The Didactic Balance: Simulation and Experimentation

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In this era of technological progress, the educational games have recently generated a new field of research, at the crossroads of the didactic and the educational engineering. In a previous paper, the authors presented "the didactic balance": an educational game with a didactic vocation to help the learners to overcome their difficulties while solving one-degree equations. In this paper, we propose to experiment it with a sample of students from middle school. The analysis of the data collected allows us to advance some conclusions on the attainable educational goals, particularly in terms of skills transfer, and on the limits to be exceeded for the integration of this type of game in schools.

Keywords: Math education, educational games, equations of first degree

INTRODUCTION

Solving one-degree equations of type "ax + b = c" is an important chapter in the school curriculum of the learners (Vlassis et al., 2000). Firstly teached in middle school, several difficulties appear in the understanding of basic concepts and resolution techniques. Some students come to apply blindly the procedures they did not never control the foundations. Indeed the resolution of such equations involves many other concepts, like that of the unknown (Malisani et al., 2009), the concept of equality (Kieran, 1981) and the meaning of the letter (Booth, 1984), or the transition from arithmetic to algebra (Filloy et al., 1989).

Teaching one-degree equations of type "ax + b = c" serves on the one hand, to master the different techniques to solve equations, and on the other hand to use these equations to solve some daily life problems. We distinguish many principal teaching methods. The first one consists to introduce the technique of solving and the problem to solve at the same time. But this problem-solving approach is generally too complex in the sense that the idea to introduce of a concept by a problem places the learner in an instability position by asking him to involve some old knowledge in order to build some new ones (Berté et al., 2009). In the specific case one-degree equations, learners have to enlist their arithmetic knowledge, which will ask them to use some hard algebraic techniques (Vlassis & Demonty, 2000). Herscovics & Kieran (1980) also point out the poor modeling skills of the learners which often exceed them, even sometimes in the simplest situations, because they consider that the problem-solving process consists only to translate a real problem into an unknown language. Oliveira et al. (2017) distinguish two types of difficulties, the first one in the understanding of problem relations and the second one during the algebraic manipulations. The second method consists of directly teaching the solving techniques with two approaches, the first one is purely arithmetic while the other one is completely formal (Vlassis, 2000). The table below summarizes these two methods.

TABLE 1
THE DIFFERENT APPROACHES OF SOLVING METHODS (VLASSIS, 2000)

	Method	Definition	Example
Arithmetic approach	Substitution method	It consists of giving, in a true-false process some numerical values to the unknown until to obtain the desired equality.	The equation «*2x=4*» has «*x=2*» as its solution, for the unique reason that 2×2=4.
	Recovery method	We expect from the learner to consider as a new unknown, a full algebraic expression that contains the old unknown.	To solve equation *2(3-x)=2*, the student is asked to consider the expression as a new unknown, and to deduce by substitution that 3-*x=1*, before concluding that *x=2* is the hoped-for solution.
	Reciprocal operations method	It consists in recognizing the operations that have been applied on the unknown to obtain the solution and then apply their reciprocal operations on the result to find at the end of a reciprocal process the value of the unknown.	In the case of *3x+1=7*. The unknown was multiplied by 3, before adding 1, to obtain 7. Then, the learner is asked to subtract 1 to 7, to obtain 6 and then divide it by 3 to obtain *x=2*.
Formal approach	Equivalent equations method	This method is based on the fundamental properties of equality, it consists in applying the same operator to both members of the equation.	$3x+5 = 6x-10$ $3x+5-5 = 6x-10-5$ $3x = 6x-15$ $3x-6x = 6x-6x-15$ $-3x = -15$ $\frac{-3x}{-3} = \frac{-15}{-3}$ $x = 5$

For our purpose, we will focus on the following types of equations:

$$x + a = b \quad (1)$$

$$a.x = b \quad (2)$$

$$a.x + b = c \quad (3)$$

$$a.x + b = c.x + d \quad (4)$$

Berté et al. (2009) proposed to use the subtraction property to solve equation (1), to use the quotient property to solve equation (2), and both the two ones to solve the equation (3). Finally, for equation (4), he proposes other techniques: to use of the properties of equality or to use of the zero difference properties.

Most teachers, when solving equations with their students rely on a shortened form of the formal method, based on the following two rules:

- **i.** Any number that changes the place of a term in the equation also changes the sign;
- **ii.** Any number that changes place in the equation is replaced by its inverse.

Qetrani et al. (2021) and Vlassis & Demonty (2000) have shown that when using this shortened form of the method, the equality universal properties do not appear enough clear, which generates several frequent errors. The third method based on the balance model (Lhachimi, et al., 2020) alluding to the analogy between the equality and the equilibrium in a balance. It consists in to use the equality properties while solving an equation with a balance (Berté et al., 2009; Vlassis, 2002). This model to solve linear equations makes also the learner in a situation of self-learning, which facilitates the understanding and resolution of these equations (Atteh et al., 2017).

The digital technologies (computer algebra systems, graphic symbolic calculators, micro-worlds etc.) play a very important role in students' development of at least one kind of use of algebraic language in general and the idea of the variable in particular (Lagrange and Chiappini 2007). A lot of research confirms this viewpoint. In this paper we will focus on educational games and how it can be used to solve equations.

Nowadays, educational games are beginning to take an important place in the modern mathematics teaching system. They especially allow the learner to acquire some new knowledge by mobilizing his own one's. We distinguish many definitions of what is an educational game:

TABLE 2
DEFINITIONS THE EDUCATIONAL GAME

for Caillois (1967), an educational game should be	for De Grandmond (1995), an educational game should be	For Brougère (2012), an educational game must obey five rules:
free, random, playful and fictitious.	A free action that cannot be telecommuted; An random activity, that dependent only on the fantasy of the player; A spontaneous activity, without any pre-established rules; An activity that appeals the intrinsic motivation of the player.	The "real" fiction: the game should ensure a maximum of reality within the fiction; The autonomy: the game must give the player a large margin of the decision-making; The rules: they structure the game; The frivolity: without any consequence on reality, without any measure that risk to slow down the player decisions; The random character which is the essence of the game. Games are never the same twice. You never know in advance how it will unfold and end.

Many research has focused to know how the educational games stimulate and motivate the the student during his learning situations by marrying the playful aspect with the learning objectives (Checa-Romero, 2016). For example, Moyer and Bolyard (2003) pointed out the engagement of the students while studying by using an educational game. It is that feeling of commitment which provokes in them the desire and motivation to learn. Lawrence (2004) consider that the emotions, the satisfaction, the excitement, the enthusiasm and the pleasure that the learner feels during an educational game considerably promote his apprenticeships. Barab et al. (2005) pointed out the fact that the students have been submerged since their childhood by many sophisticated digital games, this facilitates the integration of educational games in the learning situations. Shreve (2005) noted the potential of the educational games to motivate the students to explore some knowledge areas that they might not have done through the traditional modes and techniques of learning.

Other research has focused on the impact of the educational games to structure the knowledge of the students. Thus, Rosas et al. (2003) and Shaftel et al. (2005) have shown the considerable impact of this games on the memorization of new information and on the assimilation of new concepts. Steinman & Blastos (2002) and Gee (2003) showed how the educational games have a significant impact on the students to implement their own strategies while solving some mathematical problems. Shaftel et al. (2005) have proved how the educational games can provide an ideal environment for experimenting the incorrect solutions, that should be considered not as errors, but as steps leading to assembly the pieces of the mathematical knowledge puzzle.

Some other research has focused on the impact of the games on the integration of the knowledge among students. Hence, Green (2002), Moyer & Bolyard (2003), Gee (2003) and Dickey (2005) agreed that the games promote the integration of information among the learners, which allow them to establish connections between the concepts and concertize their learning. On the other hand, Moreno & Duran (2004), Shaftel, Pass & Shnabel (2005) as well as Purushotma (2005) approved, after some experimentation, this positive impact on the integration of information.

Regarding the impact of games on the development of the problem-solving skills, the experimental research leaded by Gee (2003) has highlighted the positive impact of the games on the skills and strategic capacities of the students, to make decisions, to understand a problem, to propose some solution strategies a playful and relaxed learning atmosphere.

THE EXPRERIMENTATION

A Brief Description

In a precedent work (Lhachimi et al., 2020), we gave a detailed description of the educational game, the "Didactic Balance game", that we innovated to improve the students capacity to resolve equations of first degree. Here, we will focus to experiment this game in order to verify how enough our game is efficient to remediate the errors of the students. We therefore present an experimental study of our remediation method, we will use the "Didactic Balance game". We opted for a mixed research method that combines between quantitative and qualitative data analysis methods in order to collect different and various information. This approach will enrich the results of our research: on the one hand, it enables us to detect the obstacles and the difficulties related to the resolution of the first degree equations, and on the other hand it enables us to verify the effectiveness of our remediation method. For our purpose, we leaded our experimentation in two consecutive phases according to the pedagogical scenario that we have proposed (Appendix 2), in the first phase we proposed to resolve some equation before discovering the game. In the second, the teacher propose to the learners to discover and play the games, before resolving other equations. The goal is to compare to compare the results obtained before and after trying the game. We also integrated a questionnaire on the behavior of student players, to study the efficiency of the game to remediate the difficulties of the learners to resolve equations.

To achieve this experimentation, we have chosen to publish online our game on the Geogebra website, so that the game can be accessible to the students and teachers through computers smartphones or tablets in a simpler way. Also our game is publicly available and accessible for non-commercial use. We have added sound effects and graphics in our game to create a complete game environment and to attract learners attention. Regarding the material, we have proposed the experimentation in two different ways depending on the connection availability of the room: the experiment takes place in a room equipped only with a computer and a video projector, or in a multimedia room.

The Experimentation

In total, 10 experimentations are carried out and proposed to different groups of 20 students with the presence of their teacher: 4 teachers and 200 learners were involved. The majority of learners (68%) have smartphones, 14% bring their own computers. And 13% of learners have tablets. But, only 5% of learners do not have neither smartphones, nor computers or tablets.

The equations proposed are of four types of difficulty levels: level 1: $x+a=b$, level 2: $x-b=c$, level 3: $ax+b=c$ and finally level 4: $ax+b=cx+d$ (see Appendix 1). At the beginning of the experimentation, we invited the learners to fill their personal information, to resolve some equations and to fill the Part I of the

Appendix 4. Then, the teachers presented them the game environment in front, and invite them to discover, play and enjoy the game. During all this time, the teacher is available and disposable to provide them any clarification or necessary technical assistance about the game of required. After enjoying to play and resolve equations with the "Balance Game", we ask again and invite the students to resolve handy others equations, without using the game. Finally, we ask them to complete both parts II and III of the Appendix 4 to express their reactions and the difficulties they perceive. We asked also the teachers involved in this experience to express their reactions by filling the Appendix 3.

For the purpose of our study, the questions sheet intended to the learners were written in order to detect the errors made by them, and how much using the "Didactic Balance" can perform their skill, while that intended to the teachers was written to measure the effectiveness of our remediation method of the difficulties that encounter the students during the resolution of the first degree equations. The data entry from the questionnaire was done by the using software Excel. For their analysis, we were based on the descriptive statics approach by using frequencies and percentages. The results are presented in the following section in the form of tables and graphs accompanied by comments.

The Data Collected

The results that we are going to present in this section come out from the analysis of the questionnaires proposed for both students and their teachers, the interviews carried out with the teachers and from some facts observed during the experimentation. We will firstly present the results and the percentage collected of the responses of the Appendix 4. We will use histograms and tables to present the numerical results.

As mentioned here above, 200 students and 4 teachers were involved in the experimentation. In a first time we asked each students to resolve handy, with paper and pen, this 4 equations, whose solutions are all integers.

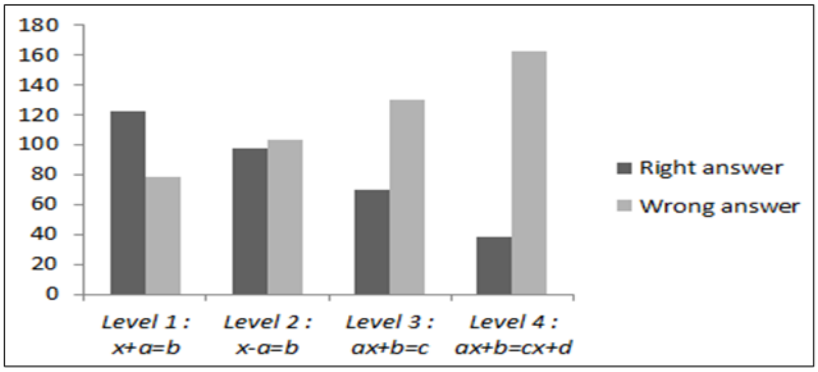
- Level l: x+4=1;
- Level 2: x-3=2;
- Level 3: 3x+2=8;
- Level 4: 6x-3=4x+5.

The results of this diagnostic test are summarized in the following table and represented using the graphs here below.

TABLE 3
THE PERFORMANCES OF THE STUDENTS BEFORE TESTING THE GAME

Equation type	Number of right answer	Number of wrong answer
$x+a=b$	122	78
$x-a=b$	97	103
$ax+b=c$	70	130
$ax+b=cx+d$	38	162

FIGURE 1
THE GRAPHICAL PARTITION OF THE PART 1 ANSWERS



We thus easily notice that the majority of the students do not have great difficulties in solving the equations of type (1) and (2), and only a small minority success in solving those of type (3) and (4). Indeed, a simple computation of the correlation coefficient between the difficulty level of the equations and the difficulty of the students in solving these equations gives us the value 0.99. In other words, the association between the two variables is strong, up to being perfect.

After letting the students enough time to discover our educational game and before measuring its impact on the performance of students in solving first degree equations, we ask them to express their first reactions by filling questionnaire (Part III, Appendix 4). The first information we get, is that 88% of the students liked the game and enjoyed to play it, while only 12% disliked it. 45% find the game funny and easy to play, 42% judge its difficulty to play as normal and correct, while 14% find the game hard and complicated to game.

TABLE 4
DIFFICULTY LEVEL OF THE GAME AND STUDENT SATISFACTION RATIO

	Difficulty	Satisfaction
Easy	14,00 %	12,00 %
Normal	42,00 %	88,00 %
Hard	45,00 %	

We get 1 as a value of the correlation coefficient between the difficulty level of the game and the student satisfaction percentage. Once again, the correlation between the two variables is strong, up to being perfect. We are now working on to make the game more attractive, interactive, easy to play and funny. We wanted to know more on which round the students find more difficulty. In fact, the game (Lhachimi et al., 2020) is proposed in three rounds: modeling round, reduction round and finally the resolution round. The answers of the students on this subject give us the following information: 26% of them found difficulties in the third round (the resolution step), only 5% of them found difficulties in the first round (the modelisation step), while 18% of learners did not find any difficulty in any step. We can then conclude that the major obstacle encountered by the students while resolving equations, is not the modeling round which appeals on his strategic skills, nor the reduction round which calls on his algebraic thinking, but rather the resolution round that appeals to his capacities of interpretation of a data.

As mentioned above, and in order to evaluate the efficiency of our game in the improve of the students skills in solving equations, our experimentation scenario was planned in three phases:

- Ask the students to solve, handy with a pen and paper, four different level equations;
- Let them to discover and enjoy playing the game, with the assistance of their teachers;

- Ask the students to solve, handy with a pen and paper, other four different level equations;
- Compare their performance before and after testing the game.

The following table summarizes the number of right and wrong answers for each equation level.

TABLE 5
THE PERFORMANCES OF THE STUDENTS AFTER TESTING THE GAME

Question type	Right answer	Wrong answer
x+a=b	160	40
x-a=b	149	51
ax+b=c	107	93
ax+b=cx+d	53	147

We observe the, and that after testing, 80% of success in equations of type (1), 75% in equations of type (2), 54% in equations of type (3), and 27% in equations of type (4). Before testing the game, the percentages were respectively the following: 61%, 49%, 35% and 15%. The statistics are very and clearly significant: the performance of the students has considerably and significantly increased after testing the game tested.

TABLE 6
THE PERFORMANCES OF THE STUDENTS AFTER TESTING THE GAME

Equation type	Before the game	After the game	Difference
Level 1: *x+a=b*	61,00 %	80,00 %	19,00 %
Level 2: *x-a=b*	49,00 %	75,00 %	26,00 %
Level 3: *ax+b=c*	35,00 %	54,00 %	19,00 %
Level 4: *ax+b=cx+d*	19,00 %	27,00 %	8,00 %

The main remark we can observe is that the performance increase considerably in all the levels, with the exception of level 4 or the performance difference is only 8%. It is worth to point out that this is the level where the students have more difficulties and where our game is less efficient.

CONCLUSION

In this section we will summarize the main purpose of the game, how it can help to remediate the difficulties in the resolution of equations of first degree. Firstly, the Part I of the experience (resolution of the equations before testing the game) reveals us in which type of equations the students make more errors (these are the level 4 equations of the form ax+b =cx+d). Secondly, the Part II of the experience, when the students fill the form about their first reactions after testing the game reveals us in which round of equations resolution process the students find difficulties. It is the final round when the game ask them just to well interpret a geometric situation and give the solution. Honestly, we did not expect to see them in difficulty in this stage, but rather in the round 2, where many algebraic manipulations were required. The two main questions we can ask are the following: what type of didactic obstacle this difficulty can interpret. The game notification and design in this special round is really clear or not. If yes, we will work in to improve this and avoid any ambiguity. Finally, the Part III of the experimentation (resolution of the equations after testing the game) reveals us, that in the case of equations (4), where the students make more errors, the "Didactic Balance Game" is less efficient than in the other level. Only a +8% performance ratio between the two times (before and after testing the game), against 19% and 26% for the other levels. The authors, as a continuation of this work, will focus to understand this situation and propose a didactic solution.

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APPENDIX 1: LIEN THE GAME « THE DIDACTIC BALANCE »

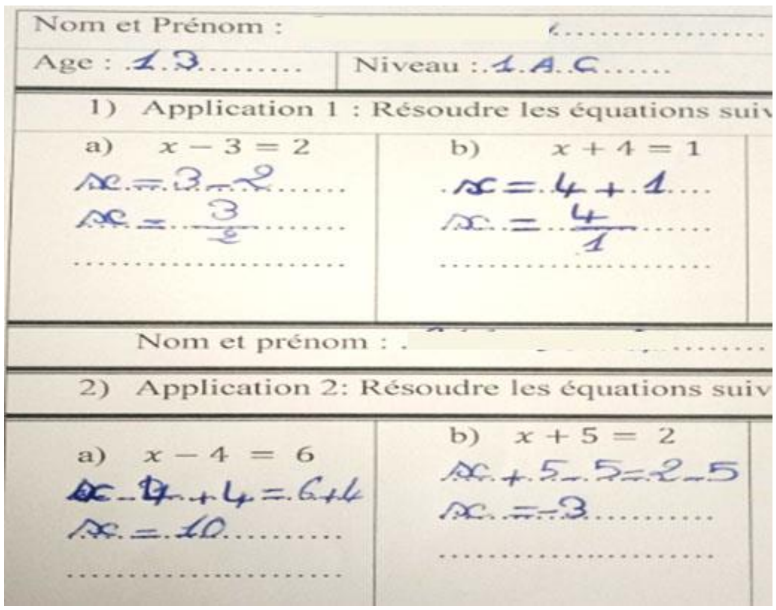
Level 1 : accessible on line via the address :	**https://www.geogebra.org/m/mfhn7hp4**
Level 2 : accessible on line via the address :	**https://www.geogebra.org/m/mfhn7hp4**
Level 3 : accessible on line via the address :	**https://www.geogebra.org/m/jwbzhavt**
Level 4 : accessible on line via the address :	**https://www.geogebra.org/m/wjw5jbfe**

APPENDIX 2: THE PEDAGOGICAL SCENARIO

Mathematical approach	Algebraic
Didactic situation	Resolve equations of first degree
Level	Middle school
Location	Multimedia room
Task	Solve equations of first degree by using the algebraic method
Background required	The use of letters The use of negative numbers The use of algebraic operations

Activity length	The teacher role	The student role
25 min	Distribute the Appendix 4	Fill the Part I of the Appendix 4
15 min	Introduce the game	Focus
55 min	Orient the players	Discover the game, play and enjoy
25 mn		Do the activities asked, and fill the Part 2 and 3 of the Appendix 4

APPENDIX 3: SCREENSHOTS OF THE STUDENTS PERFORMANCE, BEFORE AND AFTER TESTING THE GAME



APPENDIX 4: THE STUDENTS' QUESTIONNAIRE

Part I

Full name: ……………………………

Old : ……………	Scholarship level :……….

1) Resolve the following equations :

• $x - 3 = 2$	• $x + 4 = 1$	• $3x + 2 = 8$	• $6x - 3 = 4x + 5$
………..…………	………..…………	…………………..	…………………
………..…………	………..…………	…………………..	…………………
………..…………	………..…………	…………………..	…………………

Part II

Full name : ……………………………………………………..

2) Resolve the following equations :

• $x - 4 = 6$	• $x + 5 = 2$	• $2x + 3 = 7$	• $5x + 2 = 3x - 4$
………..…………	………..…………	…………………..	…………………
………..…………	………..…………	…………………..	…………………
………..…………	………..…………	…………………..	…………………

Part III

3) Do you have a :

Smartphone ☐ Computer ☐ Tablet ☐ No one ☐

4) How much do you play video games ?

Frequently ☐ Sometime ☐ Rarely ☐

5) Do you enjoy playing video games?

Yes ☐ No ☐

6) How may you classify the Didactic Balance Game ?

Boring ☐ Amazing ☐

7) How much difficult did you find Didactic Balance Game?

Easy ☐ Normal ☐ Hard ☐

8) Did you feel that the "Didactic Balance Game" may help you to perform your skills in the resolution of equations of first degree ?

Yes ☐ No ☐

9) Which round in the "Didactic Balance Game" you judge hard to play

Round 1 ☐ Round 2 ☐ Round 3 ☐ Round 4 ☐