from the original slide-based document*).

Production. We ask participants to think about the adaptations to consider, the target elements (no restriction to the ones we show them) and source elements to consider (the instruction is given on the last slide of the previous step). We encourage them not to restrict their imagination to technical considerations or about how could be collected some learners' information. We also ask them to put down in writing or figures a maximum of their thoughts (no constrained formalism) using simple paper-based notes. We let them make this production by themselves but allow them to ask any questions wherever they need. They can use all the time they need up to 30 minutes maximum.

Collect. In this short step, participants take some photos of their paper notes and send them to us by email.

Discussion. Within this step, participants present their ideas. The objective is twofold: being able to interpret and understand their notes, and making them detail their findings. This step is much more a discussion than a presentation but our questions are only intending to ask them details, not structuring or guiding the discussion.

Post Interview. This last step is another semi-structured interview based on predetermined questions. Some of these questions are about summarizing the identified adaptations, others are about the production step itself: how they proceed to identify them, how they consider their production, if some guidance were missing, etc. We then finally discuss the specification and usages of adaptation/generation elements and rules by teachers.

In order to find some participants, we contacted at first official french organisms related to the educational field for elementary and middle schools (targeted audience for the training of multiplication tables). Based on the limited positive answers, we used the *snowball sampling* technique by asking first participants to give us some contacts about other potential interested participants.

3.3 Collected Data

We realized 11 interviews remotely using a video-conferencing system. 9 participants accepted to be recorded (video and sound). The participants' profiles are outlined in Table 1.

The interviews last between 1 and 2 hours, 1.5 hours on average. The shorter step was the production one. For 4 participants on 11, the production has required interactions and exchanges, mixing up the production and discussion steps. We tried not to influence and simply guide them to detail their thoughts. All participants put down their production on paper that we collected.

Table 1: Participants' main working activity.

ID	Main information
#1	6^{th} grade retired teacher
#2	Middle maths teacher
#3	Maths division pedagogical advisor
#4	2^{nd} Grade teacher in a priority education zone
#5	Recently graduated of a primary school teaching Master diploma
#6	2^{nd} Grade teacher
#7	5^{th} Grade teacher
#8	5^{th} Grade teacher in a priority education zone
#9	Instructor about teaching adaptations for children with Autism Syndrom Disorder
#10	2^{nd} Grade teacher
#11	Maths assistant professor in College

4 ANALYSIS AND MAIN FINDINGS

The pre- and post-interviews and productions answers were analyzed based on the participants' notes, the recorded interviews (including production step) and our own. We highlight the main findings.

Former or current teachers have different experiences about adaptation in classrooms. It goes from simple additional guidance of students with difficulties, to content and exercises dedicated to specific students or groups. Most of the time, content and exercises are the same for all students, with some optional additional resources delivered to the fastest students.

Participants' productions are mainly driven by their own experience about teaching and adaptation on their daily teaching routine. Most of them started by identifying learner-independent information about how to practice the training of multiplication tables: order for the tables, difficulty levels based on changing the answer modalities, ordering or not the multiplication facts, varying the information to find (the product at first, one of the operands in a second time), etc. Some participants consider that mixing up different tables is possible when these tables have been at first achieved independently. Other times, participants consider the explicit combinations of different tables or specific number facts. They also consider the training objectives and activities according to the learner's grade from 2nd to 6th.

Participants take into account the learner when considering that each generated exercise has to cope with the current learner's progress within his learning path. Some objectives are prerequisites for others whereas various objectives can be performed independently. Based on their experience using existent maths serious games, two participants proposed to associate different learning paths to groups of student, according to their level. Finally, only the participant #9 (no teaching expertise) expressed learner-centered needs for adapted and progressive difficulty inside and outside the generated exercises, but without being able to express how to put into practice this difficulty in regard to this mathematical context. Only a few of the participants proposed to use learners' previous incorrect answers to drive the difficulty level of the generated questions or for proposing tricky choices.

It is worth notice that no participant expressed generation rules or adaptation rules in general. They mainly focused on the elements to consider, not on how they will be used to really generate exercises adapted to learners. In relation to the post-interview answers, we observe that the participants were generally satisfied of their production, and had not felt the need for more guidance (except the ones who required our intervention). They do not use any particular formalism, their notes are mainly hand-written sentences without any schema or graphic representation, except the use of arrows to link ideas.

5 CAPTURING THE DIDACTIC FACET FOR GENERATING ADAPTED EXERCISES

The main finding of these interviews is that most of the participants dealt with the generation of adapted exercises on a very didactic viewpoint. They followed a top-down approach, thinking about, at first, on learning paths of objectives and activities that can be relevant for most learners. They could identify groups of learners requiring dedicated paths but rarely focused on a single learner. Their approach were more about personalizing general-purpose activities than taking into account every individual's needs as a starting point. Participants were naturally thinking about the didactic facet but failed to explicit specific adaptation or generation rules. However, an implicit and shared generation logic can be identified.

Because the didactic facet of generating adapted exercises is fundamental and must be tackled as a very first step, we decided to focus on it.

5.1 Objectives and Method

In order to capture the didactic facet we propose a metamodel specifying most of the information expressed by the participants. Because of the inherent subjectivity of metamodels it is worth noting that it can still be debatable or not convenient to cover information and needs of other teachers. However, our proposition relies on a generic structure that can be convenient for other didactic contexts.

Also, our objectives are to i/ verify the metamodel expressiveness to model the complete perspective of some participants' viewpoint, and ii/ prove that such models can drive the partial generation of adapted exercises (machine-readable with no ambiguity).

5.2 In-depth Interviews

We decided to propose another interview to two participants in order to deepen and develop their ideas about what to consider and how to use it to generate adapted training exercises about the multiplication facts. These two participants were #3 and #8.

Each interview took approximately one hour and a half. They both occurred at distance using a video-conferencing system. They were free to start from scratch or from their previous notes. We guide them to express their ideas on the following subjects, extracted from all the previous interviews: What are the objectives? Are these objectives composed of sub-objectives or different difficulty levels? How all these elements are related to the didactic field of the multiplication tables? How these elements are sequenced? Are there some prerequisites or dependencies? How these elements are associated to learners? What defines a generated activity? How these activities are related to the objectives or other elements? How the generator component should decide which objective to deal with? How to choose the activity to generate if several are related to the elected objective?

They were free to express any idea. We do not impose them to deal with these subjects in this order.

5.3 The Metamodel

All elements from the two in-depth interviews, added to those always collected, led us to specify the metamodel illustrated in Figure 3. It captures invariants and variants into concepts, properties and relations. We used the Ecore format (Steinberg et al., 2009) to build the metamodel.

5.3.1 Overview

The metamodel is composed of 3 inter-related parts (different colors in Figure 3), each one having its own root element. This 3 parts composition is related to the 3 perspectives from (Laforcade and Laghouaouta, 2019). The top and main part concerns the specification of the teachers' viewpoint (*Domain* root). Models in conformance to this part can be considered as the *domain models* required by the generation process. For now, these domain models only deal with the didactic and pedagogical facets. Other dimensions, like the game-based motivational dimension, will be considered and specified in this part.

The second part is the one starting with the *Context* element: it models the *learner models*, i.e., the information about one learner that will be used to drive the generation of an adapted exercise. This part of the metamodel has some relations to the first *domain* part.

Finally, the third and last perspective specifies the elements to generate. This part also refers to the domain part.

5.3.2 Generic Elements

Although this metamodel is related to the training context of multiplication tables, some information are generic enough to be relevant for other didactic contexts about declarative knowledge.

The *Domain* root element is composed of three container elements: *Scenarios*, *Declarative Knowledge*, and *Activities*. *Scenarios* gathers all different learning scenarios that a teacher can declare. A *Scenario* is a set of *Objective*. It corresponds to the didactic concept of *learning trajectory* (Diwan et al., 2019)(Mendes et al., 2021). Each *Objective* has a list of *Level* that will support the learning progress or difficulty for a same objective. An *Objective* can have some prerequisites, each *Prerequisite* referencing a *Level*, from another objective, that should be achieved. When the referenced level is the last one of an objective it means that the overall objective has to be achieved. The different learning activities are declared as *ActivityType*. They define various parameters about the activity to generate. A *Level* references one of these activity types.

Every *Learner* is associated to a *Scenario*. Enrollments could have been made by the intermediary of groups or the entire class but, according to the generation viewpoint, the generator only requires the information of the learning path for the considered learner. A *Learner* is then associated to a set of *CurrentObjectiveLevel*. They relate to a *Level*, and can also relate to one *Level* among the ones associated to that objective, in order to specify if this objective/level are achieved or still in progress.

Unlike our previous works (Laforcade and Laghouaouta, 2019), the generation does not have the same three iterative and incremental steps. In our context, we first have to select only one *objective* to consider. We then select the only one *activity type* defined for the selected objective. We consider these two steps as the *high-level* exercise. Finally, the next step will consist in generating an ordered list of questions, sometimes including several answer options (the *low-level* exercise). The *HighLevelExercise* is then the only element to generate considering our decision to restrict this study to the two first generation steps.

It is worth noting that the metamodel do not tackle the rules about how levels or objectives are achieved, or how the learner information are tracked and identified: it only considers what has to be provided for being used by the generation logic.

5.3.3 Context-related Information

The metamodel also captures (see Figure 3) some information related to the training of times tables.

From the domain part, these information are about the knowledge to train and the activity types that characterize different training configurations. In the context of multiplication tables, this knowledge is about the tables, composed of multiplication facts (multiplicand and multiplier), to consider. It is possible to declare particular set of multiplication facts (for example all facts equals to 12: '3×4', '4×3', '6×2', '2×6', '1×12', '12×1'). Teachers can then associate an objective to one or several set of multiplication facts. Sometimes, teachers also need to de-

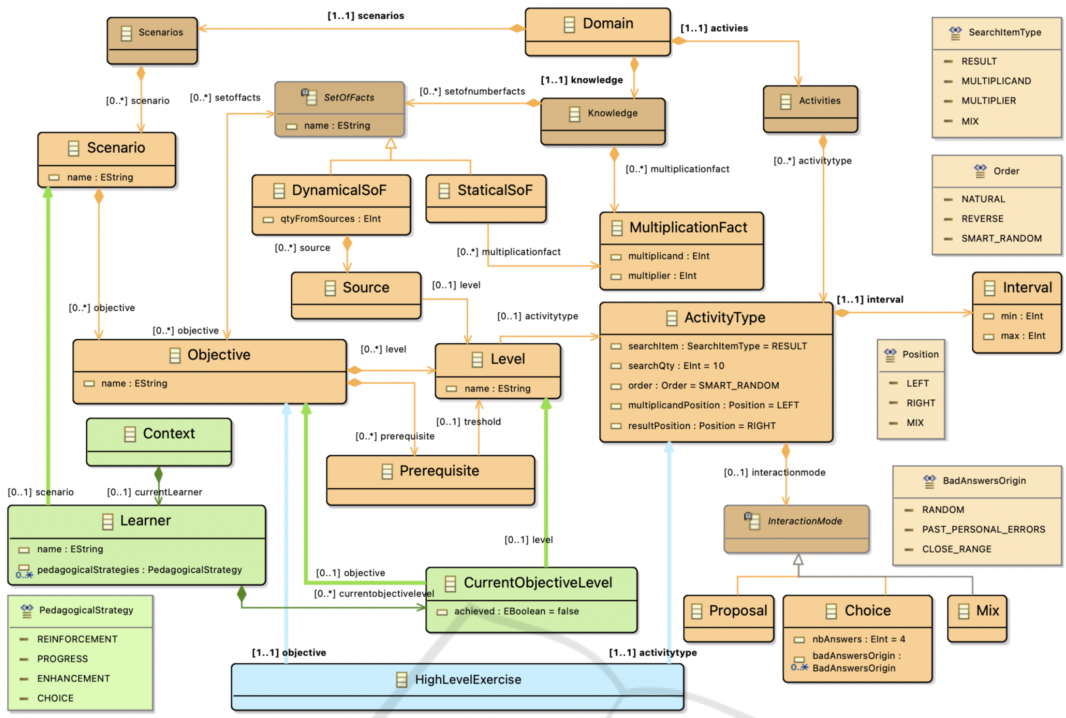

Figure 3: Metamodel capturing information required to realize a generation of adapted exercises from a teacher viewpoint.

fine *dynamical* set of facts. For example, the objective *mastering the mix of 2 simple tables* can be set to concern 2 tables from a specified range (for example tables 2, 3 and 5) in accordance to the first two ones available from each learner's progress. To this end, the associated knowledge will be a *DynamicalSoF* with a *qtyFromSources* attribute set to 2, and having 3 *Source* referencing, for example, the fourth level (on 5) of 3 objectives concerning the tables 2, 3 and 5. The two first achieved objectives/levels referenced by these 3 sources will provide their own *SetOfFacts*.

The characteristics of the activity types are also context-sensitive. Teachers express these parameters: the search item to identify (multiplicand, multiplier, product or a mix). The quantity of facts to consider (picked up from the pool of facts associated to the objective that is refilled with the same sources when empty). The questions order: original pool order, reverse, or "smart" random (i.e. a fact cannot be chosen randomly twice while the pool is not empty). The display of the products on the *left* or *right* of the equals sign (e.g., '$3\times? = 15$' or '$15 = 3\times?$') ; the *mix* value means that 'left' or 'right' is chosen for each question. The multiplier interval as min and max values (for examples "1-10", "2-9", "1-5", "6-12", etc.). The position of the multiplicand: for example, if we consider multiplicand 2 times multiplier 5, we can propose "2×5" or "5×2" ; this can be useful to represent tables according to the teacher's viewpoint or to generalize the understanding of the multiplication tables by provide learners with some randomized position for each question (*mix* value). Lastly, the answering mode among 'proposal' (learners have to submit an answer), 'choices' (learners choose between different proposals), or a 'mix' of both (randomized mode at runtime for every question). Note that the 'choices' mode can also set the number of proposals and how they are proposed (random values, values close to the good answer, previous false answers of the learner).

A combination of values allow teachers to specify the kind of activity they want for a tuple <objective, level>. It is very useful to propose a progressive challenge for the different levels of an objective. It also allows to take into account the various learners' audience and current understanding of these multiplication facts and other underlying multiplication-related knowledge like commutativity, division, etc.

Teachers also express several pedagogical strategies to decide which objective choose among the eligible ones. An eligible objective is an objective without prerequisite or one with achieved prerequisites. Sometimes, teachers prefer encouraging the mastering of an objective (*enhancement* strategy), i.e. progressing into the levels, before dealing with other objectives. The *progress* strategy encourages newly eligible objectives or the tuples <objective, level> that are prerequisites to other objectives. Other strategies can focus on *reinforcement* former achieved objectives based on multiplication facts that have been met and answered incorrectly in other in-progress objectives, or simply to let the *choice* of the objectives to the learner. Teachers can define a list of strategies for every learner (individually or as a group). Either way, at the generation time, the context model precises the strategies for the learner concerned. Strategies are then sequentially applied until an eligible objective can be selected.

6 APPLICATIONS

6.1 Evaluating the Expressiveness

The metamodel has been been build upon information from in-depth interviews with teachers. It could then be considered straightforward to verify that its expressiveness allows the modeling of these teachers' viewpoint. Nevertheless, metamodeling is also a subjective and tooled activity which can lead to some differences between the resulting metamodel and the intentions to model. We then specified the two participants' viewpoints as *domain model* conformed to our metamodel proposition, from the *Domain* root.

It is also important to verify that the expressed *domain models* can also be handled appropriately in order to participate in the generation of *HighlevelExercise models*, by using some *context models*.

6.2 Simulating a High-level Generation

We aim at generating, for now, high-level models in accordance with the context and domain models given as inputs. A low-level generation will then focus on generating an exercise with questions and/or choices according to the selected activity type and multiplication facts. One can notice that this second generation will used the previous high-level models as inputs as well as other required information from the context (e.g. the learner's previous incorrect answers for the considered facts) or from the domain.

The generation to simulate concerns the high-level part. We already modeled two domain models according to the viewpoint of the two teachers. In order to simulate the generation, we need a dedicated tooling framework, test-cases using specific context models, and some generic generation rules.

6.2.1 Verification Process and Tooling Framework

The verification process we followed consist of these steps: 1/ Use of the EMF framework to generate Java code allowing to load, save and handle models conformed to the metamodel; 2/ Specification of a domain model for the two in-depth teachers' viewpoints; 3/ Development of a generic code (only based on the structure and generic semantics of the metamodel) able to generate high-level exercises (using the code from step 1); 4/ Identification and modeling of limit value tests, for each domain model, as context models; 5/ Testing and comparisons with expected results.

6.2.2 Generation Rules

We highlight in Algorithm 1 the main steps of the generation rules as a generic algorithm that is convenient for different didactic contexts.

Algorithm 1: Generic high-level generation algorithm.

1: collect all available objectives for the learner referenced in the context model;
2: filter the eligible objectives (no prerequisites or achieved prerequisites);
3: apply the strategies associated to the considered learner, according to their definition order, until one strategy implies the qualification of an objective;
4: select the appropriate level for this objective (last unachieved level, otherwise the first level);
5: select the related activity type for this tuple <objective, level>;
6: create an output model conformed to our metamodel and built from the *HighLevelExercise* root.

6.2.3 Context Models, Predictions and Results

As preconditions, we states that there is always at least one available objective and one eligible objective. Indeed, the contrary will mean that the domain model is not correctly defined. We consider for now that it will be the responsibility of future "authoring tool" to ensure these preconditions.

For both specified domain models, we identified an average of 20 limit value tests in order to verify specific situations (for examples, a very first generation wherein the learner has no *CurrentObjectiveLevel*, objectives with zero, one or all prerequisites that are achieved, behavior of the different strategies application, etc.

To this end, we modeled as much fictive context models as test cases. We manually identified the set of possible predictions, i.e. tuples of objectives/levels. We compared these predictions with the results obtained from our high-level generator component using one context model and one domain model at a same time. The objective was twofold: help us developing the generator code, and verify its final behavior.

7 ONGOING WORKS

We planned to continue this exploratory study and (meta-)modeling approach by the following perspectives: i/ considering the low level generation into the three inter-related parts of the metamodel (domain/context/exercise); ii/ taking into account additional pedagogical information like *feedbacks* to give and *post-actions* to realize after correct or incorrect answers; Indeed, gamified learning experiences should have early, frequent, meaningful and rapid feedback (Faiella and Ricciardi, 2015); iii/ experimenting the specification of domain models (process and tooling) directly by teachers thanks to user-friendly authoring-tools; iv/ exploring the *gaming* facet to generate not only learning exercises but also gaming activities. Indeed, tailoring gamification is a current trend in the educational context (Klock et al., 2020)(Rodrigues et al., 2020).

This last perspective is very important. It will tackle the need for some new adaptations to learners' gaming preferences, based on different gameplay, game mechanisms, and aesthetics, to identify and design correctly, in order to better engage and motivate learners to practice the multiplication exercises.

8 CONCLUSIONS

This article intended to explore how the generation logic and the underlying elements involved are expressed from the teachers' viewpoint in learning games. First, we conducted an interview-based exploratory study about the training of times tables. We related its preparation and analysis. This work led us to collect many information about a didactic-centered viewpoint of adaptations to take into account although no explicit generation rules has been identified. Nevertheless, these information can be used to capture the didactic facet of the generation.

We then proposed, as a second contribution, a metamodel specifying all these information. The metamodel has generic concepts, properties and relations that can be relevant for other didactic contexts about declarative knowledge centered. The metamodel also embeds context-related information about the times table context. This metamodeling approach allows to capture invariant informations as well as generation variants whose semantics can be taken into account in the generic generation logic by considering the input models given to the generator.

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