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The AI Effects of Learning Through Digital Educational Games on the Understanding of the Concept of Equation Solving

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Abstract

This work aims to evaluate the AI effects of learning through a digital educational game by questioning the concept of solving a first-degree equation. Learning through a digital educational game is concretized by the set of interactive situations allowing the apprehension of algebraic properties to solve an equation, these situations based on the educational game are set up before any traditional course introducing the method of equation solving centered on the equality property “add the same number to each equation member”. In order to carry out our work, we randomly selected a sample size of 207 learners in their first year of secondary school. We set them up in three groups of equal size (two experimental groups and a reference group), with the experimentation consisting of three stages, from devolution to a test, via a-didactic situations (action and formulation). We distributed the roles to the teacher and learners according to a pedagogical scenario. The results obtained after analyzing the learner’s productions show that learning through the digital educational game had a positive effect on the learner’s engagement in an a-didactic situation and on their understanding of the equation-solving method. We argue that understanding the formal method of solving an equation is more complicated than applying it directly.

Keywords: A-Didactic situation, Conceptual understanding, Digital educational game, Equation solving, Learning.

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1. INTRODUCTION

With the revolution in artificial intelligence (AI) and its increasing evolution, the transition from traditional to digital classrooms in Moroccan school environment, the production and use of digital resources such as games, interactive applications and simulations, etc., to teach and learn mathematics present a major challenge linked to the lack of the hidden face, that is the didactic production of these digital resources and their use in a didactic situation. These resources can be used for personalize learning according to the learner-player profile and during all phases of learning, whether to introduce mathematical concepts or to remedy learners' misrepresentations [1].

One of the main aims of teaching mathematics at the secondary school level is to teach mathematical concepts and skills to remedy errors made by learners. In our teaching practices, we've noticed that learners have difficulties in solving first-degree equations, which gave rise to our first idea is to help learners overcome some difficulties in solving equations by using digital games, since learners are attached to anything that is interactive and more particularly to digital games.

Indeed, digital play offers interesting and new possibilities for manipulating and representing mathematical objects [2]. Several academic researchers have studied the AI effect of digital game used in the classroom, on the development of algebraic thinking [2, 3], and other mathematical notions [4–6]. They focus on the particular quality of student engagement and motivation. Solarz (2014) [7], reports that young people contributed to playing to solve equations even in non-didactic situations. [8] have shown that interactive digital games can play an important role in the development of mathematical thinking. Dave (2014) [9], highlights the value of an interactive virtual world in which learner's gestures reinforce their understanding of numerical operations. According to Venant (2015) [10], it is important to recognize the value of interactive digital content in advanced programs, but the question of its effective utility remains for discussion. The rise of digital games has prompted researchers to look at different ways of integrating them into teaching [11]. Studies in pedagogy [5, 6] have shown that digital games can support the learning of mathematical concepts and enable the beneficial engagement of students in a didactic situation.

The digital educational game has developed solving methods that have the effect of immersing learner-players in an a-didactic situation [12]. Its objective is to discover mathematical notions in the various situations integrating this type of game simply and effectively way unlike normal didactic situations (board-marker), based on this proposal. Our problem is: The AI effects of a digital educational game "Balance Game" on the understanding of the formal method of equation solving in college and high school.

To analyze this problem, we will immerse learners in a classroom game situation, using a digital game the Balance Game [13]. We then study the AI effect of this game on engagement and understanding of the formal method of equation solving.

Following this problem, we assumed that this game has an effect on:

- H1: learner's involvement in an a-didactic situation.
- H2: understanding the formal method of solving equations, i.e. discovering the equality property.

Following on from our hypotheses, we're paying particular attention to 1^{er}-degree equations as a taught concept, and the semiotic representations that the digital game gives learners around this mathematical concept in a-didactic situations (of action or formulation) that we feel are the most suitable for experimenting with the game in the classroom.

2. THEORETICAL FRAME

2.1 The "Balance Game" in a Didactic Situation

Brousseau (1998) [14], has defined situations as a set of conditions in which one or more actors evolve relationships with each other or with their milieu or environment. The author highlights two categories of interest: didactic and a-didactic situations.

The didactic situation is the set of relationships between one or more learners, a teacher and an environment mobilized by the latter to enable the appropriation of specific knowledge. The main objective of this situation is the teaching and learning of mathematical concepts, through the evolution of knowledge towards scholarly knowledge. Knowledge in a didactic situation manifests itself in different forms, either as a solution or as a means of establishing an optimal relationship Brousseau (1998) [14]. The educational game plays an important role in a didactic situation in which the discovery of knowledge is clear and the relationships between learners, teacher and environment (digital game) are well matched.

The a-didactic situation is defined as a didactic situation where the intention to teach is hidden from the eyes of the learners [15]. This situation hides the role of the teacher, and is managed by the learners, who are the main actors in the situation, and who are faced with specific knowledge in order to highlight the interaction between the "Balance Game" environment and the learners. Faced with such a situation, the latter will act, formulate hypotheses and seek to validate their answers through their interactions with the environment, which is full of imbalances, contradictions and difficulties. The environment then becomes the cause of the learner's adaptation and exploration of new knowledge.

In our work, we are particularly interested in a-didactic situations that have a purely didactic purpose. According to Brousseau (1998) [14], the learner acts independently of the teacher's expectations in such situations. For the learner, this action takes on a legitimate character of necessary autonomy. The teacher's role is limited and hidden from the learner's viewpoint, and from the knowledge at stake in the situation. The environment takes charge of the teacher's didactic intentions, but the learner's role becomes that of the main actor in the situation, autonomous and investigating a problem linked to mathematical knowledge.

We propose for this work that the game "Balance Game" is a main element of the environment, this game can be defined as a digital educational game based on AI, and it allows learners to learn the formal method of solving equations in a digital game environment, FIGURE 1 below illustrates the main interface of this game.

The "Balance Game" can be used not only in a didactic situation, but also in an a-didactic situation. We cite the elements of a-didacticity in the situation:

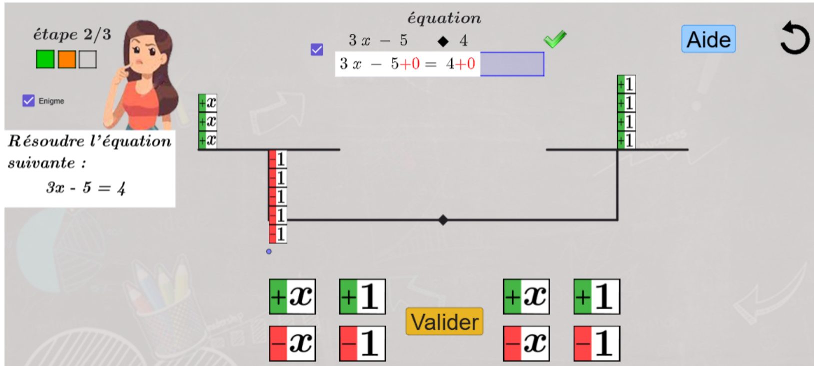

Figure 1: Environment (Balance Game).

- The learner can design a response outside the expectations envisaged and desired by the teacher;
- The modification of the learner's knowledge is conditioned by an insufficient approach in the form of a search for equilibrium, which is adaptation with the "Balance Game";
- Every teaching-learning process is optimized by the demand for an objective to be achieved in the form of targeted knowledge;
- The possibility of action and feedback exists in the game;

This shows that the game has met the conditions for a-didacticity, and learners can play in an a-didactic situation.

2.1.1 The concept of devolution

Brousseau (1998) [14] has defined devolution as a learning process in which the teacher makes the learner responsible as an actor, so that the learner becomes the main player in his or her own training by obtaining answers to the problem posed in the a-didactic situation. In devolution, the learner takes charge of the game that the teacher wants him or her to play, so that the learner feels responsible for exploring knowledge, without feeling guilty about the result he or she is seeking.

2.1.2 Action situation

Brousseau (1998) [14] has defined the (a-didactic) action situation as one in which the learner is faced with a problem, which brings into play knowledge to be taught subject to the proposed conditions. The learner is obliged to act on the environment by taking action to obtain information from the environment (Balance Game). On his part, via feedback, the environment sends back information about his actions so that he can judge and adjust the result of his actions without the teacher's help. Figure 2 below shows the action situation between the learner and the Balance Game.

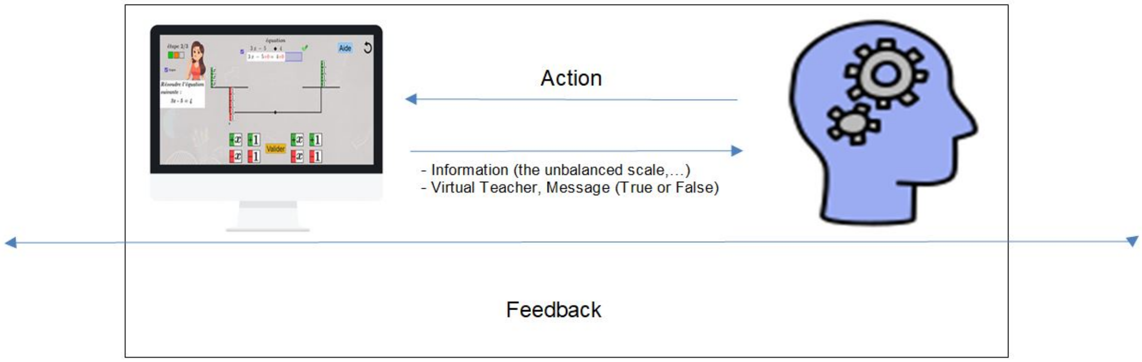

Figure 2: The action situation between learner-player and Balance Game.

2.1.3 Formulation situation

In this (a-didactic) formulation situation, the teacher suggests a problem to learners that links at least two learners with an environment, with one learner formulating the knowledge in question with regard to the other who needs it to translate it into an effective solution for the environment. The aim is to achieve shared success and break down learning inequalities.

Learners can communicate with each other in this situation, as they have a known register of linguistic and semantic resources that they use to create a message. However, the situation in which the communication takes place may lead to a modification of this register. The formulation of knowledge requires that this knowledge exists beforehand, as an implicit model of action in both learners.

2.1.4 Environment and environmental feedback in a didactic situation

In an a-didactic situation (when using the game), the student learns by adapting to an environment (Balance game) that produces difficulties, imbalances and contradictions through a process of assimilation-accommodation. This environment is an antagonistic system. According to Brousseau (1998) [14], the learner constructs or modifies his or her relationship with knowledge as a response to the teacher's intentions. The environment is thus defined as everything that acts on the student and/or what the student acts on. The student acts on the environment to draw information from the situation and to determine whether or not his or her strategy is adapted to the situation. Feedback will take place as the student modifies his or her relationship to knowledge as a response to the environment, to ensure and control his or her strategies.

3. METHODS FOR SOLVING EQUATIONS

Solving equations is an important chapter in the school curriculum, and one that crops up again and again in various forms (first degree, second degree, differential, algebraic, matrix equations, etc.).

Teaching and learning equations involves two types of skills that should already be acquired by the learner. These are:

- The ability to establish a strategy for solving first degree equations;
- The ability to model a real-life problem into a mathematical one.

The first equations encountered by learners are those of the first degree «$ax + b = c$». In this type of problem, learners will look for the possible options for solving equations and the most appropriate resolution method for a given context. Didacticisms have distinguished several methods, such as:

3.0.1 The substitution method

In a trial-and-error approach, numerical values are assigned to the unknown until true equality is obtained. For example, the equation «$2x = 4$»has the solution $x = 2$, for the sole reason that $2 \times 2 = 4$, this method not only familiarizes students with the concept of a particular solution to an equation, it also opens them up to the true/false mathematical debate, the first line of defense against reasoning by the absurd or by case disjunction [1].

3.0.2 The formal method

Subject to strict rules, this involves first identifying the operations that have been applied to the unknown, then recognizing the reciprocal operations, and finally applying a common operator to both members of the equation to transform it into another equation with the same set of solutions as the original one. For example, to solve the equation«$3x + 6 = 12$», students must structure their reasoning in the following chronological order: First, add the opposite of 6 to each equation member. Then, divide by 3. Finally, deduce $x = 2$.

3.1 Link Between Play and the Formal Method

Although much appreciated and used by almost all teachers, according to Not (1988) [16], this method constitutes a form of treatment in its own right, where the purpose of its use is lost, where students find themselves in an out-of-context situation, when sometimes they lose the sense of what they were looking for before when they modeled their initial problem.

The educational game we are proposing in this work adopts this formal approach to resolution, with the major concern of not falling into the slippery slope evoked by Not. Indeed, one of the basic rules of educational games is that the player-learner must appropriate the problem while playing, and must never be out of context. The designers of educational games take great care with this detail: at every stage of the game, the major objective of the game (in our case, finding the unknown) must be omnipresent in the mind of the player-learner.

In the Balance Game, we can offer learners equations given directly in algebraic language, for example: solve the equation $2x + 3 = 5$. This type of question involves directly finding the value of

x in an algebraic context. With this in mind, we have proposed the following method of solving the problem: changing the algebraic frame to a game, to make it easier for the students to understand. In this frame change, we represent the equality of the two equation members by the pan balance. Also, the letters and numbers are represented by tokens to facilitate the introduction of the letters (unknown). Finally, we ask the learners to deduce the value of the unknown.

4. METHODOLOGY

We have opted for a mixed-methods approach between quantitative engagement rates and qualitative learner outputs to validate the hypotheses. This approach will enrich the results of our research and will help us to study:

- The AI effect of the Balance Game on learner engagement in an a-didactic situation (action or formulation) and a normal situation.
- The game allows learners to discover the formal method, i.e. to discover the properties of equality.

We present some of the learner's images during the experimentation. FIGURE 3 illustrates an action situation between the learner-player and the environment (game) while FIGURE 4, illustrates a formulation situation between the learners - a learner-player - the environment (game).

Figure 3: Learner-player in the action situation.

To test our research hypotheses (H1 and H2), we sent an activity (see Appendix A) and a three-question test (see Appendix B) to a total of 207 randomly selected learners. First, we divided the sample into groups of equal size (GE1 and GE2: two experimental groups, GR: reference group). Secondly, we will adopt the experimental plan detailed in a 2-hours session according to the scenario below (see TABLE 1).

Note: The "G.R" group, which is immersed in the normal didactic situation, carried out the activity without a game, using only the board and marker as they usually do in a normal situation.

Figure 4: Learners in the formulation situation.

Table 1: The experimental plan

Course	**Devolution: the teacher explains the game to the learners in such a way that they can play the game.**		**Situation Action: The learner - The Balance Game.**	**Situation Formulation: The Balance Game - The learner - learners.**	**Final test**
Group	G.E.1	G.E.2	G.E.1	G.E.2	The three Groups
Didactic tools	Interactive board	Video projector	Interactive board	Video projector	Paper - pencil
Duration	10 min.	10 min.	40 min	40 min	30 min.

5. RESULTS AND POST-HOC ANALYSIS

5.1 Commitment to Learning Through Play

To test hypothesis H1, we based our analysis on the results collected through a statistical survey, measuring the percentage of learners' engagement and correct responses in different situations (action, formulation, and normal). TABLE 2 below presents the results in percentage form for measuring engagement based on learners' responses in the two a-didactic situations (action and formulation) and the normal situation (marker chart).

Table 2: Percentages of learner involvement in different situations

	G.E.1 Action situation	**G.E.2 Formulation situation**	**G.R Normal situation**
Learners were able to formulate a response	(69) 100 %	(58) 84 %	(54) 78.26%
Learners were unable to formulate a response	(0) 0 %	(11) 16 %	(15) 21.74%

The percentages in TABLE 2, above show all learners were able to engage in learning during the action situation. However, during the second formulation situation, engagement was slightly dropped. A significant drop in engagement during the third situation justifies that the digital game method enables better engagement of learners in the action situation. This could indicate that this method of discovering new mathematical knowledge was initially effective. This can confirm hypothesis H1.

5.2 Correct Test Answers (Appendix B)

The Erreur : source de la référence non trouvée below shows the percentages of correct answers to the two test questions (Appendix B).

Table 3: Percentages of correct test responses

	G.R in a normal situation	**G.E.2 in a formulation situation**	**G.E.1 in an action situation**
Question A: Solve $\mathbf{2} \times +\mathbf{4} = -\mathbf{6}$	21 (30.43%)	22 (31.18%)	27 (39.13%)
Question B: Solve $\mathbf{3} \times +\mathbf{2} = \mathbf{8}$	27 (39.13%)	29 (42.02%)	36 (52.17%)

TABLE 3 shows a slight increase in the correct answers to question A across all situations. Similarly to question A, there is an increase in the number of correct answers to question B. In all situations, this increase may indicate improved learning quality, learner engagement, or variations in the comprehension process. This also confirms hypothesis H1 and prompts us to examine the learners' productions to understand their effect on the understanding solving method.

5.3 Examples of Learner's Productions

We present some of the learner's productions during the test:

According to FIGURE 5, above, the learner has successfully represented the equation *2x + 4=-6* on the balance, following the model he saw during the game. He then tried to isolate the unknowns on the left-hand side of the scale by adding "-1" tokens to both sides. However, the mistake made by the learner in this case was that he added only three "-1" tokens, i.e., "-3" instead of "-4". We noticed that this type of mistake appeared only in the paper-and-pencil test. In case of using the game "B.G.", the error disappears, because the learner can check his choices.

In question 1)b), the learner correctly found the value of the unknown. He completed the three equation-solving steps during the formulation situation and test.

FIGURE 6 above shows the learner's output for the test (Appendix B). In the first question 1)a), the learner correctly represented the equation in the scale, and passed step 1 of the game. He then crossed out the four "+1" tokens on the left-hand tray. The arrow from the left to the right tray means that he has moved the four tokens. During this move, the learner changed the sign of the tokens,

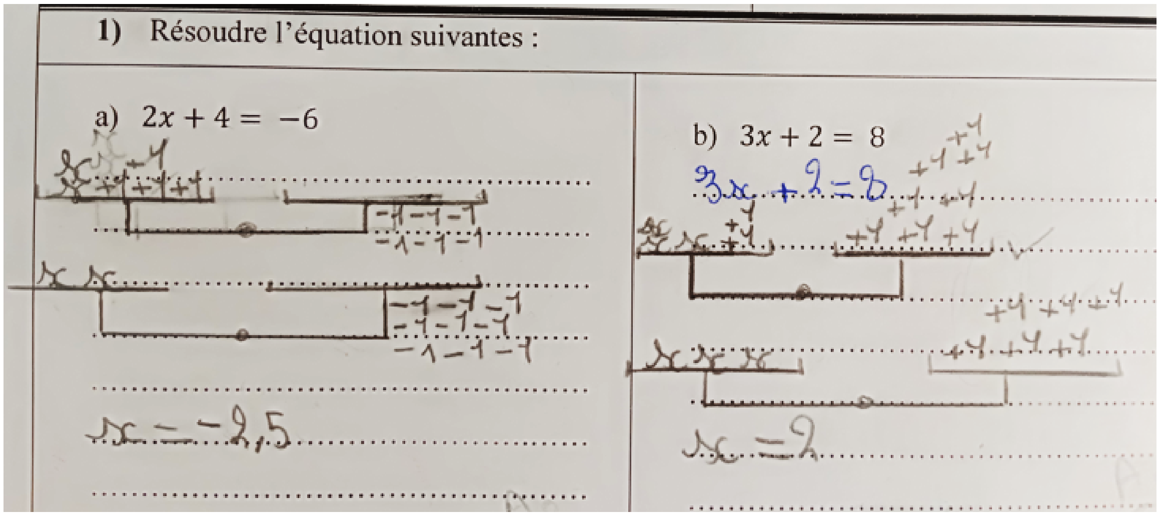

Figure 5: Example of a learner's production in a formulation situation.

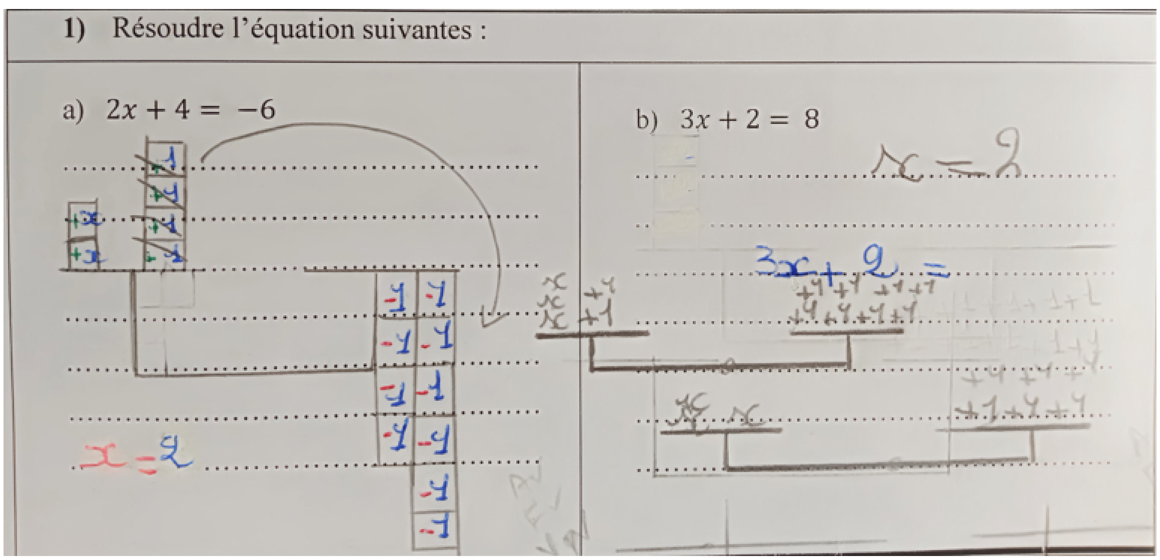

Figure 6: Example of a learner's production during a formulation situation.

thus passing step 2. However, the learner did not correctly deduce the value of x, which means he is having difficulty deducing the value of x in step 3.

We've just seen that, when solving the first degree equation $3x + 2 = 8$, the student correctly represented the equation in the balance. He then removed two "+1" tokens from the two pans of the balance. He has succeeded in isolating the unknown on the left-hand pan and the known numbers on the right-hand pan, which means he has succeeded in the second stage of the game.

Finally, he deduced the value of x. He divided the number of floors horizontally.

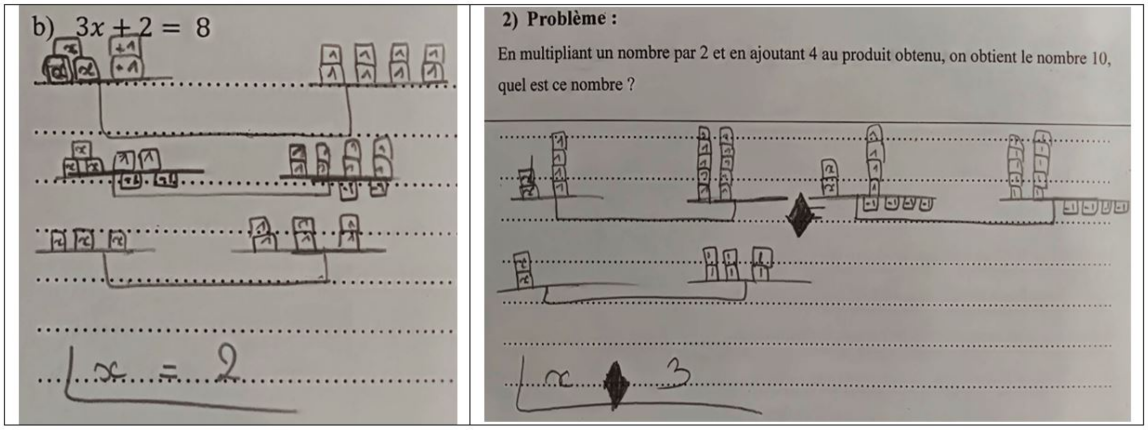

Figure 7: Example of a learner's production during the action situation

The FIGURE 7, above shows that the learner has successfully answered question 1)b). We'll now try to analyze his method of resolution. In the first step, the learner represented the equation $3x + 2 = 8$ in the scale. Next, he added two "-1" type tokens to each pan of the balance to isolate the unknowns on the left pan and the constants on the right pan. Removing the positive and negative tokens, he obtained the equation $3x = 6$. Finally, the learner arranged the constants in three equal sets, with two "+1" tokens in each set. He then deduced that the value of x is 2.

We observe that the learner has used the same method to **model** and **solve** a **new problem in a different context**. This confirms that the "Balance Game" enriches learner's knowledge to build up part of their knowledge (the method of equality properties), i.e. gives learners **a better understanding of the method of solving first degree equations** (confirms hypothesis H2).

6. CONCLUSION

By way of conclusion, this work aimed to answer the research problem, which concerns the effects of a digital educational game "Balance Game" on the understanding of the formal method of solving 1^{th} degree equations in secondary school. The study was carried out to measure learner's percentage involvement in different situations (action and formulation) on the one hand, and to test their understanding of the formal method on the other.

To do this, we explored this situation by carrying out a field experiment with learners in their first year of secondary school. We then used a mixed-methods approach between quantitative engagement rates and qualitative learner outputs to validate the hypotheses.

The use of the "B.G." game has been beneficial and the results obtained are appreciable. These results have enabled us to confirm that its use favors learner engagement in both situations (action and formulation). In addition, it promotes the discovery and understanding of the formal method of solving equations.

The digital educational game used in this work, particularly the "Balance Game" delivers satisfactory results in a non-didactic action situation through visual and symbolic interactions. This game is based on static (non-generative) algorithms, meaning it cannot reinvest data collected through the experiences of learner players. It also cannot personalize learning based on the player's level. Our goal is to find a tool that will fully deliver satisfactory results and meet the needs of effective learning. In other words, we are looking for a tool to make learning experiences through games personalized to each learner's current level, more structured, and more adapted to learner diversity while respecting their autonomy. AI makes it possible to provide this service, collect data from learner players (problem-solving methods, errors made, etc.), reinvest this data to personalize learning, and offer situational games more suited to each learner's level.

From a prospective perspective, digital educational games integrating AI are becoming, for us, a challenge to make learning effective, where learner players can promote the discovery and understanding of mathematical concepts in a way that is both practical and practical.

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Appendix A: La Balance Game activity

1) fill in the dotted lines with the appropriate number

$$\cdots + 3 = 5; \qquad 2 \times \cdots + 3 = -5$$

2) Access the Balance Game platform.

3) Use the balance to solve the proposed equations.

4) **Deduce a method** for solving the equation.

5) Test (See Appendix 2).

Appendix B: Test

First and last name: ....
Age: .... Level: .... Medium: ....

1) Solve the following equation:
a) $2x + 4 = -6$ b) $3x + 2 = 8$

2) Problem:
Multiplying a number by 2 and adding 4 to the product gives the number 10. What is this number?