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# Improving the Working Memory During Early Childhood Education Through the Use of an Interactive Gesture Game-Based Learning Approach

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**ABSTRACT** One of the most socially and culturally advantageous uses of human–computer interaction is enhancing playing and learning for children. In this paper, gesture interactive game-based learning (GIGL) is tested to see if these kinds of applications are suitable to stimulate working memory (WM) and basic mathematical skills (BMS) in early childhood (5–6 years old) using a hand gesture recognition system. Hand gesture is being performed by the user and to control a computer system by that incoming information. The research was developed using a quasi-experimental design with a pre-test and post-test, using both an experimental and control group through three phases: the first one was the prior evaluation of the learner's skills; a second phase in which the use of the technology was developed; and a final phase of evaluation. In the evaluation phases, working memory was measured using the Corsi task, and the basic mathematical skills using the test for the diagnosis of basic mathematical competencies (TEDI-MATH). The results provide clear evidence that the use of these technologies improved both working memory and basic mathematical skills. We can conclude that the children who used GIGL technology showed a significant increase in their learning performance in WM and BMS, surpassing those who did normal school activities.

**INDEX TERMS** Basic mathematical skills, early childhood education, gesture interactive game-based learning, human-computer interaction, working memory.

## I. INTRODUCTION

Human-computer interaction (HCI) is a growing field of research which focuses on the relation between human beings and technologies. HCI tries to understand the methods that humans can use to communicate with computers and defines new interaction paradigms. These new interaction models have a wide range of applications ranging from research to industry, entertainment, and education.

In recent years, the games industry, looking for more interactive experiences, has developed a set of new devices and technologies that provide users with a more natural interaction than a simple gamepad, keyboard, or mouse can. These devices, such as Kinect [1], or Wiimote [2], allow tracking of the body and hands of the players, recognizing their movements and gestures, and enable a more natural interactive experience [3], [4]. These devices allow the development of new somatosensory applications which increase user immersion and motivation, providing more fun games [5], [6].

Recently, all these ideas - new HCI paradigms, games and somatosensory devices - have been combined to develop a set of applications generically called gesture interactive game-based learning (GIGL), which aim at the improvement of learning performance through interactive games. GIGL opens new opportunities to learn complex contents by using new paradigms, for example, through body or hand movement, which provide a foundation for new learning models [7]. These techniques are especially of interest in primary and secondary education for several reasons. Firstly, more natural interfaces can be made [8]. Secondly, learners can use their body as a tool; this will reduce physical passivity and increase their motivation [9]. Thirdly, the child can be supervised by teachers while they solve specific tasks, and feedback can be obtained for the system in real time [10]. Many studies report that GIGL can increase both the ability to learn [11]–[13] and motor skills in different ranges of ages [14], [15]. However, the overall education of children should stimulate other kinds of abilities rather than simply learning and motor competences.

Executive functions (EF) are brain-based cognitive feature skills that facilitate, essentially, thought and self-regulation. Executive functions are based in the prefrontal cortex of our brains and assist with goal-setting and decision-making. Luria [16] proposed three different functional units in his research studies on the brain. The first unit is located in the limbic system and is responsible for alerting and motivation. The second unit is located in the post-control cortical areas and is responsible for the reception, processing, and storage of information. Finally, the third unit is located in the prefrontal cortex and is responsible for the programming, control, and verification of the activities we carry out [16]. According to Alexander Luria, the third unit located in the prefrontal cortex is the most important unit for executive functioning.

There are three main types of executive functions: working memory, inhibitory control and cognitive flexibility [17]. Working memory is a cognitive system that allows humans to manipulate and recall a limited amount of retained chunks of information for a brief period [18]. Numerous studies have demonstrated that working memory is of central importance for acquiring knowledge [19] and is needed for a variety of complex cognitive tasks and abilities [20]. Moreover, it has been shown that working memory is a better predictor of academic success than intelligence [21].

The main contribution of this paper is proving that at a very early stage of childhood, it can be observed that the executive functions, with a focus on working memory, can be improved and positively impact the mathematical skills developed through GIGL. This hypothesis was proven experimentally by a standard test, which shows an increase in children's cognitive abilities through computer game play. The set of GIGL developed applications surround the limitations of traditional interfaces used in childhood education such as a keyboard, mouse, or gamepad, by replacing them with a somatotype device.

In the next sections, the design and implementation of a gesture-based learning application are described. This aims to increase executive functions, specifically working memory, in order to study its impact on the basic mathematical skills of children. Firstly, a literature review is presented, describing the main concepts of executive function, game-based learning, and gesture-based learning. In Section 3, the materials used in our research, such as hardware and software, are described. Section 4 presents the methodologies used in this research and the design and implementation of the application, while the experimental procedure is discussed in depth. Following this, Section 5 outlines the results obtained and discusses them. Finally, Section 6, summarizes the conclusions.

## II. LITERATURE REVIEW

### A. EXECUTIVE FUNCTIONS

There is no overall agreement on how to define executive functioning, but most authors agree that it refers to top-down control processes that are involved in regulating action. Executive functions include the set of processes that underline conscious and planned behavior directed to goals. They are associated with responding to new or difficult situations and the ability to inhibit the behaviors that move us away from the objective pursued, through the deliberate control of thought, emotions, and actions [22]. As Carlson [23] notes, executive functions refer to high level self-regulatory cognitive processes that help in the supervision and control of thinking and action. These abilities include inhibitory control, planning, attentional flexibility, error correction, detection, and resistance to interference [23]. For these reasons, these skills are important for initial learning in kindergarten.

Executive functions are basic skills for gaming; players need to be able to navigate the game, remember a map, and focus on goal-relevant information while blocking out irrelevant memories and constructing a mental representation of the problem to be solved. Through deductive thinking and experimenting with potential solutions, users learn how the system works and how to solve the problem. This process requires players to retain vast amounts of information for navigation, representation-constructing, and solution-testing. The information is processed by an individual continuously drawing upon their limited pool(s) of working memory to temporarily store information and to direct their attention [24], [25]. The amount of working memory involved in a task and how many is allocated is determined by media features and user characteristics [26].

From an attention control perspective, gaming ability expertise may have a positive impact by helping individuals to identify which information elements are relevant to certain goals, and which data to block out. A learner's gaming skill expertise is also a critical factor in searching for object-relevant details to concentrate attention on [26] and [27]. Therefore, players with better executive skills will be more capable of maintaining attention to achieve the purpose.

Although individuals are not born with a high degree of executive function skills, they have the potential to develop them [28]. However, the process of acquiring these functions takes a long time, beginning in infancy and continuing into early adulthood, and after that, is developed further through life experience. Usually, children build their talents through engagement in meaningful social interactions and in enjoyable activities that draw upon skills at increasingly demanding levels.

Working memory, as an example of an executive function, has been selected for four reasons. The first reason is that its relationship with mathematical performance has been evidenced in many studies for a wide range of ages [29], [30]. This is especially remarkable in children, where our research is focused [31]–[33]. The second reason is that working memory can be used as a predictive element of mathematical skills [21], [34]. This predictive value is more significant than the rest of the executive functions [35]. However, it must be taken into account that, according to [36] and [37] executive function of inhibitory control in mathematics problems is greater than that of the executive function of working memory during the first years of schooling. According to [38] the capacity of prediction extends to the first years of primary education. The third is that the predictive value of working memory is influenced by the period of childhood growth, where visio-spatial memory seems very strong [39], [40].

Testing visuo-spatial short-term working memory, as it would be necessary to explain that there is currently no agreement on how to define executive functions, but most authors who published in this field agree that they refer to processes of top-down control. As this is involved in the regulation of the action, these processes are key in early childhood education. For some researchers, the executive functions are constituted by: inhibition, planning, flexibility, working memory, and fluency, while others suggest three functions: a temporarily retrospective function (working memory), a temporally prospective function dedicated to anticipation and preparation of responses, and a mechanism of control of the interferences that suppress the incompatible conducts with the established goal. Although, the model of the greater agreement is perhaps one of Miyake and others [41]. For them, there are three basic aspects of executive functioning: inhibition of dominant responses, updating, and supervision of representations in working memory and change between tasks or mental sets.

Researchers such as [42] and [43] suggest that the predictive capacity of mathematical performance in primary education will be more powerful if verbal work memory is measured because, in childhood, this last skill carries more weight. The fourth reason is that the relationship between the executive job memory function and mathematical performance does not seem to depend on the type of memory to be evaluated, but the importance of each type of memory is not equal for each basic mathematical skill [44].

There are several potential benefits for the learning-based approaches which can be identified through the relationship between the EF of working memory and the BMS of children in early childhood education. Bull and Scerif [45] investigated the existence of a relationship between EF and BMS in children in preschool and primary education. The results show that the BMS is significantly related to all assessment tasks. These authors propose that the difficulties of the children in mathematics are due to the poor results in the EF of working memory and the EF of inhibitory control. Espy and others [46] carried out an investigation to determine if the EF were related to the BMS of the children of infantile education. For this, they examined 96 children through EF tasks to evaluate working memory, cognitive flexibility, and inhibitory control. Working memory and inhibitory control predicted early arithmetic competence. In addition, they deduced that the EF of working memory, cognitive flexibility, and specific inhibitory control are related to emerging BMS at the childhood stage.

On the other hand, Geary and others [47] evaluated the relationship between the performance of children in mathematical tests and their performance in completing tasks of working memory and processing speed. They found that children with a normal performance in mathematics were faster and more accurate when responding to tasks that presented demands for identification of numerical sets, recovery, and retention of numerical information, linear estimation, and counting capacity. Likewise, their capacity of recognizing numerical sets was related to their performance in visuospatial working memory tasks. Children with difficulties processed this information more slowly, requiring greater effort in determining the size of the sets.

Bull *et al.* [46] conducted a longitudinal study in which they aimed to predict whether there is a relationship between EF in the early childhood education stage and a better performance in primary education in reading and mathematics. To do this, they first evaluated children in preschool with regard to EF, in reading and mathematics. Then, they evaluated the boys and girls at the entrance to primary education, at the end of the first year of primary education, and at the end the third year of primary education. The results showed that a better performance in EF gives the children a better performance in reading and mathematics in the entrance to primary education and the first years of this stage. They found that EFs predicted better overall performance and that visio-spatial working memory was a specific predictor of mathematical ability.

Toll *et al.* [48] carried out longitudinal research to identify whether EF, working memory, cognitive flexibility and inhibitory control can act as predictors of mathematics performance. Results of their investigation show that the working memory EF predicts the performance in mathematics, even better than the preparatory skills of mathematics.

The presented research is part of a group who evaluate and investigate the three executive functions. However, this study focuses on working memory, because the author designed educational games and studied their impact on working memory being the one with the greatest weight in predicting success or failure in mathematics in the future.

### B. GESTURE-BASED LEARNING (GBL)

In gesture-based learning, the learning process occurs through the interaction between users and computers based on natural movements, as in daily life. These movements are tracked by a somatosensory device which [49] can scan the space and calculate the localization of an object, user's body, or body part in real time. This technology not only follows tracking of the human, but also recognizes the motions of the head, face, hands, arms, and/or body as gestures. Since this experience, gesture-based technology has been under continuous development with the aim of providing different learning channels for children, which could help them to understand academic materials more easily [50]–[52].

The greatest impetus has been the appearance of the new low-cost devices as such as Microsoft Kinect, Asus XtionPro, and Wiimote inherited directly from the video game industry.

Wiimote is a one-hand controller design like a traditional gamepad but also includes a set of accelerometers and infrared sensors which work synergistically to allow the user to interact and manipulate elements, via gesture recognition and pointing, on a screen [53]. This controller has been used for several research activities within a wide range of ages, from senior children, in order to train hand motor skills [15], to assisting children with attention deficit hyperactivity disorder. This demonstrates how hand-eye coordination, motor control, and visual perception [15] can be stimulated through the use of this interactive element.

Kinect V1, V2, and Asus XtionPro are similar devices. Their tracking capabilities are based on the time-off light range camera [54], which can reconstruct a depth image of the capture volume allowing the system, through real-time processing, to track body joints from more than one single user. Microsoft Kinect V2 includes two software packages, Kinect Studio V2, and Visual Gesture Builder, which are used for natural gesture recognition. The first one allows recording of information captured by the sensor, and the second, the definition of new gestures in an agile, visual and simple way. The software makes use of artificial intelligence algorithms to learn the characteristics of a gesture from a series of samples that have been previously recorded and defined by the user. The main advantage of this controller over the Wii Remote is that the users do not have to hold any elements. Microsoft's Kinect has been used effectively with children, focusing mainly on motor skills [55]–[57].

### C. DIGITAL GAME-BASED LEARNING (DGBL)

DGBL is currently one of the most popular topics in education because it allows active participation and enhances the learning process. Prensky [58] defines a digital game-based approach as an instructional method that incorporates educational content or learning principles into video games, with the goal of engaging learners. He identifies twelve basic characteristics, fun, play rules, goals, interactivity, feedback, adaptive, win state, challenges, resolution of problems, interaction, representation and storytelling.

Nowadays, game-based learning and gesture-based learning are used together, connecting learning and physical activity [59]. It is easy to find a wide set of possible applications, for example, they have been used for software engineering lectures [60]; geography courses [61]; Chinese language learning [62]; English listening [63]; and mathematics [64], [65]. In addition, authors have reviewed the impacts of digital game-based learning on many skills, including the acceptance and efficiency of teachers [66]; the self-efficacy of children [12]; collaboration or interaction between peers [67], [68]; and assessment issues [69]. Researchers and teachers must determine how these games should be developed in order to obtain the required result. Garris *et al.* [70] proposed the input process outcome model (IPO), which has been adopted as a tacit paradigm for most studies on learning games. The IPO model delimits three elements: (1) the input, which illustrates the design of the instructional process; (2) the process, which introduces the cycle of the game and allows for the user's feedback on their experiences; and (3) the outcome, through which thorough analysis of training objectives and outcomes is made. Fig. 1 illustrates this process. The IPO paradigm has been applied successfully for several research projects; for example, [71] used this model to improve children's proficiency in the English language, [72] introduced a motivation assessment-oriented IPO game model to create an educational game. Taking into account the playful nature of children, we have adopted the IPO model to the design and implementation of a gesture-based learning application in order to show that processes that underline conscious skills, such as working memory, can be reinforced.

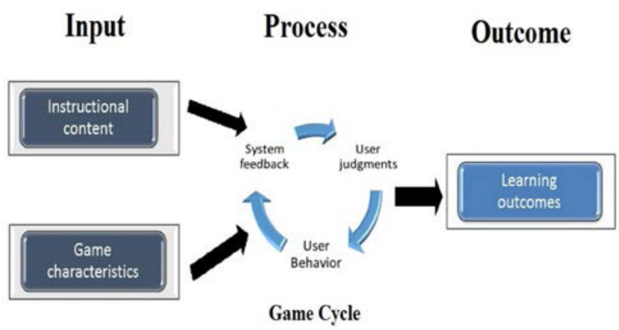


**FIGURE 1.** IPO game-based learning model [70].

## III. MATERIALS

### A. HARDWARE

The hardware used is composed by a PC connected to a Kinect (as somatotype devices) and a big/TV screen where the applications are shown. The learners stand up in front of the screen where they can interact with the applications, Fig. 2.

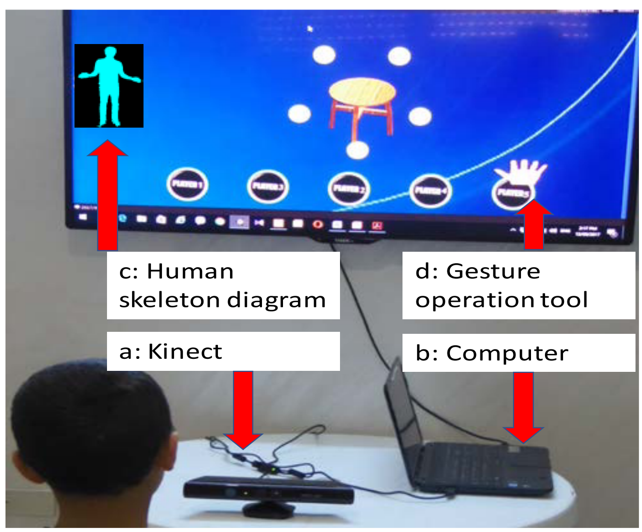


**FIGURE 2.** Interactive gesture game.

### B. SOFTWARE

The protocol of GIGL procedure is composed of nine applications; each one presents a similar software architecture, Fig. 3. The core of the software is a Unity3D application. Unity3D is one of the most popular graphics engines. It is cross-platform (PC, consoles or mobile devices), and used mainly for video game development. For this project, we highlighted two of its characteristics; ease of creating an interactive 3D application, and the ability to support interactive communication with the Kinect. The logic of the system was individually designed for each activity and was integrated into the graphics engine by a script programmed in language C#. The data from the different experiences, playing experience, profile, results, was stored in an MYSQL database.

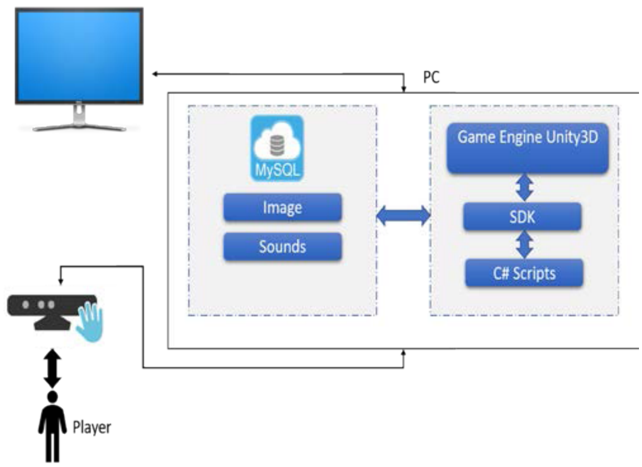


**FIGURE 3.** System architecture.

As the system has been developed to be used for very young children 5-6 years old, the type of interaction has to be very simple. We used only a short set of gestures; select, drag, drop. These gestures are, in general, standard to every application and the devices should recognize them without problems. However, due to the certain phenotypical characteristics of children such as height, length of the arms, the size of the hand and fine motor skills, the size of the gesture recognizer had to be re-tuned. The process we followed to incorporate gesture is the following:

1) The children play in front of the system, replaying several times the same gesture and recording a series of examples, for these records Microsoft Kinect Studio V2 is used. At least two sequences are needed for each gesture; one for training the system and the other one as a test to check the effectiveness of the recognition results. This step is developed in a test application. Fig. 2.
2) The characterization of the recorded is performed by a human expert, indicating to the system in which moments the gesture is being performed (when a gesture begins and when it ends) through a timeline tagging using Visual Gesture Building which allows the system to be trained and encoding the gesture in a file.
3) The system is trained using the Adaboost algorithm [73] which allows a sensor to characterize any generated gesture. The effectiveness of the detection of each specific gesture is checked using the data obtained as a test recording file.
4) This information can be imported into Unity3D through the software development kit (SDK) and used for real-time recognition.

## IV. METHOD

### A. PARTICIPANTS

Participants in this experiment were taken from four classes in a kindergarten in CEIP Ponte dos Brozos, Spain. The research protocol was approved by CEIP following the authorization process, which addresses the legal aspects for the fate of collected information and assure the safety of participants through meeting with tutors to apply the inclusion and exclusion criteria. We selected 60 children, level 2 preschoolers between 5 and 6years old, who were divided into two groups. The first group (male = 15, female = 15) is the experimental group (EG) and the second one (male = 14, female = 16) control group (CG). The test was conducted from September 2016 to May 2017.

### B. DESIGN OF THE LEARNING ACTIVITY

The activity program was composed of two blocks. The first block corresponds to the initial session where there is a presentation of technology, work methodology, and the previous game in order to enable an adaptation to technology. This block is needed since new activities and technology can present difficulties at these ages, as the children are in a phase of incipient improvement of fine motor skills and it is necessary to perform an initial training. The experimental group, individual, pairs or in groups of five, carried out three weekly sessions of thirty minutes in a specific area of the classroom. The duration of the program was four months, so each participant had twenty sessions in a specific class at the same school. All the children completed all nine games; however, they did a game in each session. As mentioned before, the learning procedure was organized into nine activities or games. The activities were designed to combine the IPO model proposed by [70] and the properties of learning games proposed by [58]. Throughout the input stage, instructional content is linked with game characteristics, which together contain the teaching material and the game. The main characteristics of our nine activities are listed below and given in Fig. 4:

1) Capture the fish. A fish swimming in the sea and a number are shown on the screen. After five seconds, the number disappears, and the learners have to capture as many fish as the number showed. The concept of number, the process of calculation, and working memory are stimulated because the original number and the number of fishes they catch must be remembered. This game is played on an individual basis. Fig. 4a.

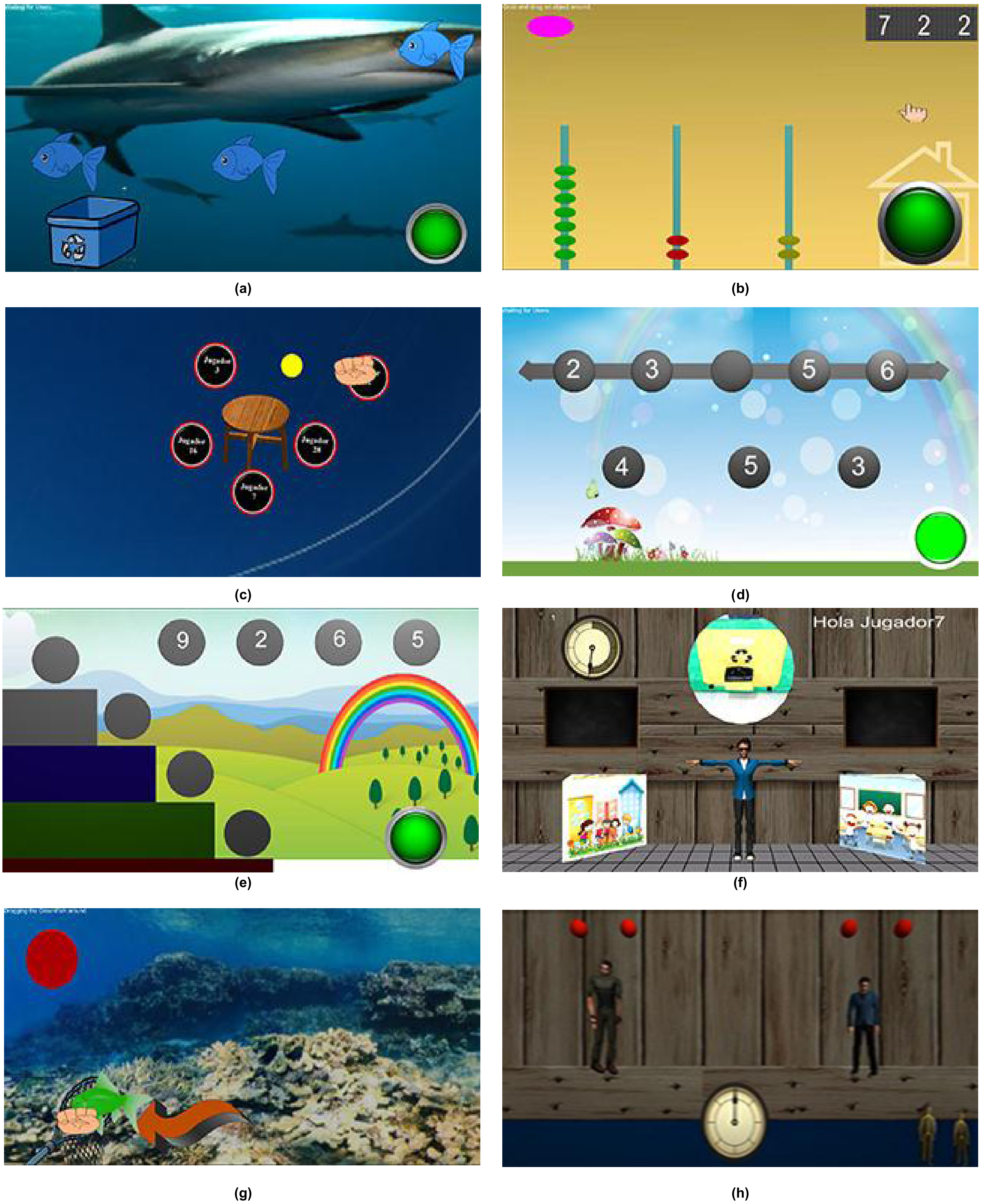


**FIGURE 4.** **Graphic User Interface of the Game-Based System. (a) Capture fish. (b) Abacus. (c) The chair and advance chair. (d) Counting by jumping. (e) Order number. (f) Inside-outside class. (g) Scuba diving. (h) Toy dolls.**

The expected output from this task is to stimulate the ability of children to calculate using working memory.

2) Abacus. Three numbers (for five seconds) and three poles appear in the screen. The learner has to catch and locate on each pole a number of balls equal to the number over the pole. The stimulation is centered on the concept of three-digit numbers and the working memory as the previous case. This game is also played on an individual basis. Fig. 4b. The expected output from this task is to stimulate the

ability of children to remember numbers up to three digits.

3) The chair. The application shows a table with several pictures of other children. The application changes the position of two pictures only, and the child has to relocated them at the correct position. Working memory will be practiced because the children have to operate with the correct location of the characters. This game is designed to be played in small groups of five players. Fig. 4c. The expected output from this task is to stimulate the executive function of the working memory.
4) The advance chair. This game is similar to the previous one with the difference that every picture changes its position rather than only two. Fig. 4c. The expected output from this task is to further enhance the executive function of working memory thorough including five pictures in the task rather than two pictures.
5) Counting by jump. The children have to calculate the correct number in a sequence. The mathematical concepts of number and sequence have to be understood in order to choose the correct one. This game is also played on an individual basis. Fig. 4d. The expected output from this task is also to enhance the executive function of working memory thorough finding the missing number in a series of five numbers.
6) Ascending or descending order for numbers. A stair with a number on each step is presented; the user has to match the number and order in either an ascending or descending direction. This game is also played on an individual basis. Fig. 4e. The expected output from this task is also to stimulate the ability of executive function of working memory through sorting a series of four numbers, ascending or descending.
7) Inside outside. A set of pictures of different elements is shown. The children have to say if the object is inside or outside the class by putting his/her hand up in a given period of time. The number of objects chosen in each category is presented. This game is also played on an individual basis. Fig. 4f. The expected output from this task is a double test for the executive function of working memory through recognizing the location of ten objects and using a gesture that correspond with each location.
8) Scuba diving. An undersea scene is presented. Several fish of different colors appear, along with a colored circle showing the color of the fish which have to be caught. The color of the circle can change during the task developments. We focus on executive functions. This game is also played on an individual basis. Fig. 4g. The expected output from this task is to encourage working memory by matching the color of the displayed object with the color of the processed object
9) Toy dolls: two children participate in the activity together. Two avatars with two colored balls at the top are shown. On the screen are two puppets on the bottom right, one corresponding to each child, which move. The player has to reproduce the movement that the dolls make as long as the colored balls are green, and when the balls are red, they have to stop moving. With this task, we are practicing working memory because the learners will have to remember the movement of the doll to reproduce it. This game is designed to be played in pairs. Fig. 4h. The expected output from this task is to encourage working memory by recalling the last movement following the change in instruction to decide whether to continue or terminate the task.

From a general point of view, we can find in the activities the Prensky characteristics summarized as follows:

1) Fantasy: For example, experience under the sea, or virtual avatar dancing.
2) Rule/Goal: catching a determined number of fishes, ordering, choosing the right position.
3) Sensory stimuli: Visual, audio, and hand movements for each game.
4) Feedback: Simulate a hand on-screen, dragging and dropping pictures, numbers, and objects with the movement of the hand, visual feedback. Correct correspondence between the pictures and the hand gesture; placing the pictures, putting numbers in the correct place.
5) Challenge: Correct scoring, remembering situations, remember movements or colors.
6) Mystery: A random sequence of numbers, pictures or objects in the game.
7) Control: The participants need to think, decide, and use their hands to play the game.

### C. EXPERIMENT PROCEDURE

First, we have to remember that the objective of this research is to develop a procedure based on GIGL in order to observe its effects on early childhood education for working memory and mathematical skills.

The experimental process design was carried out by a quasi-experimental model with pre-test and post-test with a control group (CG) and an experimental group (EG). In order to avoid problems arising from the sample size (of 60 subject), non-parametric contrast tests were developed, in this case, specifically, descriptive analysis and the Mann-Whitney Test [74].

To assess working memory, the Corsi Test was used [75]. With this task, we obtained data on three variables that are the total score of the test, the total score of correct answers and the spin memory. To evaluate the basic mathematical skills, the test for the diagnosis of basic mathematical competences, TEDI-MATH, was used [76]. TEDI-MATH is a battery that allows you to identify the difficulties that children of pre-school education have in the numerical field. It is a test of individual application, for approximately thirty minutes, consisting of twenty-five tests grouped into six large areas of numerical knowledge (counting, numbering, Arabic numeral system, oral numerical system, logical operations, operations with image support, operations with arithmetic statement, operations with verbal statement and size estimation) whose internal consistency ranges from 0.84 and 0.99, the test-retest reliability between 0.66 and 0.88 and the construct validity between 0.698 and 0.861. The protocol was developed in five steps:

1) The 60 children were evaluated using Corsi test and TEDI-MATH test.
2) Two homogeneous groups control group and experimental group were developed using a cluster analysis of the previous scores, bellow in order to verify the homogeneity of the groups an analysis of variance ANOVA was performed Median (M) and Stand Deviation (SD) data are given. The researcher assumed that all children do the same in school, even if they are from different classrooms because that is what the teaching coordination bodies of the centers are for. Therefore, as we have two groups in the homogeneous pre-test, one that does nothing and a second that does the same as the previous ones plus the intervention in executive functions if when comparing them in the post-test there is an improvement in the one that received the treatment in the variables under investigation. The researchers also extrapolate to the intervention because there is no other reason to justify that comparative improvement with their peers.
3) The control group continued with standard education methods while the experimental group develops the technology-based activity program. The standard education methods are to continue with the ordinary teaching-learning process that all children of these ages have in the standard educational system, without specific intervention in executive functions. Children of the control group also received the standard education.
4) When the activity program ends the children's, skills were reevaluated.
5) Statistical analysis inter/intra groups were dev

## V. RESULT AND DISCUSSION

The statistical analysis of the data has been carried out using the Statistical Package for Social Sciences (SPSS) version 23. As mentioned previously, firstly, two homogeneous groups were developed, under the studied variables (step 1 and 2).

In relation to working memory, the descriptive analysis shows that the groups obtain similar scores between the control group (M = 2.73, SD = 0.78) and the experimental group (M = 2.60, SD = 0.99). Likewise, the Kruskal-Wallis test indicates that there are no differences between groups in working memory ($\chi^2 = 0.48$, p = 0.79). From these results, it is clear that the groups are comparable in the working memory variable Table. 1.

The same happens with the basic mathematical skills in which the descriptive analyzes shows similar scores between the control group (M = 1046.20, SD = 262.65) and the experimental group (M = 1046.73, SD = 263.90). Likewise, the Kruskal-Wallis test indicates that there are no differences between the groups in basic mathematical skills ($\chi^2 = 0.11$, p = 0.95). From these results, it is clear that the groups are comparable in the variable basic mathematical skills Table. 1. In relation to the control group and the experimental group, the descriptive analysis shows that the control group obtain scores in the post-test (M = 2.80, SD = 0.89) lower than the post-test scores of the experimental group (M = 4.43, SD = 0.60) as presented in Table. 2 and Fig. 5. The Mann-Whitney test shows that there are statistically significant differences between the control group and the experimental group (U = 61.50, p = 0.001) as shown in Table. 3.

**TABLE 1. Differences in the pre-test in working memory and basic mathematical skills.**

| Variable | Grupo | M | SD | Rank | $\chi^2$ |
|---|---|---|---|---|---|
| Working memory | Control Group | 2.73 | 0.78 | 17.55 | 0.48n.s. |
| | Experimental Group | 2.60 | 0.98 | 43.45 | |
| Basic Mathematical Skills | Control Group | 1046.20 | 262.65 | 17.90 | 0.11n.s. |
| | Experimental Group | 1046.73 | 263.90 | 43.10 | |

*p< .05; **p< .01; n.s.: not significant

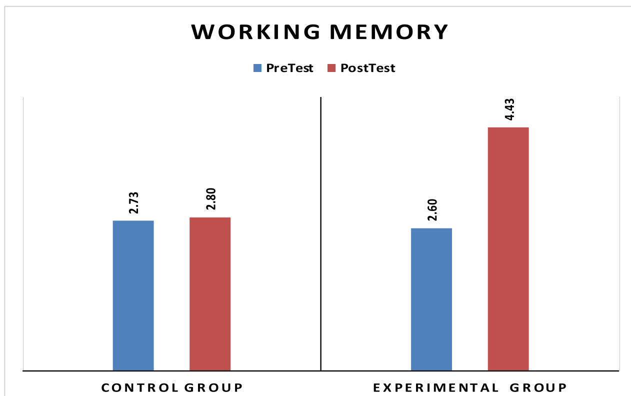


**FIGURE 5. Comparison of the mean score in working memory.**

In summary, in the working memory variable, there are statistically significant differences between the control group and the experimental group in favor of the research groups that received the educational intervention (experimental group). Therefore, in the working memory variable, there are statistically significant differences depending on whether the children of have received or not educational intervention in working memory, also in mathematical context, in favor of the educational intervention.

In relation to the control group and the experimental group, the descriptive analyzes show that the control group obtained scores in the post-test (M = 1157.07, SD = 259.47) lower than the post-test scores of the experimental group

**TABLE 2.** Differences in the pre-test and post-test in working memory and basic mathematical skills.

| Variable | Group | M | SD | Z | Ranks | $\chi^2$ |
|---|---|---|---|---|---|---|
| Working Memory | Control Group | 2.80 | 0.88 | -0.20n.s. | 17.77 | 44.84 |
| | Experimental Group | 4.43 | 0.60 | -4.65** | 43.23 | |
| Basic Mathematical Skills | Control Group | 1157.06 | 259.46 | -3.19** | 18.02 | 41.65 |
| | Experimental Group | 1536.46 | 131.52 | -4.78** | 42.98 | |

*p< .05; **p< .01; n.s.: not significant

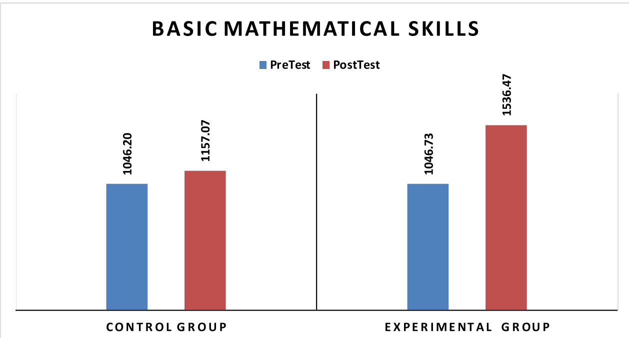


**FIGURE 6.** Comparison of the mean score in Basic Mathematical Skills.

(M = 1536.47, SD = 131.52) as shown in Table. 2 and Fig. 6. The Mann-Whitney test shows that there are statistically significant differences between the control group and the experimental group (U = 72, p = 0.001) as shown in Table. 3. In summary, in the variable basic mathematical skills, there are statistically significant differences between the control group and the experimental group in favor of the research groups that received the educational intervention (experimental group). Therefore, there are statistically significant differences in terms of whether or not the children of early childhood education received the educational intervention, in favor of the educational intervention, but there are no statistically significant differences depending on whether the children received this intervention or not.

In summary, the obtained results verify that the intervention in working memory in a mathematical context improves the development of working memory and basic mathematical skills in children in early childhood education. The objective of the present research has been fulfilled, which is to verify if it is possible to improve the performance in working memory and basic mathematical skills through a program prepared for infant education.

In relation to the obtained data in the post-test, the analysis shows that all groups of the present investigation improved with respect to the pre-test evaluation as shown in Table. 2, in Fig. 5 and Fig. 6. In working memory, the control group does not show improvements, while the experimental group does.

In the control group, the post-test scores (M = 2.80, SD = 0.89) are higher than the pre-test scores (M = 2.73, SD = 0.79), and there is no statistically significant differences (Z = −0.20, p = 0.84), in the experimental group the post-test scores (M = 4.43, SD = 0.60) are higher than the pre-test scores (M = 2.60, SD = 0.99), resulting in statistically significant differences (Z = −4.66, p = 0.001). The lack of statistically significant differences in the control group may be due to the cognitive process is not usually explicitly worked in nursery schools, so there is no improvement through the ordinary teaching-learning process. Obtaining statistically significant differences in the groups intervened, the experimental group can be attributed to the educational intervention, obtaining the expected results.

**TABLE 3.** U values of the mann-whitney pretest/ posttest for control and experimental groups.

| Variable | Pre Test | | Post Test | |
|---|---|---|---|---|
| | Control Group | Experimental Group | Control Group | Experimental Group |
| Working Memory / Basic Mathematical Skills | 61.5 ** | 72 ** | 68 ** | 75.5 ** |

*p< .05; **p< .01; n.s.: not significant

In basic mathematical skills, all the groups improve with respect to the pre-test evaluation. In the control group, the post-test scores in basic mathematical skills (M = 1157.07, SD = 259.47) are higher than the pre-test scores (M = 1046.20, SD = 262.65). statistically significant differences (Z = −3.20, p = 0.001), in the experimental group the post-test scores (M = 1536.47, SD = 131.52) are higher than the pre-test scores (M = 1046.73, SD = 263.90) produce statistically significant differences (Z = −4.78, p = 0.001) as shown in Table. 2. The presence of statistically significant differences in the control group may be due to the content on which the curriculum is concerned, so it is expected that the participants will gain improvement in the stated variable during the course of the year; while the differences produced in the experimental group can be attributed to the fact that the educational intervention program achieved the results initially proposed.

To identify the differences between the groups of the present research in the post-test, the Kruskal-Wallis test was used, which indicates that there are statistically significant differences between the control group and the experimental group in the working memory variable ($\chi^2 = 44.84$, $p = 0.001$) and in the basic mathematical skills variable ($\chi^2 = 41.65$, $p = 0.001$).

## VI. CONCLUSION

This study aimed to develop a favorable virtual interactive learning environment for early childhood. This approach combined the gesture-based learning model and the game-based learning model and aimed at improving the working memory and mathematical skills. The research embodied a significant characteristic, in that it can be developed individually, in pairs and small groups. Therefore, it can be considered as innovative, since most educational technology programs are individually developed. Thus, it is decreasing the human and material resources needed. This study also created a physical activity session based on the IPO in order to motivate the learning process, through which the instructor could give suitable feedback based on the individual participant's behavior to encourage their interest in the learning content and to encourage them to accomplish the task through the playfulness of the game.

The statistical analysis of the data obtained through the Corsi and TEDI-MATH tests shows a significant increase in the working memory and mathematical abilities of those children who used the technological resources. The statistical values obtained, show that there were significant differences in the working memory and mathematical skills between the experimental and the control group. The results in the experimental one, are along the same line of the results presented by [33], [48], and [77]–[80]. These differences indicate several things. First of all, that the different applications stimulated the children in a significant way. Second, during the learning process, the system gave suitable feedback to the users in order to increase their interest through a kindness set of activities. The set of games with gradual complexity and the characteristic of the IPO model; fantasy, rule/goal, sensory stimulation, challenger, mystery, and control, provided an engaging environment that created a suitable learning environment. The small differences in the control group are related to the different tasks that this group perform in their regular classes.

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