Digitalization of educational plays for quality education

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ABSTRACT

Repetitive tests on a learning material help schoolchildren to memorize and to learn this material. Psychologists call this phenomenon the testing effect. Skilled teachers use learning plays to embed routine tests in an engaging way. To widespread this practice, we propose a framework to digitize learning plays embedding routine tests into educational videogames. We have identified the smallest set of game design elements required to build an educational videogame out of a learning play. We have used the self-determination theory to group game design elements, and to define a breakdown structure for engagement engineering. This structure helps select the appropriate design elements for an engagement driver. We have applied the framework to digitize a learning play. We have tested the digital play with 238 schoolchildren who considered it as a video game. The video game tested a proposed pattern to create challenges allowing an engaging flow experience. The pattern increased responses (9%) and created time distortion (24%). Delivering rewards following variable schedules reduced errors (49%) and increased time distortion (16%). This research explores how to digitize learning plays into engaging educational video games and how to design engaging video games to remediate missed learning.

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1. INTRODUCTION

In Morocco, primary education has made progress in enrollment. However, concerns about the quality of primary education persist. The ministry in charge of national education in Morocco has started an initiative based on play-based routine activities to help school children acquire the basic skills in oral language comprehension, reading and math [1]. These play-based activities use learning based on repetitive routine tests.

Plays are an established didactical tool used in educational environments that can help school children develop cognitive and social skills [2]. On the other hand, repetitive assessment or testing enhance retention of material more than additional study of that material [3]. Psychologists call this phenomenon the testing effect.

Multiple researchers have been exploring how to use video games for instruction and game-based learning [4]–[6]. Video games designed for instruction are called educational video games or serious games. Several initiatives have tested serious games in primary education and reported positive results in language and calculus learning [7]. We propose to explore how to digitize learning plays into educational video games to take learning plays outside classrooms. Digitalization should enable school children to practice more, to remediate to miss learning and to get additional benefits from these learning plays.

Video games are fun, joyful and engaging. Games usually use challenges and artificial conflicts [8]. School children identify well today what is a video game and what is not. To be considered as an educational video game, a digital version of a learning play has to provide an experience similar to video games. To build engaging educational video games out of learning plays, we had to identify the important building blocks that compose engaging educational video games.

Several authors have proposed compilations of recurring game building blocks [9]–[12]. If current research has identified many game building blocks that contribute to engagement, this research provides limited indications on which game building blocks to use in a given context. For example, the video games Tetris, Angry Birds, and Super Mario Bros are different still all three are very popular and engaging. Tetris proposes just reflex-based challenges requiring mastery of control [13]. Angry Birds challenges learners to fling birds at pigs that eat their eggs [6]. Super Mario Bros has multiple difficulty levels that adjust to learner skills and offers an emotionally appealing fantasy related to game skills [4]. These three video games use different building blocks and are differently engaging. We wanted to understand how such games motivate us. We also wanted to leverage this understanding to design engaging educational video games.

To digitize learning plays into video games, we wanted to identify first the smallest framework to use in the digitization process that will get school children to consider our digital plays as video games. Afterward, we wanted to add progressive game design elements to make an educational video game more engaging. We explored group game design elements into categories related to similar psychological drivers of motivation. Through this grouping, we wanted to explore selecting design elements that add together to a specific motivation driver.

The self-determination theory is a generic psychology model for human motivation [14]. Multiple researchers are using this theory to model the motivational pull of video games or to select design elements for gamification [13], [15]–[17]. This research builds on similar approaches but applies the self-determination theory to design educational video games.

Adjusting game difficulty to growing learner skills helps get learners into a state of optimal experience called the flow state [18]. Researchers identified well that adjusting challenges to skills fosters engagement [19], [20]. However, there are limited indications on how to design challenges that adjust to skills. In this research, we propose a design pattern to design a flow experience in the context of educational video games used for repetitive testing.

Incentive systems ease failure and motivate school children to play [21]. Skinner [22] have identified that the impact of incentives varies based on how incentives are arranged over time. We wanted to test the impact of incentive systems on engagement and easing failure in the context of educational video games.

We have tested the proposed framework to digitize a mental multiplication play. We have tested the built educational video game with school children and have measured engagement. The first results showed that the proposed approach was working. Our questions related to this research were: i) How to identify upstream if the digitalization of educational play is feasible; and ii) How to select the smallest set of game design elements to design engagement in educational video games?

Scholars, designers and industry specialists looked to identify what contributed to engagement and motivation in video games, and from that in educational video games [5], [6], [23]. Some researchers looked into what components were making educational video games “fun” or engaging [6], [9], [10], [12]. Others looked into how patterns and methodologies can guide the design of engaging educational video games [8], [24]–[28].

Game elements: Through a series of observations, surveys and interviews, Malone [23] has generated three main elements that made video games “fun”, namely challenge, curiosity and fantasy. Other researchers proposed elements that they considered necessary conditions for a game [8]. Deterding *et al.* [11] proposed to define game design elements as a set of building blocks or features found in many games. Deterding *et al.* [11] recommended considering the elements that are found in most games, but not necessary in all games, and playing a significant role in gameplay.

Hunicke *et al.* [24] proposed the mechanic-dynamic-aesthetic framework (MDA) that identified a set of characteristics observed in video games and named them aesthetics. The MDA framework stipulates that interaction characterizes a video game, and not the content. Hunicke *et al.* [24] proposed the MDA model to make this aesthetics emerge from game dynamics through internal mechanics.

Several authors have proposed compilations of recurring game building blocks. Reeves and Read [10] propose “Ten Ingredients of Great Games”, which include avatars to represent oneself; narrative context; feedback; reputation rank and level; competition under rules; time pressure and teams. Garris *et al.* [9] compiled a list of characteristics of engaging educational video games from multiple researches. This list has six elements that are challenge, mystery, rules and goals, fantasy, sensory stimuli, and control. In a recent research, Plass *et al.* [6] argued that most researchers agreed on the following building blocks of educational video games: learning objectives and related content, game mechanics, narrative, visual aesthetics, incentives and musical score.

Game development methodologies: Other researchers explored “how” to design educational video games and looked into patterns and methodologies to drive the process. They wanted to define the work breakdown structure. Amory [29] proposed the game object model framework to design, compose and generate serious games. This framework identified some interesting building blocks and tasks, was complex to use, and had limited success.

Yusuf *et al.* [25] proposed a conceptual framework for serious games. The framework proposed a set of entities to capture learning capabilities, intended learning outcome, as well as the gaming requirements. The proposed framework is conceptual and does not provide any guidance on how and where to put these entities into play. Ibrahim and Jaafar [26] proposed an educational game design concept that builds on three pillars: learning content modeling, pedagogy, and game design. The proposed concept puts emphasis on usability, fun, and syllabus matching. The research from [25] and [26] indicated that the game elements of educational video games should be in relation with learning objectives. These relations should be considered during design time.

Saavedra *et al.* [30] developed some digital resources to help school children learning mathematics in Mexico. Considering the lack of well-defined processes and standard methodologies, they proposed a game development process based on software development paradigms. This research sparks from the needs similar to our research. However, it does not describe how to design learning within serious games nor how to engineer engagement.

Roungas [27] considered that many serious games were still created in an ad-hoc manner without using a game design document. He identified some common components and concepts found in serious games and argued that they should go into a design document. The components of the design document were similar to a game breakdown structure. He proposed a conceptual model to capture the characteristics of these common components and a process to keep this document up to date. His approach promoted design through documentation. He did not cover which components to use for engagement.

Barbosa *et al.* [31] proposed a methodology to design and develop serious games. The proposed methodology had two components, a main game with quests and a set of learning tasks embedded as mini-games. Based on a similar approach, Silva [32] proposed a practical methodology for the design of educational serious games. This methodology aims to identify all-important project phases and steps needed to define learning mechanics from first objectives to user experience. This research proposed to design learning tasks as mini-games embedded within an entertaining game.

Researchers are proposing methodologies to analyze or develop specific categories of educational video games or serious games. Plass *et al.* [6] argue that conclusions and models drawn from specific subjects may not be universally applicable to others. To our knowledge, there is currently no research addressing how to digitize learning plays into educational video games.

Motivation theories: Motivation has been conceptualized from various angles and psychology literature refers usually to two big types of motivation: extrinsic and intrinsic. Operant conditioning is a psychology theory leveraging extrinsic motivation [14]. Skinner developed the operant psychology theory and contributed to the behaviorist learning model [33]. The behaviorist model highlights the importance of reinforcement in learning through immediate feedback and regular reinforcement. Operant conditioning is behind the reward systems used in education or video games. Skinner identified also that rewards produced different impacts on behavior based on how they arranged over time. He called the arrangement patterns "schedules of reinforcement" [22].

Self-determination theory (SDT) delves into the “why” behind behaviors [14] and provides a model for intrinsic motivation. According to SDT, three components facilitate motivation: competence, relatedness and autonomy. When a learner or a player has a sense of competence, autonomy or relatedness when performing a task, he usually experiences this task as intrinsically motivating. Researchers has started using the SDT framework to model engagement in video games [13], [15]–[17].

Csikszentmihalyi studied situations where a person is focused on a single task or activity. They direct their attention toward the task without experiencing many thoughts about himself or his performance [18]. He introduced the term flow state that described a state of complete absorption or engagement in an activity and that referred to the optimal experience.

Flow state is a source of intrinsic motivation. An important condition for the flow state is the balance between game challenges and growing player skills. Researchers have analyzed engaging games through the flow model [19] and analyzed the balance between challenge and skills on motivation [20]. Kiili [34] explored how to foster engagement with players of serious games and proposed a model built around the flow model. This research described observed flow states, and the consequences of flow states. However, they did not provide any indication on how to design such a flow state.

Incentive systems are also used in educational video games to motivate users to play or to ease disappointment [21]. Incentive systems can be point-based (one reward for 10 points), action-based (one reward for 10 actions) or time-based (one reward for 10 minutes of time play). To set up an incentive system, we need to define the rewards and the schedules. There are different forms of rewards among which points, ranks, badges, leaderboards, avatars, item granting, resources for gameplay, and so on [35].

The way we structure the delivery of rewards is called reward contingencies or schedules [22]. Rewards can be linked to the number of responses or to the playing time. Rewards can also be delivered after either a fixed or a variable amount of responses or time. This leads to four categories of reward schedules [36]: i) Fixed ratio schedules (FRS): provides a reward after a fixed number of actions or responses; ii) Variable ratio schedules (VRS): provides a reward after a random number of actions or responses; iii) Fixed interval schedule (FIS): provides a reward after a fixed interval of time; and iv) Variable interval schedule (VIS): provides a reward after a variable interval of time.

2. METHOD

2.1. Smallest framework to digitize educational plays

There is strong evidence that feedback enhances intrinsic motivation [14] and that challenges help students learn [20]. The smallest framework to digitize an educational play should have at least two elements: a challenge-feedback loop design pattern and scoring rules. These two elements transform digital play into a video game. Salen and Zimmerman [8] defined a video game as an "artificial conflict, defined by rules, that results in a quantifiable outcome". Plass *et al.* [6] argued that the challenge-feedback loop defined "what was a game". In a video game, the challenge-feedback loop presents a challenge to the player; collects his response or action, assesses the response, and provides him with immediate feedback. Figure 1 depicts the challenge feedback loop with its three components.

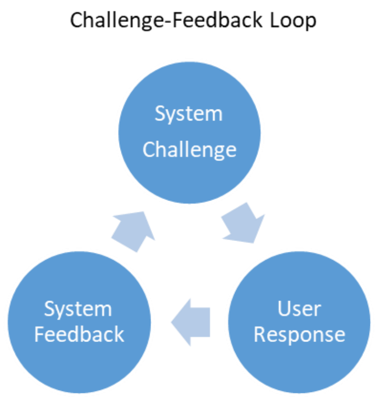

Figure 1. The challenge-feedback loop

2.2. Points for immediate and cumulative feedback

The challenge-feedback loop alone is not enough to make a digital play delivering a video game experience. We need the rules and the 'quantifiable outcome' identified by Salen and Zimmerman [8]. Points and scoring rules answer this requirement. Points, badges and leaderboards (PBL) form three of the basic and widely used game patterns to provide feedback [36], [37]. Points are basic elements that reward for a correct response or action or penalize for a wrong answer. Points provide immediate feedback while scores provide cumulative feedback [16]. Badges are defined as visual representations of achievement and represent cumulative feedback [16]. Leaderboards rank players based on performances and provide cumulative and competitive feedback [38]. Points, badges and leaderboards act as progress indicators of user performance [38]. Some research findings indicate that points, levels and leaderboards do not harm intrinsic motivation [38].

2.3. Hierarchy of game elements

Researchers have identified multiple game design elements that influence engagement. However, some of these elements are high-level features like challenge, complexity or fantasy. Garris *et al.* [9] called these elements "characteristics". Hunicke *et al.* [24] called them aesthetics. Other game design elements are building blocks like incentive systems or musical scores [6]. Deterding *et al.* [11] identified that game elements are at varying levels of abstraction. He distributed game elements on a 5-level hierarchy to distinguish interface elements from game design patterns or game design principles.

To sort game design elements, we propose to use an approach similar to the MDA model [24]. The building blocks enable building a system which behavior builds a game characteristic via interaction. Interaction is key, as without interaction, no game characteristic can show up [24], [39]. Figure 2 illustrates the relationship between building blocks and game characteristics. The proposed approach defines a two-level hierarchy.

Figure 2. From building blocks to game characteristics

2.4. A psychological theory to cluster game characteristics

Researchers have identified multiple game characteristics and building blocks that influence engagement, [9]–[12]. However, these building blocks are so diverse that we needed some guidelines to select which ones to use in a context. We wanted a model for factors influencing motivation that should help us identify which design elements to use for specific contexts.

The self-determination theory or SDT [14] is a current theory studying human motivation and engagement. SDT identifies three psychological needs that encourage motivation: competency, autonomy, and relatedness [14], [15]. According to the SDT theory, a task is motivating for a person if this task puts this person in a context where he has a sense of competency, autonomy, and/or relatedness.

Ryan *et al.* [15] have used the SDT model to analyze the motivational pull of video games. They identified that experiences of competence, autonomy, and relatedness provide significant accounts of player motivation and enjoyment with video games. They identified that players feel competent by facing and overcoming challenges. A sense of autonomy develops when players feel their actions are freely chosen, or when they feel they have a sense of mission and purpose. A sense of relatedness develops when players feel in relation to a group of significant others, or what they do matters to others.

Ryan *et al.* reviewed empirical evidence published in [15] and enumerated a first list of game design elements that helped players experience competence, autonomy, or relatedness [13]. Sailer *et al.* [16] have tested the influence of video game elements visible to players on the satisfaction of psychological needs behind motivation. They hypothesized the influences of some game elements on psychological needs. They ran afterward a randomized controlled study with 419 participants to measure influences in the context of two video games. Wee and Choong [17] conducted a study to predict the effectiveness of a variety of game design elements in enhancing the intrinsic motivation of users prior to implementation of a gamification project. Table 1 presents these mappings.

Table 1. Game design elements influencing sense of competence, autonomy or relatedness

Research	Competence	Autonomy	Relatedness
Przybylski *et al.* [13]	Skill-graded challenges; Positive feedback; Competence needs	Meaningful stories; Avatars, characters; fantasy narrative; Non-fixed structure; Personalization	Groups for cooperation Groups for competition Chat
Sailer *et al.* [16]; proposed matching	Points, badges, leaderboards, performance graphs	Avatars; Meaningful stories (volitional engagement);	Teammates; Meaningful stories (shared goal)
Sailer *et al.* [16]; measured influences	Sense of competence influenced by points, badges, leaderboards and performance graphs	Task meaningfulness influenced by points, badges, leaderboards and performance graphs.	Sense of relatedness influenced by avatars, meaningful story, teammates
Wee and Choong [17]; proposed and measured influences	Challenge Feedback Short cycle time Theme or fantasy	Personal profile Non-fixed structure	Competition Cooperation Chat-based social network

2.5. Mapping game characteristics to engagement drivers

In this research, we have used a modified version of the characteristics identified by Garris *et al.* [9]. The list of characteristics compiled by Garris *et al.* [9] does not address cooperation or multiplayer games. Cooperation influences the sense of relatedness according to SDT. The MDA model defines 'fellowship' as an aesthetic referring to games with a social framework. We have added fellowship to the list of characteristics used in this research.

In Angry Birds, players fling birds at pigs. The game mechanics build on a fantasy that is very appealing to players. In Super Mario Bros video games, the fantasy can include a narrative that invites a player to reestablish a lost balance. The player can experience the game quest as a meaningful task. Opponents and helpers can populate the fantasy world. As such, the player gets a sense that his role is affecting others. Based on these remarks, we have divided fantasy into three components: mechanics, meaningful story, and characters. Table 2 presents the list of characteristics used in this research. This table also presents the psychological needs influenced by these characteristics.

Table 2. Mapping of video game characteristics with motivation drivers

Video game characteristics	Mechanism	SDT motivation drivers
Challenge and goals	The feeling of efficiency and success	Competence
Complexity	Ability to balance challenges with skills	Competence
Rules and goals	Clear goals. The rules define how to reach the goals. Mechanics enable player to act freely within the space delimited by the rules.	Autonomy
Control	Control experience and customize characters	Autonomy
Fantasy (Meaningful story)	Narrative develops a sense of meaningfulness	Autonomy
Fantasy (Mechanics)	Sense of freedom when using unusual tools or mechanics	Autonomy
Sensory Stimuli	Invites a player to accept another type of reality	Autonomy
Fantasy (Characters)	Narrative offers the player a relevant role impacting others	Relatedness
Fellowship	Shared goals	Relatedness

2.6. A breakdown structure to engineer engagement

We stipulated that video game characteristics be implemented via game building blocks. Figure 3 presents the building blocks related to game characteristics. This figure also groups game characteristics and building blocks by psychological needs. It depicts a top-down structure that helps select the game characteristics and building blocks to use for an engagement influencer. This is the breakdown structure for engagement engineering.

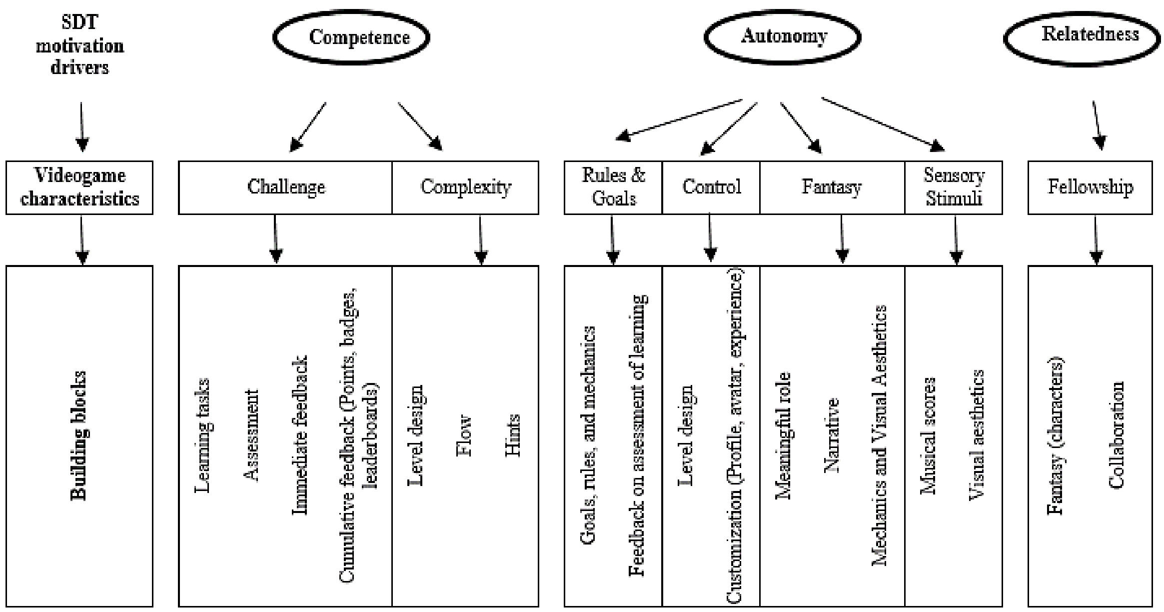

Figure 3. Engagement engineering breakdown structure

2.7. The 3D space for engagement engineering

SDT models intrinsic motivation as an experience related to the fulfillment of three psychological needs that are independent of each other. In this research, we propose to model the engaging experience of a video game as a vector of a three-dimensional vector space. The three psychological needs behind intrinsic motivation are the basis of this vector space. The engagement of an educational video game can be projected on the psychological needs: level of challenge, level of autonomy, and level of relatedness that this video game proposes. Game design elements used in the video game influence the values of these coordinates. Figure 4 depicts this representation using an example.

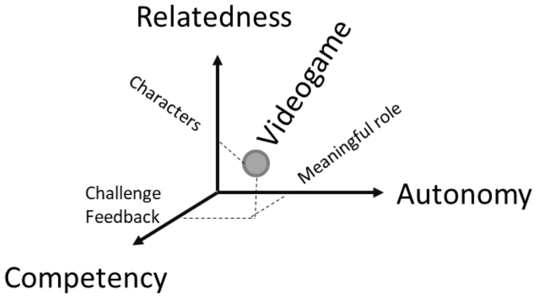

Figure 4. Engagement of a video game represented as a vector

2.8. The map of game elements for engagement engineering

A large body of research demonstrated that intrinsic motivation is strongly tied to positive performance outcomes [40]. However, a beginner does not necessarily experiment with a sense of competence when he starts playing or learning. In a systematic literature review, Sun *et al.* [41] reported that scaffolding, collaboration, and ease of use were identified as important triggers of students' interest in learning in digital environments. Scaffolding is the support given to a student through the learning process. Jerome Bruner created the theory of scaffolding that outlines six ways instructors can support learning, [42]: i) recruiting interest, ii) reducing degrees of freedom, iii) maintaining goal orientation, iv) highlighting typical task features, v) controlling frustration, and vi) demonstrating idealized solution paths.

We have used the scaffolding theory to create a map describing how to sequence the engagement building blocks during the gameplay. Figure 5 depicts graphically the proposed map. In this figure, "meaningful purpose" and "freedom to choose" represent the two mediators of autonomy in the context of video games.

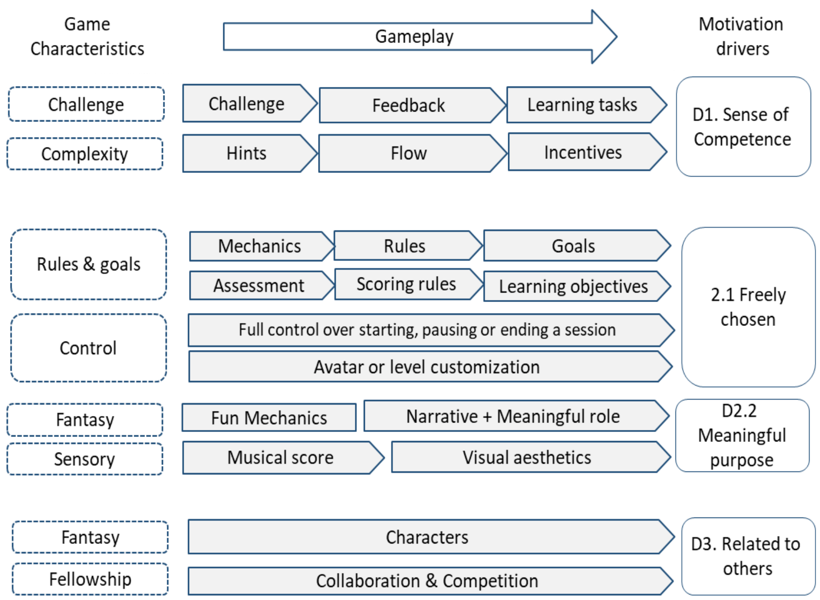

Figure 5. Map of game elements for engagement engineering

2.9. Pattern for a flow experience design

The theory of flow experience states that perceived challenge and skills influence engagement and immersion, which in turn influence positively learning [18], [20]. The design of educational video games should offer challenges that progressively match developing skills. However, we found no design pattern indicating how to create progressive challenges out of a learning objective.

To create a flow experience, multiple video games use a sequence of levels with progressive challenges. For educational video games, to define a level with increased challenge, we propose a design pattern based on changing the conditions of the learning objective. The conditions of the learning objective are the context given to the school children when testing a knowledge or a behavior [43]. We propose to act on the *order* in which we test the learning material. Usually, learning material carries some natural order. For example, multiplication tables have an order, alphabets have an order, and positions of words in sentences have an order. We propose to test the learning material using three orders, the natural order, the reverse order, and a random order. We can also add a time constraint. Table 3 illustrates variations of conditions to increase the challenge of a learning objective.

Table 3. Defining levels with increased challenge through variations of conditions and degree

	Conditions under which learner demonstrates knowledge (video game)	Measurable degree to assess performances (player)
Current level (n)	Present challenges first in an increasing or "natural" order	Player recalls the correct answer from memory (order is acting as a hint)
Following level (n+1)	Present challenges in a reverse order	Player recalls the correct answer from memory (reverse order acting as a hint)
Following level (n+2)	Present challenges in a random order	Player tells the correct answer when asked (random order removes any hint)
Following level (n+3)	Present challenges in a random order and set a time duration constraint	Player tells the correct answer within the constrained lapse of time

2.10. Using incentive systems to ease disappointment

In this research, we have used points for immediate and cumulative feedback. We have also used badges as rewards to glorify success or ease disappointment. To ease disappointment, we have tested delivering badges "earlier than expected" using variable schedules. Table 4 lists the tested strategies. As the flow requires adjusting challenges to skills, we wanted to test adjusting delivery of badges to player difficulties.

Table 4. The reward delivery strategies tested to ease disappointment

Strategy	Calculation	Description
FRS (Points)	Score = Points; Reward = FRS (Points)	The default behavior. A reward is delivered after a fixed amount of points.
VRS (Points)	Score = Points; VRS= FRS (Points +- Adjustment)	The adjustment increment is modified according to user progress and difficulties.
FIS (Responses)	Score = Points + 20% wrong answers; FIS= FRS (Score)	We deliver a badge to encourage participation
VIS (Responses)	Score = Points + 20% wrong answers; VIS= FRS (Score +- random)	We deliver a badge to encourage participation. The badge is delivered on a variable schedule.

2.11. Developed video game

We have applied the proposed framework to digitize a 'mental multiplication' educational video game to practice multiplication timetables. We have developed this educational video game on Android and we have made it available on Google Play Store in Figure 6. The video game 'mental multiplication' implements the proposed patterns with the following parameters:

- We have used game design elements that develop a sense of competence (driver D1 in Figure 5) and a sense of meaningful purpose (driver D2.1 in Figure 5).
- Implemented the flow design pattern with 4 levels: increasing order, decreasing order, random order, and random order with time constraint.
- Rewards were points, ranks and badges. Points provided immediate and cumulative feedback. Badges were pictural rewards (items) to glorify success or ease disappointment. The badges were not certificate of achievements.

Figure 6. Mental multiplication game: start screen, level map, multiplication quest screen, reward display screen

2.12. Method to measure impact of the pattern for flow design

To evaluate the impact of the proposed pattern for flow design, we have measured the variables responses, playtime, errors and quests. Our hypothesis was that these variables were an indicator of engagement resulting from a flow state. Figure 7 depicts this hypothesis.

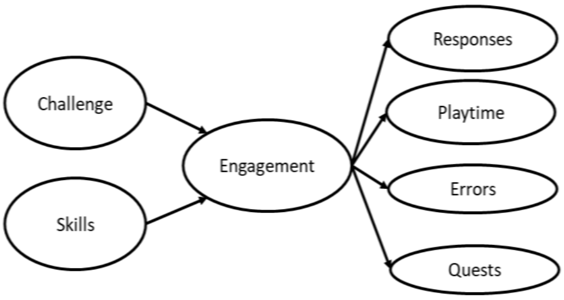

Figure 7. Hypothesis of impact of engagement on responses, playtime, errors, and quests

2.13. Method to measure impact of reward schedules on easing failure

To test badges as elements easing failure, we have tested two situations. The first situation delivered badges on a fixed schedule. The second one delivered badge on variable schedules to encourage players. To identify failure-easing situations, we have measured the same variables as for flow design. Figure 8 depicts the relations. Our hypothesis was that for hard levels, an element easing failure should positively affect player engagement.

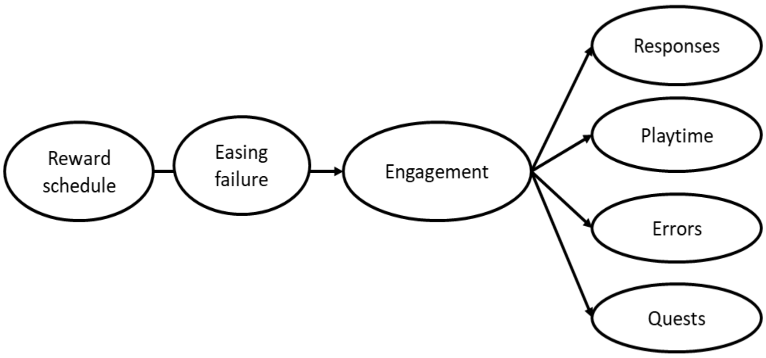

Figure 8. Hypothesis of the impact of reward schedule on easing failure and engagement

2.14. Collected data

We have used the 'mental multiplication' game to measure the impact of the flow design pattern on engagement, and the impact of the incentive system on easing failure. We have tested the game with 238 primary school students from 4th and 5th grades. The tests spanned across 13 days. School children have played multiple quests, multiple levels and experienced different rewarding strategies. Table 5 provides the main figures of the collected data.

Table 5. Main figures related to the size of the test set

Players	# days	Quests played	Responses and interaction	Duration (s)
238	13	4848	41399	541348

The educational video game has collected data automatically on user interactions and on gameplay progression. To manage points, rewards and their delivery schedules, we have developed a generic engine that collects information on player responses and performs the processing. We have extended this engine to record logs and data on player interaction.

2.15. Data measuring the impact of the pattern for flow design

Table 6 presents the values of the variables related to the proposed flow pattern. We have calculated these values from the collected data. In our tests, players got open access to levels and quests. We have used the first level as the base for comparison. In the first three levels, players have opened on average a similar number of quests (8.6) and have provided a similar number of responses (79). The rate of correct answers was high and errors decreased in levels 3 and 4, we can assume some concentration. Duration spent per level has increased from the first to the third level, thus we can assume some time distortion. Level 4 puts a constraint on time; this should explain the decrease of playtime. In level 4, players have opened more quests (+39%) and provided more responses (+9%) when compared to level 1.

Table 6. Data measuring impact of the pattern for flow design

	Mean value				Variation versus level 1			
	Responses	Playtime	Errors	Quests	Responses	Playtime	Errors	Quests
Level 1	79	807	3	8.6	Base	Base	Base	Base
Level 2	78	1026	4	8.8	-1%	27%	26%	3%
Level 3	79	1003	3	8.8	0%	24%	-7%	3%
Level 4	86	724	3	12	9%	-10%	-4%	39%
Players	174	1968	7	20	119%	144%	125%	138%

2.16. Data measuring impact of rewarding strategies

For levels 1, 2 and 3, the control strategy was the standard FRS (Points). For level 4, the control strategy was VIS (Responses). For levels 1, 2 and 4 we have tested the strategy VIS (Responses) to ease disappointment. For level 3, we have tested the strategy VRS (Points) that adjusted dynamically the increments. Table 7 provides the mean values of the collected metrics.

Table 7. Data measuring impact of delivery schedules on disappointment

Levels	Strategies	1 #Players	2 # Quests	3 #Quests/ Player	4 Responses/ Player	5 #Response variation	6 Playtime variation	7 Error variation	8 Quest Variation
1	FRS(Points)	35	307	8.8	81.9	control	control	control	control
1	VIS(Responses)	62	524	8.5	77.8	-5%	12%	43%	-4%
2	FRS(Points)	51	436	8.5	76.4	control	control	control	control
2	VIS(Responses)	89	791	8.9	78.7	3%	-6%	3%	4%
3	FRS(Points)	109	923	8.5	78.0	control	control	control	control
3	VRS(Points)	57	535	9.4	81.2	4%	16%	-48%	11%
4	FRS(Responses)	69	794	11.5	86.0	control	control	control	control
4	VIS(Responses)	43	536	12.5	87.0	1%	3%	-29%	8%

3. RESULTS AND DISCUSSION

This research presents a first proposal to design digitalization of educational plays and a second proposal based on patterns to design a flow experience, or to ease disappointment. In this section, we will present the results related to both proposals first. Afterward, we will discuss the results related to each proposal.

3.1. Results

3.1.1. Results: game analysis of Tetris, Angry Birds, and Super Mario Bros

We have based the proposed engagement engineering breakdown structure on the psychological drivers of intrinsic motivation according to SDT. Grouping game design elements by motivation drivers helped us analyze and understand the forces behind successful video games like Tetris, Angry Birds, and Super Mario Bros. The three video games implement the proposed minimal framework for educational video games. They present challenges to a player, collect his response, and provide him with immediate and cumulative feedback. In addition to the minimal framework, each video game implements multiple design elements privileges of specific axes of the engagement vector space in Figure 4.

Through increasing rates, new challenging tetramines (bricks), and pressuring time, Tetris players experience a strong sense of competence. In Angry Birds, the player flings birds at pigs! In the real world, this is a damaging task for birds. However, the video game narrative invites the player to help birds take revenge on pigs that eat their eggs. Thanks to the mechanics and to the fantasy, players of Angry Birds experience a sense of competence and a sense of meaningful tasks. Players of Super Mario Bros experience a sense of competence and a sense of mission created by a narrative. They are also in relation to a group of significant others (princess peach and bowser).

The three games are different from each other, easy to play, and each game fulfills a different mix of motivation drivers. Each game is very appealing to players in its own way, where a way is a balanced mix of psychological needs influencing motivation. The proposed engagement engineering breakdown structure highlights these ways well and enables us to engineer educational video games with engagement features that complement each other to reach the right level of influence on a psychological driver of motivation.

3.1.2. Results: analyzing game data related to pattern for flow

Did the proposed pattern contribute to engagement? On average, players have played at least two levels. In the high levels, players provided more responses (up to 9%, columns responses in Table 6), kept high levels of concentration, and experienced some time distortion (up to 24%, columns play time in Table 6).

Levels 1 to 3 had no time constraint. Level 3 presented the questions randomly and was more challenging. The ratio of wrong responses in level 3 was similar to level 1, the easiest level. However, players spent less time to finalize level 3 when compared to level 2. Level 3 is more challenging and seems to be more engaging for players when compared to levels 1 and 2.

Level 4 randomly presented the questions and set a time constraint. The number of responses increased in level 4 while errors stayed similar to levels 1 and 3. Playtime decreased because of the time constraint. Players opened on average 12 quests in level 4; they visited 1/3 of the quests twice on average. Level 4 seems to be more engaging for players when compared to level 3.

To summarize, level 2 is a “fiasco” for engagement. Levels 3 and 4 were engaging. Players have speeded up, provided more responses, or opened some quests multiple times when the level randomly presented the questions or set a time constraint.

3.1.3. Results: analyzing game data related to easing disappointment

The fixed ratio schedule FRS strategy added points to scores and had no built-in reinforcement or incentive. We used it as a control strategy. We tested a variable interval schedule VIS strategy that compensated for correct answers plus a portion of wrong answers. In levels 1 and 2, the VIS strategy produced mitigated results. The number of errors increased in levels 1 and 2. The number of responses decreased in level 1, while playtime decreased in level 2. However, VIS produced better results in level 4 where it increased the number of responses, increased the number of quests opened, reduced the numbers of errors, and also increased playtime. VIS seems more adapted to challenging levels.

We have tested the variable ratio schedule VRS (Points) in level 3. This strategy has improved engagement. It has increased the number of quests played and interactions provided by players in Table 7, columns 3 to 5. VRS has reduced the number of errors and increased attention in Table 7, column 6. It has also increased the time played in Table 7, column 7. VRS (Points) seemed adapted to a challenging level and produced more impacts than VIS (Responses) produced.

3.2. Discussion

3.2.1. Proposed engagement engineering breakdown structure

In this research, we have organized the game design elements for engagement in a breakdown structure. We proposed to consider the set of engagement design elements as a 3D vector space. We used the psychological needs identified by SDT as a three-dimensional basis of this vector space in Figure 4. When digitizing a learning play, we proposed to set first the engagement dimensions to use in the educational video game, and to select afterward design elements specific to these dimensions. We also proposed a map to sequence the game design elements during the gameplay. This approach to engagement engineering reduced complexity and facilitated our teaching of video game development. It enabled bachelor students to develop engaging educational video games with coherent design elements. The mental multiplication educational video game illustrates this result.

Sailer *et al.* [16] have tested how some surface game design elements were impacting player's engagement and motivation. They identified that this impact on motivation was mediated by the basic psychological needs of SDT. Wee and Choong [17] identified a list of nine game design elements to use for gamification and assigned them to SDT categories beforehand.

Our research builds on the ideas of Wee and Choong [17] and the findings of Sailer *et al.* [16]. However, these two pieces of research focus on gamification and do not explore the role of fantasy and narrative. Our research goes beyond as we have explored applying SDT to the design elements of educational video games. We proposed a model to help the systematic design of engagement in educational video games using the 3D engagement space in Figure 4, and the map of game elements in Figure 5.

The proposed breakdown structure for engagement engineering classifies engagement design elements along three dimensions. For some elements, the classification is based on surveys of players' experience [15], [16]. For other elements, the classification is a proposal from researchers [17] or ours. These proposals should be considered as assumptions, and we should perform additional surveys of players' experience to validate them.

The current literature says that players have a sense of control when they experience decision freedom [16]. Some researchers translate this as controlling personal profiles and game structures [17]. However, multiple commercial video games open levels progressively to players.

In our tests, all levels were open to users. We did not evaluate the impact of open levels on the sense of control. To sense a decision freedom, the player may need to be in a situation where he has to make a decision. Further research can explore the impact of making levels progressively open to players on intrinsic motivation and engagement.

3.2.2. Discussion: automated assessment governs digitalization

On-the-fly assessment of player responses conditions the ability to provide quick and accurate feedback. To assess reading or fluency, some video games ask the player to compare his response to recorded answers [44]. Such solutions do not provide immediate feedback to players.

We will argue that such an approach can reduce the task's meaningfulness for players. *We will also argue that we cannot digitize a learning play into an educational video game if we cannot digitize the associated assessment.* We identify the smallest framework to digitize learning plays as having a challenge-feedback loop, scoring rules and automated assessment.

In this research, we consider self-assessment as not being part of game design elements. We need to perform additional analysis of player experience when playing educational video games based on self-assessment. Such analysis can explore relationships between self-assessment and motivation.

3.2.3. Discussion: sensory stimuli contribute to a meaningful purpose

Games represent an activity that is separate from real life and implies a temporary acceptance of another type of reality [8]. When involved in a game, nothing outside the game is relevant for players. Musical scores and flashy graphics invite a player to accept another type of reality. We argue in this research that this contributes to making the game world have a meaningful purpose for the player. This point should be explored in more detail.

3.2.4. Discussion: design pattern proposed for flow

In our approach, we have measured engagement through the number of responses, playtime, errors and quests opened in a game. The proposed pattern for flow improved these indicators of engagement. However, in our field tests, we have not collected any data to verify if this engagement was due to a flow experience mainly, or also to other factors. Future research can add some questions either to the gameplay or at the end of a level to capture the origin of engagement and fun.

Presenting questions in random orders and setting some time constraints improved engagement. However, four levels were not enough to engage players in long playing sessions. One improvement of the proposed design pattern can be to add additional levels built on variations of order and time. A variation of order can be presenting questions in partially random orders, for example (1, 2, 3, -, 7, 8, 9, -, 4, 5, 6). We can also add time constraints to simple levels to create additional levels.

3.2.5. Discussion: design pattern proposed to ease disappointment

Delivering badges using variable schedules improved engagement when challenges were medium to hard. The impact of variable schedules is consistent with multiple findings from previous research [45]. In this research, we found out that linking the score to correct answers only, and adjusting reward triggers to errors was the most effective strategy. We found out also that variable schedules did not influence engagement for simple levels.

We have assumed that delivering badges will ease disappointment and failure. We have based our assumption on results from other researches [21]. However, we did not test if players sensed badges as easing failure or as extrinsic incentives. Because errors were low in the tested game, players may have experienced the badges as incentives.

This research can also explore replacing badges with hints. Advanced hints can be proposed to players according to variable schedules. If the play scores after a hint, they would collect the full number of points associated with the question.

4. CONCLUSION

In this research, we have proposed a framework to digitize learning plays into engaging educational video games to remedy learning misses and to make school children learn in a safe, fun and engaging environment. The proposed framework identifies first the challenge-feedback loop and the scoring rules as the smallest set of characteristics required for an educational video game. We argue in this research that the capacity to digitize the assessment of responses governs the ability to digitize an educational play into an engaging video game.

To engineer engagement, the proposed framework organizes the engagement elements within a 3D space and uses the self-determination theory to navigate through these elements. This classification invites a designer to select first the motivation drivers to target in an educational video game. Afterward, the proposed framework helps identify "what" game engagement elements to use for the selected drivers.

Flow experience is a game design element that fosters intrinsic motivation. The design of a flow experience requires proposing challenges that match growing skills. We proposed a design pattern to design flow experiences for educational video games. The proposed pattern uses the order in which we test the learning material in challenges.

We have implemented an educational video game using the proposed framework and collected data on learning activities. The analysis of the collected data showed that the selected engagement influencers were functioning and that school children were playing more. The proposed pattern for flow design as well as the incentive system improved engagement.

We have identified multiple areas of future development through which this research can develop. The proposed in-game assessment identifies school children with learning difficulties. We can build on this to trigger personalized remediation or parenting actions. When detected early, teachers, parents or IA-based game adapters can help school children remediate to miss learning. We believe that there resides the value of this research.

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