Using Mathematics Game-based Intervention on Children with Special Educational Needs: Preliminary Findings

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Abstract: Many video games incorporate positive learning principles, stimulating students' cognitive functioning and promoting problem-solving and spatial abilities. The high levels of engagement and involvement that some students can achieve with video games are notable. Hence, video games for children with a long history of school failure, such as children with special educational needs (SEN). Moreover, it may give educators immediate and ongoing assessment of students' progress. When complemented with human tutoring, video games as a game-based intervention may improve mathematics performance since instruction is more effective when adapted to students' learning needs and pace. As part of the research project "GBl4deaf – Game-based Learning for Deaf Students (PTDC/COM-CSS/32022/2017), the video game "Space adventure: Defend the planet!" was designed to stimulate arithmetic competencies in deaf and hearing children. The player must use elementary arithmetical and spatial concepts to rebuild an abandoned space station. Each challenge has three difficulty levels. In the game challenge used in this study, the player must add or remove particles to collect resources. The current research focuses on two questions: The study follows two research questions: Q1: Did the students make any progress in mathematics achievement after playing the video game?; Q2: Is the gameplay of Space adventure: Defend the planet! an engaging experience for players? A pre-and post-game mathematical test was applied to measure mathematics achievement and an observational grid to gather information about arithmetical procedures. Ten fourth- to ninth-graders participated in the study - four girls and six boys, aged between 9 and 16, three deaf and seven hearing students with different special needs (dyscalculia, cognitive deficits, autism spectrum disorder, deafness and Asperger syndrome). Due to the COVID-19 pandemic lockdown, children played the video game using Zoom video conference software in 8-12 sessions (50 minutes, two a three times/week). The results show 4% to 19% of mathematics progression after children played the video game and indicate that they maintain the use of counting-based procedures throughout the game sessions. For instance, they kept counting both addends starting from 1 or counting by 1, 2, 5 or 10 using a number line. The current data suggest that the videogame "Space adventure: Defend the planet!" allows educators to gather immediate information about students' difficulties and progression.

Keywords. Mathematics game-based intervention, special educational needs, arithmetic competencies.

1. Introduction

Mathematics is one of the key competencies of the 2030 OECD project, and personalised learning is one of the 2030-project visions of the 21st Century.

Most researchers focus on elementary numerical competencies to design effective interventions (Marcelino, Cunha Teixeira, and Rato, 2017). Studies show that basic arithmetic is a good predictor of later school mathematics achievement (e.g. Marcelino, de Sousa, and Lopes, 2017; Hornung, Schiltz, Brunner, and Martin, 2014). Improving numeracy will lead to better individual perspectives and substantially impact society (OECD, 2018), especially with lower-achieving learners, such as children with special needs.

Systematic literature reviews found that Deaf and Hard of Hearing (DHH) children have lower mathematics achievement than hearing students. Deaf children have more difficulties in abstract counting and symbolic addition and subtraction tasks (Gottardis, Nunes, and Lunt, 2011; Marcelino, Sousa, and Costa, 2019).

Computer-based intervention (a video game) positively affects learners' motivation (Gee, 2007; Kadosh and Dowker, 2013). In good game-based learning (GBL) approaches, players and students are more willing to be engaged and immersed in an activity (Habgood and Ainsworth; Ke, 2017). Moreover, video games can create meaningful learning experiences with immediate and concrete feedback and optimal levels of challenge and frustration where a failure is a motivational tool (Gee, 2007; Granic, Lobel, and Engels, 2014). Game-based learning approaches reveal a significant and positive influence in several areas of cognition (Bisoglio, Michales, Mervis, and Ashinoff, 2014), resulting in improved performance in several areas of knowledge, such as mathematics.

Chodura, Kuhn and Holling (2015) show that intervention effectiveness is associated with direct or assisted instructions regardless of learning age but reported no significant differences between computer-based and face-to-face intervention. This lack of substantial differences means that computer-based intervention can be as effective as a non-computer-based intervention with human tutors.

The duration of the intervention is one crucial variable in applying for intervention programmes. According to Kroesbergen and van Luit (2003), shorter intervention is more efficient than 12 months. The intervention approaches are considered more effective when adaptive to the child's learning needs and pace (Burns, Codding, Boice, and Lukito, 2010; Kohn, Rauscher, Kucian, Käser, Wyschkon, Esser, and von Aster, 2020).

Concerning intervention approaches, there is a lack of studies that compares the impact of computer-based and non-computer-based intervention in basic arithmetic. The thirty-five studies analysed in Chodura et al. (2015) meta-analysis do not include a mix of the two types of intervention. An intervention with human tutors plus a computer-based intervention with personalised learning may allow lower achieving learners to go further than low achievement.

The current study is under the GBL4deaf – Game-based Learning for Deaf Students project [PTDC/COM-CSS/32022/2017] using a GBL framework where a video game was designed and developed from scratch. The project aimed to evaluate the use of an educational video game for mathematical learning (basic arithmetic and basic geometry), in particular, for deaf students.

The present work explores the effectiveness of a computer-based intervention (a video game) integrating the intervention with tutors (personalised training) to promote basic arithmetic and geometry (e.g. calculation with angles) in children with special needs. The main goal is to design an effective game intervention to promote mathematics learning and engagement in children with or without special needs, particularly deaf children.
The study follows two research questions: Q1: Did the students make any progress in mathematics achievement after playing the video game?; Q2: Is the gameplay of Space adventure: Defend the planet! an engaging experience for players?

2. Method

2.1 Participants

A convenient sample of children with different special needs, aged 9 to 16, attended public schools Grade 5-9, with a mean age of 12.5 years old - except one deaf student with a home-schooled education equivalent to Grade 4. The sample comprised three deaf students, six hearing students integrated into the Special Education program, and one girl with dyscalculia.

Table 1: Participants' characterisation

	Sex	Age	Grade	Special Needs
Subject 1	M	9	4 (home education)	Deaf without CI
Subject 2	F	12	6	Dyscalculia
Subject 3	F	16	9	Deaf with CI
Subject 4	F	16	8	Deaf with CI
Subject 5	M	13	5	Autism Spectrum Disorder
Subject 6	M	10	5	Asperger Syndrome
Subject 6	M	12	5	Cognitive Deficit
Subject 8	M	10	5	Cognitive Deficit
Subject 9	F	14	7	Cognitive Deficit
Subject 10	F	13	6	Cognitive Deficit

Note. M = Masculine, F = Feminine, CI = Cochlear Implant.

2.2 Materials

Video game "Space adventure: Defend the planet!". The software used in the present study is a delta version of a standalone game produced with the Unity game engine. The game is a mathematical educational game for formal and informal learning. The player must use mathematical abilities to solve challenging puzzles to build a space base, but only three challenges are under study in the present study. Each challenge has three difficulty levels designed to provide the player with progressively advanced mathematical knowledge and reward them with the resources necessary to build and upgrade their space base. Challenge 1 consists of an addition and

subtraction puzzle in which the player must add or remove particles of an 'atom' to create a resource. Challenge 2 consists of multiplication and division tasks in which the player must decide the number of cars needed to transport the produced gears. Still, they must determine the total amount for each round by using multiplication reasoning. In challenge 3, the player applied algorithmic thinking, mental rotation and notions of angles. It includes angles calculation and rotations in a type of game known as turtle geometry to complete a plan in a 5 x 5 grid using step-by-step instructions: turn to the right, turn to the left, step forward. The video game is research-based. The detailed information on the research design and game user research could be consulted by Costa and Marcelino (2020). The complete version of the game is open-sourced ("Space adventure: Defend the planet", 2021).

Emotional questionnaire. The questionnaire is a researcher-based scale about the PANAS - Positive and Negative Affect Schedule short-version (Watson, Clark, and Tellegen (1988) that evaluates the intensity of emotions felt by the players while playing the video game. Five positive emotions were measured: satisfied, relaxed, involved, enthusiastic and excited; and five negative emotions: confused, bored, agitated, unsatisfied, and disappointed. Players were asked to answer a 5-point Likert scale (1 = not at all; 2= a little; 3 = moderately; 4= quite a bit; 5= extremely) to the following statement: "How did you feel while playing the video game?".

Game Mathematics Contents Evaluation (GMC). GMC is a researcher-based measure in reference to The 15 Minute Norm-Referenced Mathematics Test (Chinn, 2017) in his book "More Trouble with Maths: A complete manual to identifying and diagnosing mathematical difficulties". The measure was constructed to allow the subject to demonstrate procedural (and conceptual) knowledge without verbal stimuli. For a better adaptation to the mathematical contents of the video game, 28 items were selected and 16 of the original test were eliminated. The sixteen items deleted were related to algebra, fractions and basic arithmetic operations in vertical representation. Eleven items have been added to include the mathematical contents present in the video game. The final GMC comprises 38 items related to basic arithmetic and basic geometry.

2.3 Procedure

Due to the pandemic, the video game intervention to measure mathematics achievement with an initial sample of 28 deaf students was impossible to conduct; instead, a convenience sample with children aged 9 to 14 comprised deaf students (n= 3) and hearing students. Some participants integrated into the Special Education program (n= 7) with special needs. The video game was used to support mathematics teaching and learning, such as the four arithmetical operations and Basic Geometry – calculation of angles and essential algorithmic thinking (the turtle game).

The children's online intervention took place two or three times per week with sessions of 50 min in their home environment or school. The number of desirable sessions was 12; in practice, children participated between 6 to 12 weeks.

The game sessions include the children, the tutor (a psychologist researcher), a special education teacher and the sign language interpreter (in the case of deaf children without cochlear implants).

At the beginning (moment 1-M1), middle (moment 2-M2), and end of the sessions (moment 3-M3), children were asked to fill an emotional questionnaire to gather information about how they felt after playing the video game.

Mathematics achievement was evaluated before and after the game-training sessions (measured by GMC). All the intervention sessions were recorded as a complement to observation.

3. Results and Discussion

The results show 4% to 20% of mathematics progress (Figure 1). A twelve-year-old student with dyscalculia improved by 20% (Case 2). A sixteen-year-old deaf student improved her math performance by 15% (Case 3). A 10-year-old deaf boy, a home-schooled student, finished the game in eight sessions and improved math performance by 11% (Case 1)

One student (10 years) diagnosed with mild cognitive impairment improved 8% after twelve sessions (Case 8). A ten-year-old student with Asperger's progressed by 4 % (Case 6). Five students – one deaf (Case 4), a boy with

Autistic Spectrum Disorder (Case 5), and three with mild cognitive impairment did not improve after the intervention (Case 7, 9 and 10).

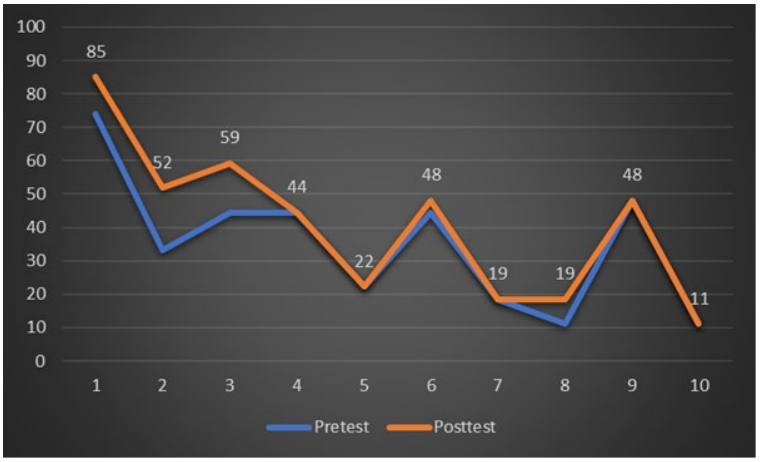

Figure 1: Mathematics Evaluation score (%) by participants before and after playing the video game

Concerning the video game as an engaging experience for players, the Special educational teachers enhanced children's motivation to play. They corroborated the results of the emotional scale applied at the beginning (Moment 1), middle (Moment 2), and end (Moment 3) of game sessions. The children felt "very" satisfied in the three moments and were willing to continue the game sessions. Moreover, all children reported feeling more positive emotions than negative ones, like feeling satisfaction, enthusiasm or being involved in game sessions.

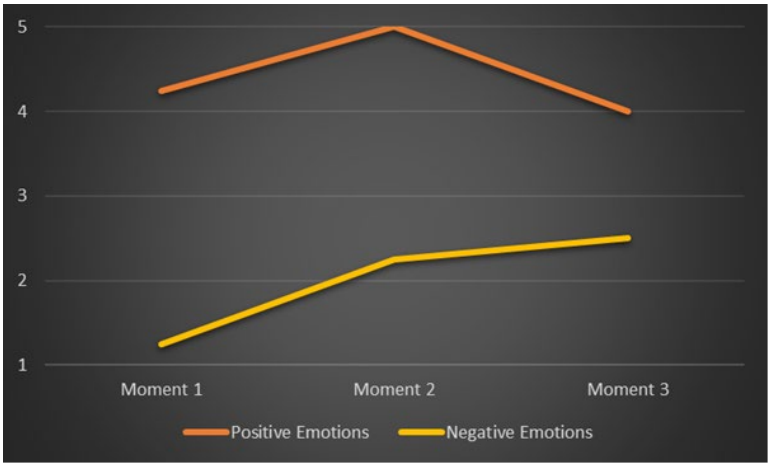

Figure 2: Positive and negative emotions reported by children at the beginning (Moment 1), middle (Moment 2) and the end of the game sessions (Moment 3). 1 = not at all; 5=extremely

The intervention results show that the video game boosts student motivation. Besides, it is a pedagogical resource that allows active learning in distance learning.

The current results suggest that the video game "Space adventure: Defend the planet!" allows educators to gather immediate information about students' difficulties and progression. Therefore, the video game was a good tool for identifying students' problems in elementary mathematics, particularly in children and young people with special educational needs. For instance, the evaluators observed that children maintain the use of counting-based procedures throughout the game sessions. Observing the mathematics behaviour while playing the game, it was possible to see that they kept counting both addends starting from 1 or counting by 1, 2, 5 or 10 using a number line instead of using no counting procedures such as compensation.

Data show slight differences before and after playing the videogame in children with cognitive deficits. The conditions of evaluation and intervention, for instance, the instrument, individual differences, family versus remote sessions, the learning pace of each child, and the number of game sessions, might explain the results.

More qualitative and ecological analysis plus additional studies are necessary to consider the video game as an effective tool to improve mathematics achievement in children with special needs. For instance, change the observational grid to include the children's game challenge strategies in the recorded game sessions.

While the video game shows potential in children's engagement and mathematics learning, the diversity of our sample requires complementary tangible resources outside the game, developed for each type of special needs, which should be considered in future work.

The study enlightens the importance of adjusting the mathematics game-based intervention approach to the child's learning needs and pace to promote mathematics achievement as a final consideration.

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