An Analysis Framework for Designing Declarative Knowledge Training Games Using Roguelite Genre

Bérénice Lemoine[a], Pierre Laforcade[b] and Sébastien George[c]
LIUM Computer Science Laboratory, Le Mans Université, Laval, France

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Abstract: The training of declarative knowledge requires repetition and adaptation to learners' needs. Learning games for training purposes should then offer a wide range of adapted and varied game situations where facts are questioned. Furthermore, answering these questions may involve many gameplays that keep the learner-players engaged and motivated to practice again and again. This article presents and justifies how the Roguelite game genre is well-adapted to tackle these challenges. It also proposes an analysis framework to support pluridisciplinary teams of teachers and game developers in identifying the key orientations for designing such training games. This framework is composed of questions to consider during the preliminary design of the training game. We have identified and used this proposition in a specific research context about multiplication tables training. The article illustrates the first results obtained which led to our first playable prototype. Finally, we outlined the major drawbacks of our first game design (i.e., first analysis), which brought us to carry out a second analysis through our proposed framework.

1 INTRODUCTION

Explicit knowledge of facts, such as multiplication tables, historical dates or geographical information, are known as declarative knowledge. Repetition is a necessary task to encourage the memorization, generalization, and retention of declarative knowledge (Kim et al., 2013; Roediger and Pyc, 2012). However, repetitive or redundant serious games as well as the ones presenting an imbalanced challenge relative to the skills of the players can be boring for the players (Streicher and Smeddinck, 2016). Therefore, to reduce the feeling of repetition, serious games targeting declarative knowledge should offer a wide variety of adapted learning game activities.

Most of existing serious games for the training of multiplication tables only present questions to answer, surrounded by game elements that do not impact the gameplay. Such training games do not propose long-term engaging activities. Poor gameplay could quickly bore students and reduce their engagement to practice (i.e., motivation, frequency, and duration of sessions, etc.). It therefore seems important to allocate as much importance to gameplay as to educational content when designing learning game activities (Marty and Carron, 2011).

This article proposes to highlight a specific game genre, Rogue*lites*. Indeed, this genre is based on several design principles, of which we propose to discuss their compliance with the requirements for efficient and adapted training of declarative knowledge. Our proposal is presented in the form of an analysis framework in order to help the design of Rogue*lite*-oriented training games. This framework involves a set of practical steps to be followed in each iteration of a prototyping-based design approach. The aim is to focus on design needs, from two dimensions (i.e., training and game), such as: technology (i.e., some information needed for the game engine/generation algorithm), game-gameplay (i.e., how the main game mechanics of the Rogue*lite* genre work), and game structure (i.e., the game rules). To illustrate our proposal, we present and discuss the application of this analysis framework during two design iterations of the same research context: the AdapTABLES project.

Test-based learning represents, in cognitive psychology, the idea that the process of retrieving (i.e., remembering) concepts or facts increases their long-term retention. Whilst tests are mainly used as summative assessment tools, they can also be formative.

[a] https://orcid.org/0000-0002-7608-3223
[b] https://orcid.org/0000-0001-8498-2731
[c] https://orcid.org/0000-0003-0812-0712

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One way to implement test-based learning is through repeated retrieval (i.e., retrieval practice). Research has shown that this method can improve long-term retention (Brame and Biel, 2015; Roediger and Pyc, 2012). Moreover, research also suggests that the benefits of test-based learning are not linked to a specific type of retrieval practice (i.e., various test formats enhance learning) (Brame and Biel, 2015). In this paper, *training* involves providing the learner with various forms of questions repeatedly, which is a form of retrieval practice.

The structure of this paper is as follows. Section 2 introduces our research context, including our AdapTABLES project and its specific declarative knowledge about multiplication tables. In addition, it presents the video game Rogue*lite* genre and discusses considering Rogue*lites* as a suitable genre for designing training games. Section 3 is dedicated to the proposition of a two-dimensional analysis framework (gaming and training dimensions). This proposal has been applied twice in the context of our project. Section 4 is then devoted to the presentation of these two applications, as well as the feedback gathered from the evaluation of a prototype in line with the first analysis.

2 RESEARCH CONTEXT

The AdapTABLES project aims to design and develop a serious game dedicated to the individual training of multiplication tables.

From a teacher perspective, the training game to design will be adapted, prior to its use, to reflect how teachers consider the training: source facts, difficulty, progress... This training *structure* can be set up for the entire classroom's students, for a group, or for individuals having specific needs. From a student perspective, the training game will follow the learners' progress, proposing facts according to their previous training sessions and results. From a player perspective, the training game will offer game levels that take into account their preferences. From a game perspective, a same training task should be tackled through different gameplays with different game elements. Finally, at runtime, the training game will have to generate varied training game activities, adapted, both in terms of gameplay and educational content, to the teachers and learners-players perspectives.

We followed an iterative co-design and prototyping approach, involving teachers and didacticians of mathematics, and game experts during the design and evaluation phases. At first, two initial steps were necessary: 1) specifying the knowledge to be trained, and 2) choosing a type of game that suits the training of declarative knowledge. These contextual elements are necessary to start designing at a high level the main key concepts and rules of the training game.

2.1 Declarative Knowledge Training

We started an exploratory research (Laforcade et al., 2022) with the help of a user group composed of teachers and mathematics experts. The objective was to specify the adaptations to take into account when considering the training of multiplication tables from a teacher perspective: what to consider (source and targets of the adaptations) and how to realize these adaptations. The main two results are: a model of the training organization into training paths, and the specification of 5 detailed training tasks.

A training path, see Figure 1, is represented by a set of objectives ordered by prerequisite relationships. An objective (e.g., "*Work on the table 2*") is broken down into progressive levels of difficulty. Each level is itself broken down into training tasks (e.g., "*Level 1: Completion 1 with search for the result, Identification by choice of the correct facts*"). A task is defined by its type and parameters. The levels' achievements are considered from both a percent of encountered facts and a percent of achievement to reach.

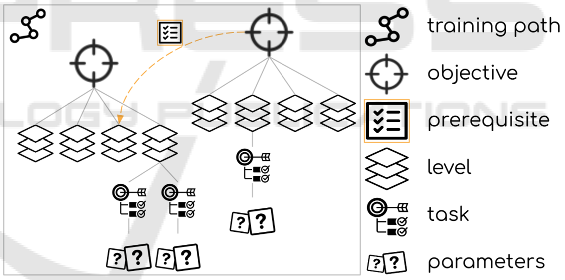


Figure 1: Knowledge Structure.

Five types of tasks have been identified with the teachers: **Completion 1**, i.e., complete an incomplete fact that has one missing element (e.g., $3\times ? = 15$, $15 = ? \times 5$, $3 \times 5 = ?$); **Completion 2**, i.e., complete an incomplete fact that has two missing elements (e.g., $?\times ? = 15$ with a set of given choices $[3, 6, 5, 10]$, $? \times 5 = ?$ or $3\times ? = ?$ also with sets of given choices); **Reconstruction**, i.e., replace, in the correct order, all important elements of a fact (e.g., $?\times ? = ?$ with a set of given choices $[3, 6, 5, 10, 15]$); **Identification**, i.e., identify the correctness or incorrectness of one or several facts (e.g., $3 \times 5 = 15$, true or false?); **Membership Identification**, i.e., identify the elements that share or do not share a given property (e.g., $[3, 5, 9, 14, 21]$ which are results of table 3?).

Considering the training tasks, their specification led us to define several parameters whose values depend on teachers' opinion and preferences to choose and set-up these tasks for each {objective, level} pair. For example, the parameters for the *Completion 1* task are presented in Table 1: the targeted tables, the multiplicand position, the result position, the interval (i.e., min/max) of the multiplier, the elements to search, the order of the questions, the modality of response, and the maximum response time.

As we are following a prototyping design approach, the design is carried out step by step. Therefore, each new iteration takes into account a little more information than the previous one. This article presents the first two iterations of our design, which does not yet include the full knowledge structuring presented. The first prototypes aim at a parameterization approach, i.e., teachers have to give the parameter values (cf. Table 1) for each learner inside the game.

2.2 Rogue*Lite* Genre

Rogue*like* and Rogue*lite* are video games genres growing in popularity this last decade. They stem from the game that pioneered this type of gameplay: Rogue (Toy et al., 1980). Rogue was a turn-based dungeon crawler game where you have to fight your way through levels of a dungeon, picking up items and defeating enemies along the way. The Berlin Interpretation (Harris, 2020) defined 8 high-value factors for Rogue*likes*, which includes:

- Random environment generation: different room layouts with randomized locations for enemies and items each time you play. This is usually realized with procedural generations, not total randomness, to avoid unwinnable situations.
- Permanent death: when the avatar die, all progress is lost and the player must start over from the beginning. No progress is carried over across runs.

Most of Rogue*likes* games fall to respect all 8 key aspects, like the turn-based gameplay with movement on a grid. As a result, people started considering these games as “roguelike-like” or “roguelite”. For now, Rogue*lite* genre is used in relation to Rogue*like* games, proposing a macro-level objective by **carrying over some items and progression** after each attempt. Some well-known commercial Rogue*lites* games are: *Hades*, *Enter the Gungeon*, *The binding of Isaac*, *Rogue Legacy* and *Deadcells*. They propose different kind of gameplay, game styles and lore as well as different features and permanent elements to reach the game cross-run objective (e.g., weapons, currencies, upgrades, etc.). For example, some collectible resources can persist between deaths and players can use them to unlock permanent upgrades and increase their chance of success.

Failure is a key-part of Rogue*lites*. When players start, the new mechanics, traps, difficult enemies and bosses, or the various features that they need to learn, will lead them to fail and/or die many times before they win their first complete run. While losing over and over again may not sound fun, Rogue*likes* typically have fast restart times and will quickly get players back into the action. Through playing more runs, players begin to understand the underlying mechanics and get further.

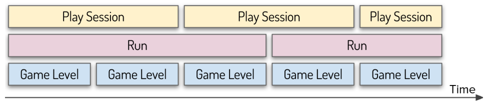


Figure 2: Rogue*lite* Training Game Flow.

The game flow (i.e., temporal representation of game sessions) of Rogue*lite* oriented games can be different from one game to another. This article considers the game flow presented in Figure 2 where a play session is a temporal session that begin when the player starts the game and that ends when he/she stops it. It is composed of complete or incomplete runs. A run is a succession of game levels, played without dying, with increasing difficulty. There are two conditions for stopping the run: the end of the game is reached or the avatar died. A game level is generally a level of a dungeon (or something similar) that is composed of interconnected rooms or areas.

2.3 Adequacy of Declarative Knowledge Training with Rogue*Lite* Genre

Replayability is at the heart of the Rogue*lite* genre, which is designed to keep players interested while relying on a repetitive mechanic (i.e., permanent death). In addition, the random environment generation feature offers a wide variety of dungeons (i.e., each generated dungeon level is different in terms of rooms, room succession and elements). The procedurally generated maps will always provide a different experience with each play through. Finally, the progress feature allows for the storage of player data. All these features are necessary elements in our research context. Repetition to retain declarative knowledge, generation of varied activities to limit the impact of repetition, and progression to keep track of the learner's progress and preferences in order to adapt the activities. Therefore, Rogue*lite* seems to be a suitable genre for declarative knowledge training, where the training game activities generated are dungeon levels.

Table 1: Examples of parameters for the "Completion 1" training task.

Adaptable element	Possible Values	Some Examples
Targeted Table(s)	From 1 to 12	
Multiplicand Position	Left $\vee$ Right	$1\times2, 1\times3, 1\times4.. \vee 2\times1, 3\times1, 4\times1..$
Result Position	Left $\vee$ Right	$1\times2=2 \vee 2=1\times2$
Multiplier Interval	Integer Min/Max in $[1,12]$	$[1,5] \vee [5,10] \vee [1,12]$
Element to search	Result $\vee$ Multiplicand $\vee$ Operand	$1\times?=2 \vee ?\times2=2 \vee 1\times2=?$
Questions Order	Ascending $\oplus$ Descending $\oplus$ Random	
Response Modality	Choice between propositions $\vee$ Input	
Max Response Time	Time in seconds	

2.4 Targeted Adaptations

Our general context is about the adaptation of the generated game *and* learning activities. This adaptation needs then to be characterized from both game and learning perspective. Adaptation is often characterized by three concepts: the source (i.e., to what do we adapt?), the target (i.e., what is adapted?) and the pathways (i.e., what methods are used to adapt the target to the source?) (Vandewaetere et al., 2011).

Foremost, in our context, the adaptation targets generated dungeon and their elements (i.e., what is adapted). Therefore, it takes place during the generation of an activity (i.e., when it is adapted). In the spectrum of adaptation defined by (Oppermann and Rashev, 1997), our targeted adaptation can be positioned in-between adaptivity and adaptability, as it uses user's data previously collected to automatically generate an activity that is adapted to her/him.

In the literature, the gaming adaptations are mostly based on players/personalities profiles (Tondello et al., 2016; Nacke et al., 2014; Goldberg, 1990) or players characteristics, such as age and genre. In our context, adaptation from a game perspective seeks to take into account player preferences to choose the game elements (i.e., source). The main idea is to represent preferences as game elements that can be activated/deactivated by the player. From the learning perspective, our intention is to use knowledge of the learner (e.g., actual level, previous mistakes) from his/her learning path (source) to adapt the dungeons' difficulty in terms of educational content.

Since the adaptation is an integral part of the generation, in our context, this article does not dissociate them (i.e., the generation criterion includes adaptation, see Section 3).

2.5 Research Question

Many questions need to be answered when designing a Rogue*lite* oriented game for training declarative knowledge. *What is generated? How and when does the avatar die? What are the consequences? What varies? What indicates a progression?* And so on. Furthermore, these questions need to be answered from both an educational and a game perspective. Moreover, in a prototyping design approach, the answers may change from one prototype to another. Therefore, our research question is: *How can the design of Roguelite-oriented learning be facilitated in a prototyping design approach?* Our proposal is an analysis framework that helps designers ask the right questions and make their choices explicit during each design iteration.

3 ANALYSIS FRAMEWORK FOR A ROGUE*LITE* LEARNING GAME

Firstly, it is important to keep in mind that we are designing a game. Therefore, although the design tends to focus on learning, the game aspect must not be neglected. To this extent, the proposed framework aims to provide a means of analyzing the design needs of Rogue*lite*-oriented learning games by specifying both dimensions through specific criteria.

The first step in designing a Rogue*lite* is the specification of game mechanisms, such as generation (e.g., what is generated? How?), permanent death (e.g., when does one die?), as well as progression (e.g., what elements are kept?). Hence, the generation mechanism involves the specification of the variety mechanism, e.g., which elements should the generation vary? In a game, as in learning, an essential notion is that of difficulty progression, e.g., how does one increase difficulty? When? In our context, the 5 mechanisms (**Generation**, **Death/Hurt**, **Variety**, **Progress**, and **Difficulty**) are criteria for analyzing needs that must be specified from both points of view. Each criterion consists of a series of questions that relate to the same mechanism. Each question should be answered in order to clarify the design needs of the learning game. The questions per criterion are:

1) Generation

Q1. Which elements are generated?

Q2. When are they generated?

Q3. On what basis are they generated? (i.e., sources of generation)

2) Death/Hurt

Q4. When can the avatar get injured or die?

Q5. What are the consequences of being injured? Being killed?

Q6. Where can the avatar be injured or killed?

3) Variety

Q7. Which elements vary?

Q8. How do the elements vary? (i.e., are the variations initiated by player action? Are they random? Is it a mixture of both? Are they based on heuristics?)

4) Progress

Q9. What is retained/preserved in-between each death? (i.e., what elements?)

5) Difficulty

Q10. What are the elements that increase or decrease the difficulty?

Q11. How is the difficulty progression designed? (i.e., if several elements have an impact on the difficulty, in what order do they occur?)

Table 2: Grid for Design Needs Analysis.

Criteria		Educational Perspective	Game Perspective
Generation	Q1		
	Q2		
	Q3		
Death/Hurt	Q4		
	Q5		
	Q6		
Variety	Q7		
	Q8		
Progress	Q9		
Difficulty	Q10		
	Q11		

The table 2 presents a structure to be completed for the needs analysis. Each row represents a criterion and is divided into X sub-rows (i.e., one sub-row per question). Each column represents a dimension (i.e., a column for the game dimension, another for the educational dimension). If both dimensions have some common information, it can be precised by merging both related cells. The proposed framework is independent of the learning field and is suitable for the design of any learning game based on Rogue*lite* genre. The following section presents the application in the context of the AdapTABLES project.

4 FRAMEWORK APPLICATION: AdapTABLES PROJECT

This section is broken down into four subsections: subsection 4.1 details the analysis for the design of the first prototype; subsection 4.2 describes the current prototype; subsection 4.3 presents the feedbacks (collected informally in real-life conditions) on the prototype); subsection 4.4 specifies the design needs analysis for the next prototype, and subsection 4.5 discusses the proposition.

4.1 First Analysis

The initial step in our iterative process was to carry out the design needs analysis for the first prototype. The initial scope was to put aside the knowledge structure by focusing on one task only (Completion 1 for multiplication tables) that will be manually set up into the game (persistent information through different training sessions). Table 3 presents an overview of the first design needs analysis.

Generation. The generated element (**Q1**) is a dungeon level and its elements (i.e., rooms, rooms order, rooms elements, elements positions and values). Each room has a type between question room and no-question room. A question room is associated to a task (i.e., the training task defined by the teacher and set-up before playing). A no-question room is a fun room where enemies, traps, and only game elements are present. The presence of purely gaming rooms intends to avoid giving the learners-players the impression that they are simply answering a disguised questionnaire. Following the game flow presented in Figure 2, a dungeon is generated when (**Q2**) the player asks for a new game level.

As mentioned in Section 2.4, our game adaptations target players' preferences. To identify the preferences, we first looked at the existing Rogue*lites* and found out that many of them offer a mechanism for purchasing items (e.g., equipments, upgrades, skills). Then, by working with game designers, we identified three kinds of preferences: 1) Content, 2) Rules and 3) Visuals & Audio (**Q3**). Content preferences are additional objects present while playing or elements that change the structure of the activity if activated. For example, an extra life or a dungeon mode (linear or labyrinthine) are content preferences. Rules preferences are elements that impact the players, the avatar or the NPCs (Non-Player Characters) behaviors. For example, increasing the enemies speed or adding a game goal (e.g., completing an activity without mistakes earns +10 coins) are rules preferences.

From the game dimension, the generation is based on (**Q3**) these three types of preferences (e.g., if a player bought and activated the labyrinthine mode, the generation algorithm takes it into account). To keep track of learners' in game progress, the generator also takes into account the last level number and state: if the previous level was #5 and was successful, then the next level is #6; in case of death, the next level is reset to #1. Level number affects the dungeon length, the quantity of rooms with questions, and the dungeon effects (levels greater than #4 are in dark mode). In the educational dimension, many tasks parameters can change depending on the level of the learners (cf. Section 2). Therefore, all learners have their own setup for the task *Completion 1* (or a shared one) defined by the teachers. These parameters values are used to produce relevant questioned facts associated to the rooms-with-questions (**Q3**). Previous encountered questioned facts and results are used to avoid answering again a successful questioned fact.

It is worth notice that both game and training dimensions can sometimes conflict. For example, if a learner-player has bought and activated the 'labyrinthine' mode and if the task setup requires the learner to meet the questioned facts in an ascendant or descendant order. In these cases, our recommendation is to consider the training dimension as a priority.

Death/Hurt. In both cases, when the avatar is injured (**Q5**), it loses a life, and when there is no life left, it dies. The player (through the avatar) gets hurt (**Q4**) when touching a foe, falling into a pit (game dimension) or when answering incorrectly to a question (educational dimension). It also happens when the time is over (preliminary set in the task parameters). Answering a question incorrectly or running out of time can only be done in a question room (**Q6**), while hitting the wrong enemy or falling into a pit can be done in both types of rooms.

Variety. In terms of game variety, different elements can be chosen by the generation algorithm. In the context of Rogue*lite*, the variations are mainly based on the types of objects, their position, the shape of objects and dungeons, and the number of elements present (**Q7**). Therefore, the decorative objects positions as well as the rooms shapes are chosen "randomly" (**Q8**) (i.e., the coherence is kept, e.g., the elements are not outside the room or the avatar can access the necessary elements). The gameplay represents the concrete way in which the learner performs the task. Therefore, having only one form of gameplay per task can quickly lead to a sense of redundancy. One way to avoid this sense is to vary the gameplay. To that extent, 4 gameplays were identified (**Q7**) for the Completion 1 task type: open the chest wearing the correct answer, pass through the door that has the correct answer, touch the foe wearing the correct answer, or type down the correct answer.

From the learning dimension, the facts to be worked on are different, until each fact has at least been seen once (**Q7**). Moreover, depending on the parameters (cf. Table 3), the facts shapes (e.g., missing element, position of the equal, etc.) vary (**Q8**). Some degree of randomness is always involved in the variation of elements. However, this randomness is limited by the preferences of the game, the educational constraints (i.e., the teachers' choices) as well as by the choices made earlier (i.e., elements already selected by the algorithm).

Progress. In order to take into account players' preferences, our main idea is to use a purchase mechanism (i.e., commonly used in Rogue*lites*) where players can buy items and then activate/deactivate them as they wish. Therefore, progression from the game viewpoint can be seen through the elements bought and the number of coins (**Q9**). Some Rogue*lites* only keeps progression when the level/dungeons are finished (i.e., the avatar did not die). Therefore, the coins are only gained if the player finishes a dungeon completely. These coins are collected through the dungeon journey (randomly appear when opening a correct chest) or win at the end according to the activated rules (for example, +10 if ending the dungeon level without any mathematics error). Training progression can be seen at the end of a dungeon (when reaching the end or dying) with statistics presenting the mistakes made, the correct answers given, and what is left to work on. All the results are persistent across the runs.

Difficulty. From the game dimension, difficulty increases during a run by increasing the number of rooms-with-question (i.e., 5 rooms first, then 7, then 9, then 11, etc.) (**Q10**). The total number of rooms may still vary according to the generation process that can randomly includes rooms without question along with the dungeon structure (tortuous but linear or labyrinthine) (**Q11**). After 5 levels played, without losing, a harder level is proposed where the player is in the dark, a torch only illuminates the avatar (**Q10**). The educational difficulty increases in accordance with the parameters defined by the teachers, but while these parameters are not changed, the questioned facts will always concern this setup (**Q11**).

These choices are mainly debatable, and intends to define a first version of the game's difficulty progression, which is bound to evolve.

4.2 First Prototype

The prototype has been developed using the Unity game engine, as a 2D game with C# scripts. It is exported and deployed as a Web platform WebGL build. The game uses an HTTP REST API (developed in .Net Core) to persist data in a NoSQL MongoDB database. In addition, a teacher dashboard is available as a web application (developed in .NET with Blazor). It allows teachers to monitor for their students: the current settings for the multiplication parameters, current achievement progress for the considered multiplication facts, current elements that has been bought. Currently, only a French version playable with both a gamepad or a keyboard is available.

Figure 3 shows 6 screenshots of the prototype. The screen 3a represents part of the current 'hub' area with four accessible elements: statistics ("Stats Generales"), progress ("Progression"), educational settings ("Reglages") and lastly the purchase panel ("Achats", i.e., game preferences). This 'hub' area is where the player starts a run and goes back after he died. It offers players a peaceful space where they can check their progress or manage collectibles (purchase, activation/deactivation). Screen 3b is an extract from the educational settings panel (cf. Table 1). Screen 3c is an extract from the item purchase panel. An example of each of the currently implemented gameplays present in the dungeon levels (i.e., choosing the correct foe, the correct door, and the correct chest) is illustrated in the Screens 3g, 3e, 3f. Finally, the Screen 3h presents an example of a room where the player has to type down his/her answer.

4.3 Experiment Feedback

The design of the prototype went through 3 iterations where it was tested in real conditions and then improved according to the feedback from teachers and students (i.e., played in classroom by students supervised by their teacher). Some empirical feedback were about ergonomics concerns (keyboard versus gamepad), playability experience, replayability inclination, motivation to play and train the tables, etc.

The rest of the information collected were related to the overall design, based on our previous analysis choices, stated in the previous section. With regard to the death/injury criterion, several problems have been identified. Firstly, children sometimes make unintentional choices due to the current 'touch'-oriented interactions that do not require the use of a button or key. Even if this gameplay problem is related to ergonomics, it can lead to a feeling of unfairness from the reward/punishment system. Secondly, some rooms have randomly positioned foes very close to the avatar's entry area: swept along by the momentum, children can lose hearts without having time to avoid them. Similarly, some room-with-question also embed holes to avoid. Teachers have pointed out to us that these game elements can disturb children when they should focus on the question.

Considering the variety criterion, children appreciated the three gameplays for choosing an answer (door, chest, and foe). This prototype offered 3 different room structures for each game, however it does not vary enough. The gameplay about touching the correct foe has been considered confusing by both children and teachers. In some rooms, foes were to be avoided, while in others the players must lead their avatar to touch the foe with the answer they choose. This is counter-intuitive, and teachers consider that identifying a correct answer should not be associated with a negative action (here, killing the foes). The prototype also proposes several rooms-with-question that require to directly type down the correct answer on the keyboard. According to the correctness or not of the answer, the right door or chest opens, or all foes die. Any incorrect answer leads to open an empty chest, open a door towards a dead end, or having no effect on the touched foe, but in all three cases, injuring the avatar. These situations were initially designed to vary the mode of response while providing similar room content, but were ultimately confusing.

As far as the progression perspective is concerned, we failed to provide a balanced way of collecting coins. Only chest-oriented gameplays (choose or write modality) can randomly contain '+1' or '+3' coins (or a 'heart'/life). Some purchased and activated rules may provide other ways to earn coins, but early successful dungeon levels may not result in any coins being earned. Moreover, the first purchased items are mainly those of the content category (extra hearts), preferred to rules. In addition, some teachers were not convinced about leaving learners free to buy and activate rules that push them to act faster, stressing them to answer quickly.

As mentioned earlier, the generation process may disable some activated rules that do not conform to the current configuration of the *Completion 1* task. This can lead to feelings of confusion when discovering the generated dungeon levels.

Table 3: Design Needs of the prototype #1.

<table>
<tr><th colspan="2">Criteria</th><th>Educational
Perspective</th><th>Game
Perspective</th></tr>
<tr><td rowspan="4">Generation</td><td>Q1: What?</td><td>One task and one questioned fact per room-with-question</td><td>Dungeon + rooms + entry + exit</td></tr>
<tr><td>Q2: When?</td><td colspan="2">When a new game level is required</td></tr>
<tr><td rowspan="2">Q3: Based on?</td><td>”Completion 1” set-up
Current progress among possible facts</td><td>Previous level number and state
Activated game elements or rules</td></tr>
<tr><td colspan="2">Task parameters have priority on activated game elements if conflict</td></tr>
<tr><td rowspan="3">Death/Hurt</td><td>Q4: What?</td><td>Incorrect answers or time out</td><td>Being touched by foes, falling into holes</td></tr>
<tr><td>Q5: When?</td><td colspan="2">Injuring causes heart lost, no more hearts causes death</td></tr>
<tr><td>Q6: Where?</td><td>Question rooms</td><td>Any room with foes or holes</td></tr>
<tr><td rowspan="2">Variety</td><td>Q7: What?</td><td>Facts</td><td>Rooms with gameplay and content</td></tr>
<tr><td>Q8: How?</td><td>Progress and past results</td><td>Random</td></tr>
<tr><td>Progress</td><td>Q9: What?</td><td>Success or failure on met questioned facts</td><td>Coins collected during successful game levels + purchased elements</td></tr>
<tr><td rowspan="2">Difficulty</td><td>Q10: What?</td><td>Questioned facts</td><td>Dungeon level length
+ dark mode</td></tr>
<tr><td>Q11: How?</td><td>In relation with the task parameters</td><td>According to previous level number and state</td></tr>
</table>

4.4 Second Analysis

This second analysis was conducted for the design of the next multiplication tables training prototype. Based on teachers' and learners' feedback, we worked with game designers to identify solutions and further directions, both from a game and training dimension.

As with the functional scope of the first prototype, the knowledge structure is still not taken into account, although all 5 task types are considered. The prototype will make it possible to manually parameterize the current training configuration for any children according to their individual progress (correspondence of a {objective, level} pair) of a learner's training path, cf. Figure 1).

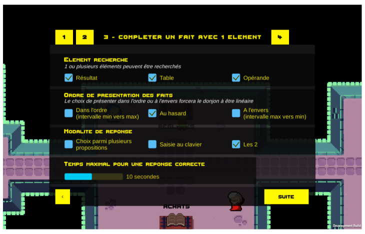
Generation. The generated element (**Q1**) is still a dungeon level composed of organized room of two types: room without question, and room with one question associated to one of the types of task involved according to the training setup. Each room is composed of various interactive elements. This dungeon level is generated when (**Q2**) the player requests a new game level, from the hub-room (to start a new run) or after the debriefing screens following a successful dungeon level. From the game dimension, the generation continues to take into account the last level number and state (**Q3**) as well as the purchased and activated features. However, the purchasable (activatable) elements have changed. These elements are explained in the following categories. From an educational dimension, each generation considers the current configuration of the learner for all types of tasks involved (from 1 to 5), and takes into account the previous questioned facts and the previous results.

Death/Hurt. The player still gets hurt (**Q4**) when touching a foe, falling into a pit (game dimension), when answering incorrectly to a question or lacking of time (educational dimension). The main difference is that the question rooms will no longer have traps and game elements that can hurt the avatar other than those related to the question to be answered (**Q6**). Getting injured in a question room will always be caused by a wrong answer or a time-out. The consequences of an injury are not changed (**Q5**), it leads to the loss of a life, or death.

Variety. In the first prototype, the different types of rooms merged game elements and gameplays. In order to propose more varieties of rooms (**Q7**), we consider a new approach (see. the conceptual class diagram in Figure 4). On one hand, the *types of tasks* are mapped to different *gameplay types* according to the current tasks parameters. Every type of gameplay requires a *quantified* number of elements having the specified *ability*. On the other hand, the *types of rooms* describe some *positions* accepting different elements having a given *ability*. By extension, different *types of game elements* are associated to the *abilities* they can manage.

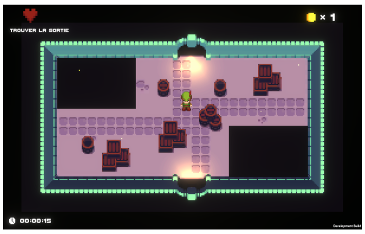
Combined, these elements will drive the generation of rooms and their built-in elements (**Q8**). As a result, the purchase mechanic now consists of players choosing items that will, if equipped (i.e., activated),

(a) Prototype's hub



(b) Training settings panel

(c) Gaming settings panel



(d) A no-question room

(e) Door Gameplay

(f) Chest Gameplay

(g) Foe Gameplay

(h) Answer entry

Figure 3: Screenshots of the current prototype features (text in French).

unlock new types of gameplays that can occur in certain rooms if they are consistent with the task associated to the room. By providing variants of game elements that share these abilities, game developers will increase the possibilities for variations. Let's take as an example the "boxing gloves" item, that allow the destruction of every "destroyable" elements (i.e., having an ability). Several elements can have "destroyable" as an ability: walls, pots, statues, rocks, etc. If the avatar is equipped with this item, it is possible to create multiple variants of gameplays. The mechanism remains the same, but the elements vary (e.g., destroy the wall, break the rock).

Progress. Equipment items are definitely purchased across runs. The coin mechanism is retained, but will be adjusted so the learners will earn one coin per correct answer. Questioned facts encountered and associated results are also saved beyond death. Therefore, the progression can be observed through: the equipments available, the number of coins, and fact results, i.e., available outside a game level (**Q9**).

Difficulty. The educational difficulty is maintained as in the first prototype, i.e., according to the parameters of the tasks supervised by the teachers (**Q11**). From a gameplay point of view, the progression according to the length of the dungeons is kept, but a new gameplay mechanism is added: the curses (**Q10**). The game progression will be structured in different minimum thresholds, unlocking curses that may or may not occur during the dungeon level to be gen-

Table 4: Design Needs of the Future Prototype (**Bold** describes changes from the first analysis).

Criteria		Educational Perspective	Game Perspective
Generation	*Q1: What?*	One task and one questioned fact per room-with-question	Dungeon structure + rooms
	Q2: When?	When a new game level is required	
	Q3: Based on?	**All tasks set-up** Current progress among possible facts	Previous level number and state **Equipped items**
		Task parameters have priority on activated game elements if conflict	
Death/Hurt	*Q4: When?*	Incorrect answers or time out	Being touched by foes, falling into holes
	Q5: What?	Injuring causes heart lost, no more hearts causes death	
	Q6: Where?	Question rooms	**Only rooms with no question**
Variety	*Q7: What?*	Facts	Different types of **rooms**, types of **gameplays**, types of **elements**
	Q8: How?	Progress and past results	Based on the **available equipments**, **gameplays**, **elements**,
		and **in relation to the tasks** ⟺ **gameplays mappings**	
Progress	*Q9: What?*	Success or failure on met questioned facts	Coins collected during successful game levels + **purchased items**
Difficulty	*Q10: What?*	Questioned facts	Dungeon level length **+ curses**
	Q11: How?	In relation with the task parameters	According to previous level number and state

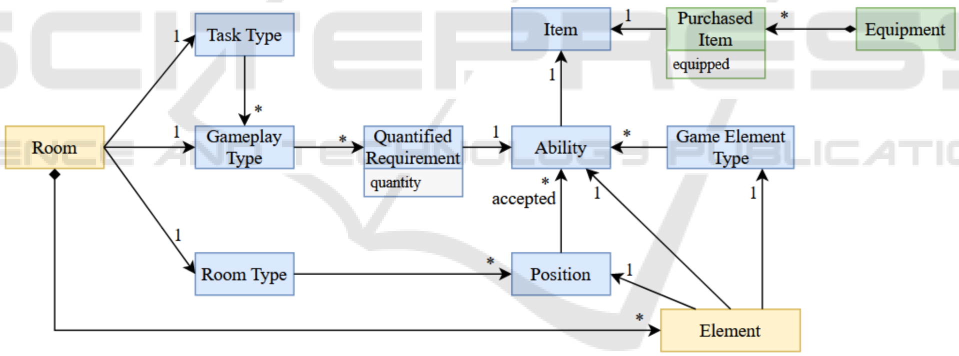


Figure 4: Conceptual class diagram illustrating the domain elements and relationships involved in considering a wide variety of question pieces. Yellow concepts are to be generated; blue concepts are specifications of the game and didactic elements available; green concepts concern each learner-player.

erated (**Q11**). For example, if we consider thresholds every 3 dungeon levels, the generation of level #10 may involve at worst 3 curses, or 0 with luck.

4.5 Discussion

The first advantage of the framework is the traceability of design choices. Indeed, at each iteration, the choices are explained and then summarized. This traceability facilitates the evolution of the design without the risk of involuntarily going backwards. On the other hand, the visual synthesis (cf. Table 2) makes it possible to check that none of the dimensions has been neglected (i.e., presence of an empty box in case of neglect). In a prototyping approach, iterations are essential to fix certain settings. However, it would seem that the use of such a framework (i.e., allowing traceability as well as visual verification of the non-neglect of a dimension) could reduce the number of iterations required. Finally, this tool provides a support that can be understood by all stakeholders of the design process.

However, the proposed framework takes into account a rather precise context: training or retrieval practice (i.e., a form of test-based learning) in the context of the Rogue*lite* video game genre. Moreover, the criteria used are those that we consider essential. Consequently, other criteria might be considered essential by other researchers or game designers. In particular, some criteria depending on the application domains might be interesting to add.

5 RELATED WORK

The literature includes many frameworks and methods for games, serious games, game-based scenario design. However, many of them are mainly oriented towards and used for the analysis of already existing games (Junior and Silva, 2021).

(De Freitas and Jarvis, 2006) proposed a four-dimensional learner-centered framework (Representation, Context, Pedagogy, Learner) to help design game-based learning scenarios. This approach is at a high level of design, which does not facilitate the transition from educational content to concrete game elements. (Winn, 2009) introduced the DPE framework, an extension of the Mechanics, Dynamics, Aesthetics (MDA) framework (Hunicke et al., 2004) for serious games. This framework is broken down into three categories (design, play, experience; i.e., the designer designs the game, the player plays the game, which results in player's experience), each described by four criteria: Learning, Narrative, Gameplay, User Experience. (Schell, 2008) proposed a method consisting of a series of questions on different aspects to be taken into account for the design of the game. This method is more generic than ours (i.e., at a higher design level) because it does not focus on a specific type of knowledge or game genre. (Amory, 2007) described GOM II, a framework for the design of educational games extended from the Game Object Model (GOM). This framework considers that an educational game is composed of a set of elements described by abstract and concrete interfaces (based on the Object-Oriented paradigm). This work is theoretical and focuses on the general design of games rather than their concrete implementation. (Arnab et al., 2015) proposed the LM-GM framework that enables the association of Learning Mechanics to Game Mechanics through the use of Serious Game Mechanics (SGM; "design decision that concretely realizes the transition of a learning practice/goal into a mechanical element of gameplay for the sole purpose of play and fun"). Nevertheless, this framework is more oriented towards the analysis of games than towards their design. (Carvalho et al., 2015) presented a conceptual model, called ASTMG, based on activity theory, which seeks to provide a better understanding of the relationships between the serious games elements and learning objectives/goals. This framework is also more oriented towards game analysis.

Many other framework and methodologies exists (Yusoff et al., 2009; Barbosa et al., 2014; Marne et al., 2012; Kiili, 2005; Silva, 2019). Some works offer methods that are closer to some general game genre (i.e., adventure games, story oriented games for (De Lope et al., 2017)). However, these works are mainly generic (i.e., they are not specific to a type of knowledge or a game genre). Therefore, being in the specific context of the Rogue*lite* genre, none of the existing works met our requirements. Nevertheless, these frameworks are not incompatible and can be used together. As examples: the framework proposed by (Schell, 2008) could be used to describe the general design of the game; the ASTMG (Carvalho et al., 2015) could be used to verify the coherency of each prototype. In short, the current frameworks that share our goal of assisting the design of learning games deal with different pedagogical objectives, different types of knowledge, different game genres. They do not aim to assist design in situations where the game genre is already identified because of its relevance to a specific learning objective. Our analysis framework is dedicated to Rogue*lite* games for declarative knowledge retention: a very specific scope. Nevertheless, multidisciplinary teams also require specific frameworks to guide them deeper in the design of relevant, adapted, and balanced learning games.

6 CONCLUSION

This article 1) presented Rogue*lite* as a suitable game genre for declarative knowledge training, and 2) introduced a design needs analysis framework for Rogue*lite*-oriented learning game. The proposed framework gives a very first insight into the mechanism and choices that benefits both to the game and training dimension. The main idea is to allow a two-dimensional design between the play and learning dimensions. This design aims at a separate description of the dimensions while allowing the verification (and maintenance) of both dimensions' conformity.

This framework was used in a prototyping design approach in the context of the AdapTABLES project. This project aims at creating a game for multiplication tables training. This article presents the application of the framework over two iterations: 1) the first iteration led to the current existing prototype, 2) the second iteration presents the design requirements of the future prototype.

In the future, we would like to apply this framework to other fields of application than mathematics. Currently, we are working on its application to history-geography facts (e.g., historical dates, countries of the European Union).

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