Development and Assessment of an Adaptive Difficulty Arithmetic Game Based Learning Object

Bruno Omella Mainieri
Vera Lúcia Antonio Azevedo
Pedro Henrique Cacique Braga
Nizam Omar
Faculdade de Computação e Informática
Universidade Presbieriana Mackenzie
São Paulo, Brazil
Email: bruno.omella@hotmail.com

***Abstract*—Country-wide assessment programs indicate that only about 43 percent of primary school children in Brazil possess mathematical knowledge evaluated as adequate for their stage of schooling. In an attempt to remedy the situation, the present study proposes an auxiliary learning object in the form of an interactive, adaptive digital game for understanding and practicing the arithmetic operations of addition, subtraction and multiplication for second grade (age 7-8) students, based on studies indicating the potential pedagogical validity of such objects. In particular, the adaptive capability of the object is focus of this investigation. This paper explores the motivations and decisions taken during development and details the implementation of the adaptive difficulty capability of the game. As the object is prepared for future tests with school children of the targeted age range, this work documents a qualitative assessment of the object through tests and validation with educators, in which 60 percent of participants agree that an adaptive game is better suited for educational use than a static one, but 40 percent present differing views.**

***Index Terms*—game-based learning, mathematics, dynamic difficulty adjustment, learning motivations**

I. Introduction

According to the 2015 survey *De Olho nas Metas* [1], which measures, among other metrics, the educational development of Brazilian students, only 42.9% of third grade students possess knowledge of mathematics that is considered adequate by the survey. Some explanation to this performance by students can be found in Prensky's work [2], in which the author argues that traditional classroom teaching is incapable of holding the attention of the youth of the 21st century. Looking back into the past century, Cohen's work [3] defends the same argument, only for the students of the decade of 1960 and the teaching techniques which were considered traditional in that time. These findings point out to a necessity among educators to constantly develop new tools to adapt to the ever changing learning needs of students. Observing the recent results of Brazilian students through these optics, then, reveals that the traditional, non adaptive ways of teaching employed in most classrooms across the country may be a cause for poor performance. Attempts to remedy this situation may then take the form of developing new learning objects.

When addressing the issue of employing adequate learning objects and techniques for the students of the 21st century, Prensky [2] defends the digital game as the optimal candidate to satisfy this need. Digital games developed and used for means other than pure entertainment, such as education, health and professional training are known as Serious Games [4]. Such games, when employed as learning objects, possess a number of characteristics beneficial for education, such as creation of ludic contexts [5], interactivity with the concepts being studied [6] and promotion of motivating and engaging experiences [7] [8] [9].

Regarding the particular aspect of games as potential motivators for the learning process, Csikszentmihalyi's Flow Theory [10] must be taken into consideration, as it proposes an explanation to what makes an experience actually motivating. According to the author, the experience in question must provide the individual with an adequate amount of challenge. Too little challenge, and it provides only boredom. Too much challenge, and frustration ensues. In order for a digital game then to provide the correct challenge for each user and, as a consequence, become a motivating learning object, Sampayo-Vargas et al. [11] argue for the use of adaptive difficulty adjustment techniques as defined by Hunicke [12]. These features of a digital game allow it to identify the player's performance and, in real time, adjust the challenge of the game in accordance to this perceived competence. Over performing users are met with increased challenge, while under performing ones will face decreases in challenge. These adjustments are transparent to the user.

The goal of this present work is twofold. First, to develop and assess the validity of a learning object in the form of a digital game to aid second-grade students in learning mathematics. The game addresses the particular topic of the arithmetic operations of addition, subtraction and, to a lesser extent, multiplication. The development of the game is guided by existing literature regarding characteristics which are considered motivating and engaging. At its current iteration, the game is tested with educators for validation on its applicability in the classroom.

Second, to conduct preliminary research about the effectiveness of dynamic difficulty adjustment in an educational game. Two versions of the game will be developed - one where challenges proposed are predetermined and static, and another where a linear dynamic difficulty adjustment system [12] [13] is employed. This latter, adaptive version will generate new challenges in real time, the complexity of which will be determined by the player's current performance in the game. The test with educators aims to gather experts' opinions on the potential for educational benefit of adaptive difficulty. While the scope of this work is limited to linear dynamic difficulty adjustment, non-linear adaptive difficulty techniques such as rule-based systems [14] will be implemented and tested in the future.

This paper is organized as follows: the second section details the analysis of existing literature for the development of the object. The third section explores process of the research, from the development of the object, describing its characteristics and functionality, to the tests carried out. The fourth section presents the preliminary results of the qualitative tests conducted. The fifth section concludes this work presenting future research prospects.

II. Theoretical Background

A. Games for Education

Huizinga [15] describes games as a subordinate concept to that of playing. According to the author, playing is an act which expresses freedom, the context of which is understood by participants to represent unreal situations rather than the reality, and which ultimately may lead to the development of skills, competences and knowledge which may be employed outside of the context of play. While the author's definition was created at a time when digital games did not exist, and as such contemplated only traditional forms of games such as sports games, board games and card games, their attributions to the act of play are valid for digital games as well, given that these can be considered a representation of traditional games in a different media [16]. Corroborating the idea that games may well be employed for educational purposes, Crawford [16] extends upon Huizinga's definition by stating that the fundamental goal of the act of playing is learning.

Garris et al. [8] attribute games' ability to facilitate learning to this media's native engaging capabilities. The authors argue for the positive effect of motivating characteristics in students' development, citing user engagement as linked to effectiveness of learning processes. Jacques et al. [17] argue that an educational experience which is engaging - that is, which is capable of holding the user's attention without need for external motivation or obligation - presents greater potential for student learning than one which is not engaging.

Malone and Lepper [9] go further in describing four particular motivations the authors consider intrinsic to games which allow these to become learning objects. These motivations are:

- Challenge: games are able to pose challenges to the user, by presenting adversity and uncertainty. According to the authors, a game should always keep the player wondering whether or not they will be able to achieve their goals. This doubt keeps the player invested and interested.
- Curiosity: the experiences promoted by games can transport players to situations which are unpredictable or even entirely surreal, and the development of the events in a game (such as the actions of another player) create uncertainty regarding future states of the game. The myriad possible ways in which any scenario may develop appeals to the player's desire for discovery and novelty.
- Control: motivation can be derived from the empowerment afforded by having one's agency effect changes in their context. Games allow players, through their interactive aspects, to exert control over the represented situation through the actions they may take.
- Fantasy: strongly related to Curiosity, Fantasy expresses the capacity of games to represent situations beyond the limitations of reality. In terms of motivation, Fantasy allows games to express abstract or complex contexts through different optics, such as through metaphors.

The authors go further in detail regarding how Fantasy can facilitate the understanding of otherwise abstract or difficult concepts. They describe the existence of two types of fantasy for learning: endogenous and exogenous. An endogenous fantasy is characterized by educational content which is seamlessly integrated in the context of the game, whereas in an exogenous fantasy the content is noticeably foreign to the other game elements. An example of endogenous fantasy would be found in a game for learning fractions where the player must slice pies according to the represented values. An example of exogenous fantasy would be found in a game where correctly inputting a fraction causes the player's character to perform a fighting move against its opponent, without direct correlation between the fraction and the action. According to the authors, endogenous fantasies are more capable of promoting motivation for learning.

Regarding Challenge, Csikszentmihalyi [10] argues that more important than simply proposing difficulties and obstacles is providing adequate levels of challenge, in which individuals are neither hopeless nor sure to succeed. Traditional games often offer a single, immutable challenge level. Since different individuals have different skills and competences [18], such arrangement is sure to provide adequate challenge only to some players.

B. Adaptive Difficulty in Games

Authors such as Malone and Lepper [9] and Garris et al. [8] agree that Challenge as an element of a game is a meaningful motivation towards learning. Csikszentmihalyi [10] however argues that different individuals at different moments will experience this motivation in different ways:

perceived Challenge is dependent on the user's competence at the task being performed. Developing a game that provides adequate challenge to all, or even most players then requires the object to be flexible in the difficulty it offers.

Some games offer multiple predefined difficulty settings or options to allow the player to tailor their experience. Certain games, both digital or otherwise, pit players against each other as a way of promoting different levels of challenge: the difficulty faced by a player is correspondent to the competence of their foe [16]. While both options offer flexibility to an otherwise immutable level of challenge posed by a game, they are still limited in the range of players to which they can provide adequate challenge. Since different individuals not only have different skill levels, but also grow in competence at unique rates, offering a range of difficulty settings can only appeal to as many types of players as there are options [18], while allowing difficulty to be defined by the skill of another player poses the risk of uneven matching of participants.

Hunicke [12] proposes that, in order to promote adequate challenge to any player, a game should be able to identify the current skill level of the player and, in real time, adapt its difficulty-generating elements to change the challenge level to better suit the player. This capacity in a game is named Dynamic Difficulty Adjustment. In order for this capacity to be available in a game, two components are necessary: one which is capable of measuring the player's skill in interacting with the game, and another which is capable of altering game elements in real time according to this measurement.

Different ways of implementing Dynamic Difficulty Adjustment in a game can be found in the literature. Silva, Silva and Chaimowicz [13] present a form of linear difficulty adjustment, where both player skill and game challenge are measured along a single, one dimensional axis. The skill measuring element in this system increases or lowers a grade given to the player's skill according to success or failures in the interaction. Performing tasks optimally according to metrics such as score, time taken or amount of tries results in an increase in the measured skill level. Exhibiting difficulty in performing the tasks, such as by achieving low scores, taking long times or being entirely unable to succeed results in a decrease in the measured skill level. The game element adapting component receives this skill level grade and compares it to expected, or average values, as defined by the game's designers. Should the player's measured skill be inferior to the lower threshold of what is considered average, the adapting component enacts changes to game elements that lower the difficulty level. The opposite occurs should the measured skill be superior to the upper threshold of average performance. Figure 1 is a representation of this system.

Spronck et al. [14] propose a rule-based dynamic difficulty adjustment system. According to the authors' proposal, each mutable game component, that is, each aspect of the game that could be altered to change the difficulty level, should be an independent Agent. Each actor has its own decision-making model, which receives information from the player skill measuring component, which is capable of assessing player skill

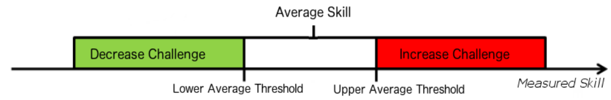

Fig. 1. Linear Dynamic Difficulty Adjustment, figure adapted from Silva, Silva and Chaimowicz [13], page 20.

in multiple dimensions, rather than as a single, continuous spectrum as in the linear model. Each Agent's decision-maker possesses a number of available rules, or specifications of behaviour, each of which is tailored to a different combination and level of player skills. The decision-maker then receives the player assessment information and uses it to choose one among the available rules, the one most adequate to the measured player competences, and immediately enacts changes on its game elements as specified by the chosen rule's behaviour. An overview of this rule-based model can be seen in Figure 2.

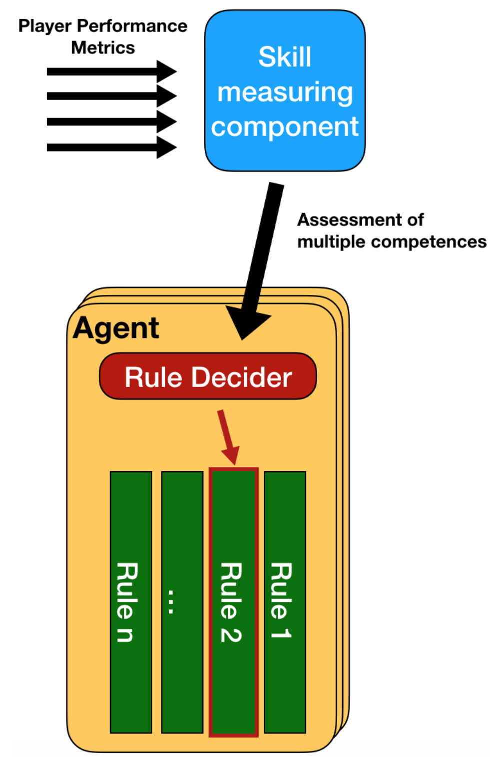

Fig. 2. Overview of rule-based adaptive difficulty, based on Spronck et al. [14]

C. Related Work

Considered the motivations for the application of adaptive difficulty games to aid the learning process, existing cases and studies in this field have been observed when assessing the validity of the techniques and the applicability of such objects in educational contexts. Based on the argumentation that the intrinsic motivations that make games adequate for educational purposes are the same that make them appreciable as entertainment objects, non-educational adaptive games were also considered in this research.

In their published work, Sampayo-Vargas et al. [11] conduct an experiment comparing the effectiveness of three learning objects for Spanish vocabulary. The authors tested an adaptive game, a non adaptive game and a traditional text-based assignment with students, measuring quantitatively their performance and qualitatively their motivation towards the experience. While there were no noticeable differences in perceived motivation between the two versions of the game, students who interacted with the adaptive version displayed greater performance, having learned on average 7 new terms each, compared to the 3.3 learned by students who interacted with the non adaptive version.

Silva et al. [13] developed an adaptive version of a commercially available game, capable of alternating between a static AI enemy, which always behaved in the same predetermined form, and a dynamically adaptive AI enemy, which changed tactics to in order to match the player's perceived skill level. Comparative tests between the two versions resulted in a preference by 85% of the participating players for the adaptive version. The authors note that the adaptive version was held back by the AI's lack of capacity to provide sufficient challenge for the most skillful players, pointing out the importance of having a system capable to appealing to the entire player base.

III. Methodology

A. Development of the Game

The goal for the development process was to create a game which could be adequately employed as a learning object to aid second-grade Brazilian students in understanding and practicing basic arithmetic operations. In order to properly achieve that goal, the game had to be motivating and engaging, as the reviewed literature provides evidence that such traits are beneficial to the learning process [17] [19].

The development of the game was guided by the definitions of motivating game characteristics as detailed by Malone and Lepper [9]. While Challenge is of primary interest for this work, due to it being the one characteristic that is affected by the presence of adaptive difficulty, the other motivating traits were also considered in the interest of making the learning object as engaging as possible.

The result of the development process is a game by the working name of Pengu. Working towards the Curiosity and Fantasy motivations cited by Malone and Lepper [9], the game presents an antarctic theme, taking place in an icy landscape where a penguin is the main character. The penguin is initially standing on one side of a body of water, and seeks to reach the opposite side. Helping the character cross to the other side is the player's main Challenge in the game.

In order to help the character achieve this goal, the player must fill the river with the correct amount of ice blocks. This amount, the Target Value, is always displayed on top of the screen. The player can manipulate the amount of ice blocks placed in the river through the calculator-like interface in the bottom of the screen. When the user first selects a number in a button, an equivalent amount of ice blocks fall into place in the river. The selected number is then displayed in the expression label, located in the top area of this calculator interface. The player must then choose an arithmetic operator from the ones available, and then follow up with another number - the second operand. At that point, the constructed operation is resolved. If it was an addition, a number of ice blocks equal to the second operand fall into the river. In the case of subtraction, a number of ice blocks equal to the second operand are removed from the river. Multiplication causes an amount of blocks equal to the already present amount times the second operand to fall into place. Regardless of the operation performed, the obtained result substitutes it in the expression label, which at this point shows the current amount of ice blocks in the river. This reflection of the player's actions in the game environment is an example of the Control motivation. If this amount is equal to target value (visually represented by having the river entirely covered in a single layer of ice blocks), the character crosses the now frozen river, and a new scenario is constructed: a new

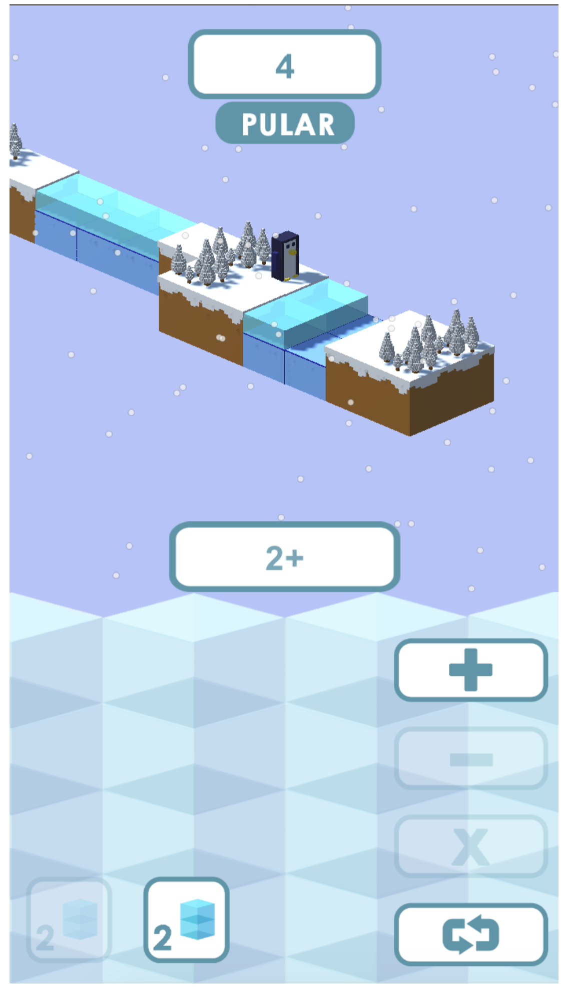

Fig. 3. Basic view of the game. The numbers manipulated through the calculator-like interface in the bottom of the screen are reflected in the blocks in the top of the screen.

river, with a new target value, a new challenge for the player to overcome. If the amount of blocks placed is superior to the target value, the challenge is not successfully completed: while the river will be entirely covered by ice blocks, additional blocks will be stacked on top of the first layer, making crossing impossible.

According to Malone and Lepper's [9] definition, the Fantasy for learning present in the game is endogenous. This is because the educational content - numbers and arithmetic operations - is presented via means natural to the game context. Each number selected in the calculator interface is directly reflected by an equivalent amount of ice blocks in the game's main view and the operations are represented one to one as changes to this amount of ice blocks. Success in achieving the target value is represented by having the correct amount of blocks placed.

Once the game was complete in term of basic features (displaying challenges, receiving and processing user input) and design (graphical representation of blocks and character as well as user interface), development moved on towards creating the challenges that would be presented to players.

B. Challenges

The main cycle of the game is based around challenges. A challenge is represented by a piece of the scenario consisting of two strips of land on opposite sides of a body of water, which varies in size. The size of this body of water, measured in game blocks, is the Target Value of the challenge. This value is displayed at all times in the top of the game's main view. The player's goal is to manipulate the numbers and operations available in the calculator interface towards the bottom of the screen in order to create an arithmetic expression which results in the Target Value. The current state of the expression is visible in the box in the middle of the screen, above the calculator interface. Each challenge determines the numbers and operations available, meaning that the player must work with the resources given, rather than having all combinations of values at hand to compose their expression. Each number presented in the interface can only be used once in the expression, becoming inactive after use (visually represented by the number turning transparent). Operators may be employed any number of times in the expression. Every challenge makes available a collection of numbers and operators which can be combined to achieve its Target Value.

The bottom-most button on the right hand side of the calculator interface, located below the operators, is the Rewind button, which removes all placed ice blocks from the scenario, resets the expression to 0 and enables all disabled numbers. There is also a button which reads *Pular* (meaning skip in Portuguese) towards the top of the screen, below the Target Value box. This Skip button allows the player to automatically complete the current challenge and move on to a different one. The purpose of this button is to prevent players from being stuck in a challenge they cannot find the solution to.

In order to allow for new challenges to be presented whenever the player completes or skips one, a list of 38 challenges was created, ordered from simplest to most complex. Complexity of a challenge is given by the amount and kind of operations necessary to achieve success, the operations available to the player and the amount of additional numbers made available. Subtraction is considered more complex than addition, and multiplication is considered more complex than either. Challenges which require multiple operations are more complex than those which require a single operation. Challenges which make available operators which are not necessary have added complexity, as the player needs to identify the adequate operation from the given choices. Similarly, challenges which make additional numbers available are also more complex. The difficulty progression of challenges is described in Table I.

Both static and dynamic versions of the game use the same challenge list, differing only in how it is traversed, and which indexes are accessed when generating a new challenge. Both versions begin at index 1, meaning that the first challenge in every game session is the same, regardless of version.

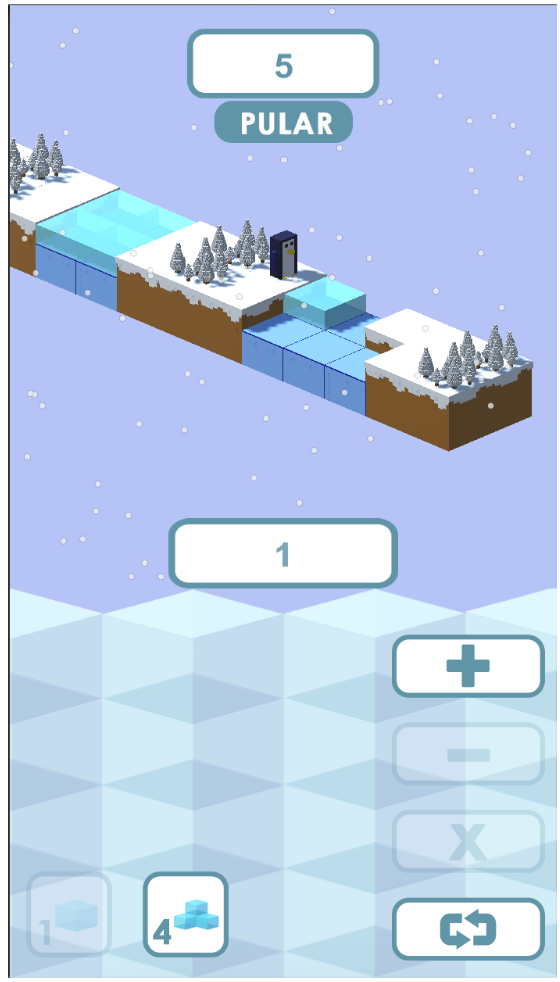

Fig. 4. In this challenge, the Target Value is 5, the available numbers are 1 and 4, and only addition is available. The user has already selected the number 1, as can be seen in the expression box as well as in the ice block placed above.

TABLE I
DIFFICULTY PROGRESSION THROUGH THE CHALLENGE LIST

Challenge Indexes	Available Operations	Necessary Operations	Additional Numbers
01-05	Addition	Addition (single)	None
06-13	Addition	Addition (single)	[1,2]
14-17	Subtraction	Subtraction (single)	None
18-20	Subtraction	Subtraction (single)	[1,2]
21-23	Addition, Subtraction	Addition (single)	None
24-25	Addition, Subtraction	Addition (single)	[1,3]
26-28	Addition, Subtraction	Addition, Subtraction (single)	[1,3]
29-36	Addition, Subtraction	Addition, Subtraction (multiple)	[1,3]
37-38	Addition, Subtraction, Multiplication	Addition, Subtraction, Multiplication (multiple)	[1,3]

1) Static Version: For the static version of game, after each challenge is completed (either through success or use of the Skip button), the index value is increased by 2 in order to access the list and define the next challenge. That means that the challenges presented to the player are [1,3,5,7,...,37]. This version has no variation in the order challenges are presented, creating exactly the same sequence of situations every time it is played, for every player. The experience proposed by this version is analogue to that of an assignment list or a test.

2) Dynamic Version: In the dynamic version, on the other hand, progression through the challenge list is variable and dependant on the player's performance. Instead of increasing the index value by 2, the next challenge presented to a player is determined by how this player has resolved the current challenge:

- Success without need for Rewind: every time the player achieves success in a challenge, an invisible variable known as Success Streak, initially holding a value of 0, is increased by 1. The change in the index for the next challenge after a success with no Rewind is and increase given by 1 + (Success Streak)$^{0.5}$, rounded down to an integer.
- Success with Rewind: making use of the Rewind button sets the Success Streak to 0. The change in the index for the challenge after a success with Rewind is an increase of 1.
- Skip: skipping a challenge sets the Success Streak to 0. The change in the index for the challenge after a skip is a decrease of 4. If the index is decreased below 1, it is set to 1 instead.

With these heuristics in place, the dynamic version aims to give players a series of challenges which are adequate to their skill level in the content being addressed. Players who excel at the simpler operations can achieve a high Success Streak, skipping ahead multiple indexes in the list, reaching more complex challenges quicker than in the static version. Players who find themselves unable to complete a challenge and opt to skip it will be presented with simpler challenges, allowing them a chance to continue practicing, while in the static version skipping a challenge would only present them with a more complex one afterwards. When a player needs to employ the Rewind button, the game offers in the next challenge a chance to get more practice in a similar difficulty rating.

The intended goal of this behaviour is to steer a player's experience towards the flow channel, as described by Csikszentmihalyi [10], where the proposed challenge of the game for each individual player is neither too little as to become boring, nor too great as to become frustrating.

The type of adaptability employed in this dynamic version is linear, based on Silva, Silva and Chaimowicz [13]. The choice for this model was made in accordance to the goals of this current work: to obtain preliminary insight into the validity of games as learning objects for mathematics as well as any evident effects of dynamic difficulty on the educational qualities of games, as perceived by educators. By developing a linear adaptation system, it is accepted that the game will not be able to measure the player's skill towards each different content being addresses, such as expertise in different operations. Acknowledging this limitation, the tests conducted on this work limit themselves to identifying limitations in completely non adaptive games and measuring educators' responses to adaptive systems in learning objects, while also assessing this particular game's validity as a learning object.

C. Test

The present study takes place before the learning object is tested with students of the targeted age range. Before application with school children, the object was validated by the educators who would employ it during classes - professors and undergraduate students in Mathematics. This validation was carried out in the aforementioned faculty at the Mackenzie Presbyterian University in São Paulo, Brazil. Besides measuring the object's validity for use in the classroom, the test also aimed to diagnose potential effects of adaptive difficulty in educational games.

The test was based on Whitton's [20] work regarding assessment of games for education, adapting the employed questionnaire for application for educators rather than students. Each one of the 10 participating Mathematics educators was given two versions of the learning object, identical in form and functionality except for the presence of adaptive difficulty. The first object, denominated Learning Object A (LO-A) did not present any form of adaptability - the challenges proposed by it were static, and progressed in a predetermined sequence. The second object, Learning Object B (LO-B) featured linear difficulty adaptation, as explained in the prior section. They were afforded an explanation of the objects' intended application and target age range, as well as of the technical differences between each version. After this introduction, they were allowed to interact with both versions freely, resetting the progression of each experience and manipulating the objects in any way they saw fit. At the end of this interaction, which lasted for an average time of 20 minutes, each participant in the study was invited to answer a questionnaire in which they offered their specialist opinion on the validity of the learning object as a whole as well as any differences in such assessment between versions.

The questionnaire consisted of 16 questions with possible answers based on a five point Likert scale. The Likert scale was chosen due to its previous application for similar studies [21] [22] [20]. Since it is a five point scale, participants are allowed to neither agree nor disagree, remaining neutral to a proposition. The questions present in the applied questionnaire were developed with the goal of measuring the educators' opinions regarding the validity of the game as an arithmetic learning object for use in the classroom.

Table II presents the statements in the questionnaire answered by the test participants. In the actual questionnaire, each statement was accompanied by a five-point Likert scale (Strongly Disagree, Disagree, Neither Agree nor Disagree, Agree, Strongly Agree), which the participants used to inform their agreement with each statement. Statements 1 through 6 regard the applicability of the game as a learning object in general, based on aspects other than the difficulty progression. Statements 7 through 10 address LO-A, the static version, and statements 11 through 16 address LO-B, the dynamically adaptive version.

Each participant was also able to leave free-form feedback and propose argumentation for each point, if they deemed necessary.

TABLE II
QUESTIONNAIRE APPLIED TO EDUCATORS

Number	Statement
1	The content addressed by the game is adequate to the target age (second-graders)
2	The way content is addressed in game is consistent with the way it is presented in the classroom
3	The visual elements of the game are an adequate concrete representation of the abstract concepts addressed
4	The game stimulates memorizing more than it does understanding and calculating
5	The visual elements introduce confusion and detract from the user's understanding of the content
6	In general, the game promotes practice and understanding of basic arithmetic
7	LO-A proposes similar challenges to those presented in the classroom
8	Some students may find the difficulty progression of LO-A too steep
9	Some students may find the difficulty progression of LO-A too gentle
10	LO-A's applicability as a learning object is reduced by the fact that the sequence of challenges is always the same
11	It is possible to notice LO-B's adaptability when interacting with the game
12	High performance in LO-B resulted in more complex challenges being proposed
13	Low performance in LO-B resulted in more complex challenge being proposed
14	The increase in challenge stemming from high performance is too extreme - the game becomes too hard
15	The decrease in challenge stemming from low performance is too extreme - the game becomes too easy
16	LO-B's adaptability makes it more adequate as a learning object than LO-A

IV. RESULTS

After the test was applied to 10 voluntary educators from the Mathematics faculty in Mackenzie Presbyterian University, the anonymous results were collected and compiled, as presented in Table III. The number of responses for each point in the Likert scale is noted for each statement, the most frequent values being highlighted with a blue background.

While the number of participants was relatively small, it was possible to identify certain patterns and opinions. Results for statements 1 through 6, regarding the general applicability of the game as a mathematics learning objects, give preliminary evidence supporting the hypothesis that the developed game is a valid learning object according to the participating educators. 100% of participants were either in agreement or strong agreement with statements 2 and 3, indicating game's addressing of the content and visual elements were deemed beneficial, while also being either in disagreement or strong disagreement with statements 4 and 5, which presented potential flaws in the game's educational potential. Only 1 out of the 10 participants was neither in agreement nor strong agreement with statement 1, which argued that the content choice was adequate for the target age group. This participant was concerned that, in some

TABLE III
QUESTIONNAIRE RESULTS

Statement	Strongly Disagree	Disagree	Neither Agree nor Disagree	Agree	Strongly Agree
1	0	0	1	3	6
2	0	0	0	6	4
3	0	0	0	2	8
4	4	6	0	0	0
5	5	5	0	0	0
6	0	0	0	3	7
7	0	0	2	3	5
8	0	2	0	7	1
9	0	0	2	6	2
10	0	2	5	2	1
11	0	0	0	4	6
12	0	2	0	4	4
13	0	1	0	5	4
14	1	8	0	1	0
15	0	7	3	0	0
16	0	0	4	2	4

educational contexts, such as low income area public schools, students may not be prepared to face the content proposed in the national curriculum and, by extension, in the game.

In regards to statements 7 through 10, which discussed LO-A, 20% of participants disagreed that the version's static challenge progression made it less suitable as a learning object. These participants stated that at certain times during the learning process, it is important to repeat the same activities that pose difficulties, granting students ample opportunity to try again on questions which they may have failed at first.

Statements 11 through 16, addressing LO-B, saw responses which point towards the dynamic difficulty aspects in the game being perceived by users. Statement 16 is of particular interest, as it directly states that LO-B is more suitable as a learning object than LO-A due to its adaptive qualities. 60% of respondents either agreed or strongly agreed with this statement, and 40% chose to remain neutral towards it. While the participants favorable to LO-B gave praise to its ability to cater to different students' needs, those who remained neutral explained that there are times when LO-A might be equally applicable, making one not strictly more adequate than the other. Coupled with the non-agreement with statement 10 by 70% of respondents, these results indicate that an adaptive game cannot be assumed to be more suitable as a learning object than a similar, non-adaptive game without additional considerations.

V. Conclusion and Future Work

These initial efforts of development and testing conducted during the present work make up a first foray into this research field. Any obtained results must be interpreted through the optics of the limitations explicitly present in this study: the developed game contains only 38 different challenges; only 10 educators participated in the questionnaire; only a linear dynamic difficulty model was implemented and tested.

Taken those precautions, it is possible to gather a preliminary understanding of the applicability of games as learning objects for arithmetic as well as the effects of dynamic difficulty in this process. All respondents to the test have expressed interest in making use of the presented game in an educational context. While some educators were in strong agreement with the idea that the adaptive version is superior to the static one for educational purposes, there was significant diversion in opinion. These moderate results are similar to those found by other studies in this field [11][13], which correctly point out that merely implementing adaptive difficulty is not sufficient for a guaranteed increase in motivation and learning. As the participants have argued, there are occasions in which static-progression games and objects are adequate, perhaps even more so than a similar dynamic object.

Further investigation is warranted in this field, and the present work will see continuation as the game is further developed to include more challenges. Other adaptive systems stand to be implemented, such as a rule-based model [14]. With the preliminary approval of educators for usage of the game as an educational tool, future experiments may be carried out with students of the target age group.

Acknowledgment

The authors would like to thank the students and professors of the Mathematics faculty at the Mackenzie Presbyterian University for their disposition and helpfulness during the process, aiding not only with the tests but also with guidance on the teaching of mathematics.

References

[1] P. Cruz, "De olho nas metas," p. 42, 2015.

[2] M. Prensky, *The Digital Game-Based Learning Revolution*. McGraw-Hill, 2001.

[3] K. C. Cohen, "The effects of two simulation games on the opinions and attitudes of selected sixth, seventh and eight grade students," 1969.

[4] D. Michael and S. Chen, *Serious Games: Games that Educate, Train and Inform*. Thomson Course Technology, 2006. [Online]. Available: https://books.google.com.br/books?id=49kTAQAAIAAJ

[5] R. C. Grando, *O jogo e a Matemática no contexto da sala de aula*. São Paulo: Paulus, 2004.

[6] K. G. M. G. Márcia Regina Gonçalves Cardoso and G. S. Oliveira, "O uso de jogos como metodologia de ensino de matemática na educação infantil," *Cadernos da Fucamp*, vol. 16, no. 27, pp. 12–30, 2017.

[7] D. I. Cordova and M. R. Lepper, "Intrinsic motivation and the process of learning: Beneficial effects of contextualization, personalization and choice," *Journal of Educational Psychology*, vol. 88, no. 4, pp. 715–730, 1996.

[8] R. Garris, R. Ahlers, and J. E. Driskell, "Games, motivation, and learning: A research and practice model," *Simulation & Gaming*, pp. 441–467, 2002.

[9] T. W. Malone and M. R. Lepper, "Making learning fun: A taxonomy of intrinsic motivations for learning," in *Aptitude, Learning and Instruction*, R. E. Snow and M. J. Farr, Eds. New Jersey: Lawrence Elrbaum Associates, 1987, ch. 10, pp. 223–253.

[10] M. Csikszentmihalyi, *Flow: The Psychology of Optimal Experience*, 01 1990.

[11] S. Sampayo-Vargas, C. J. Cope, Z. He, and G. J. Byrne, "The effectiveness of adaptive difficulty adjustments on students' motivation and learning in an educational computer game," *Computers & Education*, vol. 69, pp. 452–462, 2013.

[12] R. Hunicke, "The case for dynamic difficulty adjustment in games," in *Proceedings of the 2005 ACM SIGCHI International Conference on Advances in computer entertainment technology*. ACM, 2005, pp. 429–433.

[13] M. P. Silva, V. do Nascimento Silva, and L. Chaimowicz, "Dynamic difficulty adjustment on MOBA games," *CoRR*, vol. abs/1706.02796, 2017. [Online]. Available: http://arxiv.org/abs/1706.02796

[14] P. Spronck, I. Sprinkhuizen-Kuyper, and E. Postma, "Difficulty scaling of game ai," in *Proceedings of the 5th International Conference on Intelligent Games and Simulation (GAME-ON 2004)*, 2004, pp. 33–37.

[15] J. Huizinga, *Homo Ludens*. London: Touledge & Kegan Paul Ltd, 1949.

[16] C. Crawford, *The Art of Computer Game Design*. California: Osborne McGraw-Hill, 1982.

[17] R. Jacques *et al.*, "Engagement as a design concept for multimedia." *Canadian Journal of Educational Communication*, vol. 24, no. 1, pp. 49–59, 1995.

[18] G. Andrade, G. Ramalho, H. Santana, and V. Corruble, "Challenge-sensitive action selection: an application to game balancing," in *Intelligent Agent Technology, IEEE/WIC/ACM International Conference on*. IEEE, 2005, pp. 194–200.

[19] M. R. Lepper and T. W. Malone, "Intrinsic motivation and instructional effectiveness in computer-based education," *Aptitude, learning, and instruction*, vol. 3, pp. 255–286, 1987.

[20] N. J. Whitton, "An investigation into the potential of collaborative computer game-based learning in higher education," Ph.D. dissertation, Edinburgh Napier University, 2007.

[21] J. Greene and M. d'Oliveira, *Learning to use statistical tests in psychology*. McGraw-Hill Education (UK), 2005.

[22] N. Whitton, *Learning with digital games: A practical guide to engaging students in higher education*. Routledge, 2009.