App to Reinforce Mathematical Neurocognitive Skills During and After the COVID-19 Pandemic

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Abstract. Students have returned home, and classes have switched to online instruction, because of The Epidemiological Contingency. which encourages the search for educational alternatives and strengthening teaching-learning methods. The country has made various efforts to make education relevant (mainly in mathematics). In addition, various government institutions in Mexico and the SEP have been concerned with reinforcing the teaching-learning process, a situation that motivates researchers from various areas (Psychology, Neuroscience, Pediatrics, among others) to seek strategies to strengthen children's development of calculus. mathematical (if the brain structures are mature). An important characteristic of the brain is neuronal plasticity. Therefore, the present work converges in the development of a mobile application, based on the Educational Model and the mandatory curricular proposal of the Secretary of Public Education (SEP) that contributes to the functional regeneration of nerve cells in children up to 6 years of age, achieved sensory stimulation to reinforce mathematical epistemic thinking; thus keeping neurons active, preventing the retention capacity from decreasing with age; in addition to guaranteeing Neuroplasticity, due to the implementation of techniques to stimulate and reinforce cognitive abilities (attention, perception and memory). The results obtained in the 1st and 2nd phase of tests increased by 8%, 6% and 5% for 1st, 2nd, and 3rd students; respectively.

Keywords: Artificial intelligence, cognitive neuroscience**,** mathematical cognitve skills.

1 Introduction

In Mexico, traditional basic education did not imply the use of information technologies 100%. In this century, and with the arrival of the COVID-19 pandemic, the world had to evolve [1], face new challenges, and seek new alternatives to guarantee continuity in education [2]. The way of getting an education changed dramatically. This means that the current pedagogical approach focuses on transmitting knowledge, but no longer with the approach where memorization was privileged, but by different methods where it is contemplated: a) that information increases every day, b) discernment is generated through an unprecedented speed and that c) technology is changing dramatically.

Thus, the inclusive educational revolution begins, with the evaluation and updating of the National Educational Model [3] now known as "The New Mexican School", that guides pedagogical practice and can serve as a reference for parents and students about the training to be achieved. The idea is that the students are instructed with quality and in a comprehensive way, generating the bases to function in their environment.

Researchers, education specialists in various sciences [4, 5] (Early Childhood Education Collective y TIC, 2014), Mexico and other institutions (SEP, UNESCO, Nokia) to mention a few; support the premise "Children First", and in compliance with the curricular plan proposed in [3], contribute to the didactic strengthening and promote the use of technological advances; helping to perfect teaching, teaching practice, as well as improve quality around the world [6]. Getting students to participate actively, autonomously in their cognition and motivation under the key competence of "learning to learn".

Recent research [7, 8, 9] has dabbled in this approach. Promoting Neuroscientific Pedagogical and Cognitive Training. They also affirm that the human can understand and remember through the continuous reproduction of patterns obtained through external stimuli, generated by memories or experience. In addition, the work of [10] indicates that the changes made in the cerebral cortex (prefrontal and hippocampus where mentalization is based) will be able to influence long-term cognitive development.

Unfortunately, our country has not explored these lines of research. Therefore, the objective is to establish a collaborative work by relating and entering mobile technology, educational cognitive Neuroscience and the national basic-level curriculum proposed by the current Pedagogical Guide of the SEP; and develop a tool on Android to generate a repository and with it train an ANN to measure the level of mathematical knowledge based on student´s cognitive skills (attention, perception and memory) of aged 3 to 6.

This article is structured as follows: Section 2. State of the art, a general and relevant panorama of the proposal is given, at the same time the recent problems are highlighted and how they have been addressed by the authors; Section 3. Proposed method, where its phases and the main components of the method to build a mathematical neurocognitive app to measure the cognitive level through an Artificial Intelligence (ANN) technique are disclosed; Section 4. The results that demonstrate the functionality of the proposal are presented. Finally, in the last section, Conclusions of the document, with directions for future work.

2 Literature Review

The nature of educational challenges has been transforming. Until a couple of decades ago, the national educational effort was focused on literacy. Although the task of educational inclusion has yet to be completed for all population groups, it is unquestionable that today the greatest challenge is to improve the quality of education, due to this, updates to educational models have emerged focusing on three learnings (language and communication, mathematical logical thinking, and understanding of the natural and social world) [11, 12, 13].

In 2015, the effectiveness of web semantics based on cognitive skills was investigated and it was identified that the early development of the infant begins to develop their cognitive abilities through inquiring, exploring, investigating, and discovering the world around them. They also address the issue of the emerging role of educational neuroscience in educational reform for adequate educational neuroscientist training [14].

More recent research has addressed problems with cognitive deficits in adults [15]. In 2020, they solve this problem through the development of Android apps that can be used by primary school students and based on cognitive theory to help students learn [16] and improve their cognitive skills, especially in children autistic [17].

In 2016, an evaluation model was built that helps to understand, analyze, and objectively evaluate the learning levels and student´s abilities with respect to the conceptual content and the domain of specific knowledge [18]. In the same year in the research of [19], he was interested in the difficulty of correctly solving the addition and subtraction of common fractions, by means of the algorithm or by unconventional processes. The results reveal a strong positive correlation between the cognitive variables and the operations, which means that the development of these positively catalyzes the significant learning of the mathematical operations referred to and vice versa.

Recently researchers have developed work related to education and using techniques of Artificial Intelligence (AI). In 2014, the difficulties faced by students when learning mathematics were resolved, focusing on evaluating the distance education system, designed to develop mathematical problem-solving skills, through AI and expert systems, demonstrating functionality to identify whether the level of the questions is appropriate for the student and if not, adapt to it [20]. AI has contributed research to teaching and learning processes, through the use of computerized educational software and materials, to determine the student's cognitive level and help identify weaknesses and work on them to achieve a higher level of learning [21].

Based on these investigations, the realization of this research proposal is oriented using the ANN's as a tool to measure the cognitive abilities of basic-level students.

3 Proposed Method

Currently, educational technology has been used as teaching material, this justifies the need for a proposal that integrates the strategic techniques of cognitivism in the curriculum mapping, relying on mobile technology, to reinforce the mathematics Teaching-Learning Process to basic level (Fig. 1).

A. Modeling and Simulation´s Construction

The Fig. 1 show, like neuroscience, will allow the development of didactic strategies in mathematics since it assumes the task of penetrating the structure, the human brain´s functioning, and the underlying biological´s mechanisms of cognition; in such a way that it affects the individual's behavior through sapient emotions produced by the biological neural network.

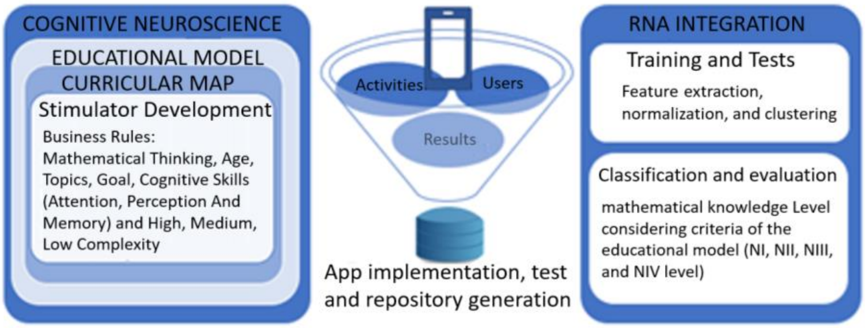


Fig. 1. Proposed method to measure the mathematical cognitive level.

Table 1. App modeling considering the axes of mathematical thinking in the Numbers topic.

General tools: Batteries and evaluation tests, graphics, images, audios, videos.
1. Represent digits with respect to the number of objects, relate to their written representation, identify between the letters, and plot in relation to the indicated direction. 2. Show collections to indicate the number of elements (greater or lesser), use movable objects to order (increasing or decreasing), remove or place as necessary; relate considering a numerical sequence and indicate its predecessor and successor. 3. Identify the equivalence relationship between the coins ($ 0.5 to $ 10), identify operators, and perform operations (addition, subtraction), reinforcing the theme of collections.

Mogollón supports this approach based on [22].

Integration of cognitive processes such as [9]:

- *Memory*: function in which the information stored in the brain is brought back to consciousness, that is, it stores and evokes assimilated content, thus allowing the execution of epistemic tasks (reasoning, understanding and problem solving).
- *Attention*: effort that individuals exert to establish themselves in a certain part of the experience such as: the ability to concentrate or stay focused on an activity, this is achieved using external means for sensory stimulation, achieving dopaminergic activation in a natural way through the motivation.
- *Perception*: mental process that transforms physical stimuli into information that passes to consciousness, forming visual environments that cause positive alterations, achieving brain plasticity.
- Integrate the educational model and knowledge receptor techniques in the stimulus generator in different topics like:

Table 2. App modeling considering the axes of mathematical thinking.

1.	Order various activities in periods (holidays, days, weeks, months, and seasons of the year).
2.	Compare lengths. Identify the order, mass quantity of objects and capacity directly or with non-conventional units.

Table 3. App modeling considering the axes of mathematical thinking.

1.	Reinforce the concepts of right, left, center, in the middle, up, down, small, medium, large, near and far.
2.	Reproduce figures and objects based on the surplus of an existing one (heart, moon, star, cross out, oval, circle, square, rectangle, and triangle). Before his acquaintance, draw and build the same things, adding colors.
3.	Reference and identify objects and classify them by some scale of measurement.

a) Table 1 show modeling of numbers axis with numbers topic (1-20), the objective is communicate, write, compare, and classify collections and identify coins.

b) Table 2 show modeling of Shape, space and measure axis with Magnitudes and measurements topic, the objective is to order the events of the day. Compare capacity direct or with unconventional drives.

c) Table 3 show modeling of Shape, space and measure axis with geometric figures topic, the objective is to establish spatial relationships and reference points. Develop geometric perception through the construction and figure´s reproduction. Compare lengths.

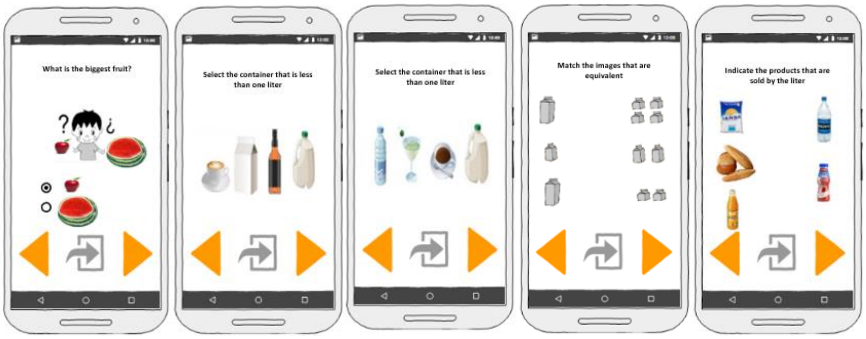
The Model proposed by the SEP contains the pedagogical approach, the reorganization of the general school system and the public policies, where the directions to follow are set out. Likewise, the curriculum foresees the benchmarks achieved in the domain of the skills expected in students, in such a way that they are perfected in their collegiate career and, through study plans and programs, contribute to the development of students [3]:

a) Guide the curriculum considering the infant's profile (digital skills and mathematical thinking)

b) Carry out the curriculum mapping in three components: key learning, curricular autonomy, personal and social development. Employ the principles and processes of the hard sciences in its main axes of the Educational Model: a) the notions of number and b) Form, space, and measure.

c) The smartphone is considered a stimulator, it will be used to motivate the learner, achieving neuronal plasticity, preparing the mind and body of infants to think critically, reflectively, autonomously; managing to retain as much information as possible.

d) Measure the knowledge acquired: here the actors intervene (the SEP, public and private schools, psychologists, neuroscientists, pedagogues, professors, parents, students, managers and businessmen; they will coexist harmoniously in the teaching process that contemplates the structure and the functioning of the



a) b) c) d) e)

Fig. 2. Measurements by a) weight, b) higher capacities, c) lower capacities. Select objects by d) equivalences e) measures and f) capacity.

mind), they contributed their knowledge and together with the different standardized assessment instruments [23, 24], it was possible to glimpse the need to estimate the percentage of success, thus:

$$x\% = ac - er \,/\, ac - om, \qquad (1)$$

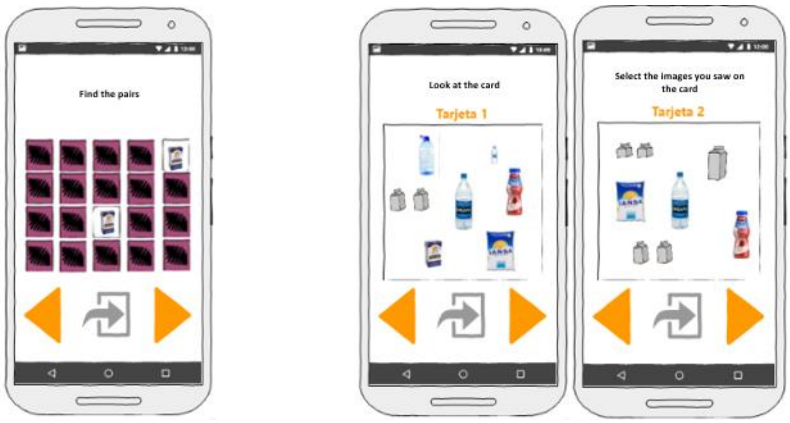
where *x%* represent the percentage obtained from the evaluated activity, *ac* the correct answers, and corresponds to the number of correct answers in each activity, *er* the number of incorrect answers and *om* the number of omitted answers. To complete the evaluation of (1), it is necessary to consider the response time in some activities: 1) of the thematic axis and 2) the level of complexity. Finally, it will be estimated with a success percentage: greater than 80 (high), greater than 60 and less than 80 and (medium) and less than 60 (low).

1) Design and construction of the stimulator and database

Each thematic axis [3] will be focused on the 3 skills, and is based on different activities that need to be evaluated and motivated to the maximum. Then, it is necessary: a) to identify the axis, b) to use the recommended instruments, achieving with them to motivate the infant in the subject to be discussed; relevant point to achieve brain plasticity, c) determine the maximum number of successful continuous reagents, to increase the degree of complexity and thus know the different prototypes that will be presented in each stage, d) to evaluate, in some cases time is decisive , e) equation (1) measures the teaching-learning process based on the ability to be reinforced manually. In this phase of the project and for an application example, the modeling of the content (magnitudes and measurements) corresponding to the axis is presented: shape, space, and measure (Fig. 2).

The objective is to assign an activity that allows making comparisons of capacity or quantity of mass that an object has, using non-conventional units of measure (Fig. 2); In order to reinforce cognitive skills, the following was considered:

- *Perception*: this is measured using evaluation batteries to ask the questions: which fruit is the heaviest? Which container has the least? and Which container that fits the least? (Fig. 2a, b and c; respectively).



(a) (b)

Fig. 3. (a) Find pairs, (b) Sample and mixed images.

- *Attention*: a series of activities are carried out, such as: relating equivalent images (Fig. 2d), selecting the objects considering their size or capacity (Fig. 2e).
- *Memory*: rely on games such as: the Memorama (Fig. 3a) or deck, the latter simulates cards where different images will be shown in a period of n seconds (assigned according to the complexity of the activity), after the time, the presents another card with new images and some of the previous ones; the infant will choose only those that were shown at the beginning (Fig. 3b) and according to the successes obtained the reinforcement will be evaluated.

The modeling of the Database (DB), see Fig. 4, contemplates the following entities: the axis contains various values: number sense, geometric figures, among others; Each of these has several associated topics: communicating and writing the first 10 numbers, comparing, matching and classifying collections based on the elements, solving subtraction and addition problems; each of these is associated with an activity, ability (attention, perception and memory) and complexity (low, medium and high).

Each registered user will have a result and details of the activity carried out, obtaining the variables: hits, errors, time, level of complexity obtained during execution. With the above, the DB is generated for the integration of the project.

Based on the analysis and design described, the application "RemaAP" available in the "Play Store" is developed and when using it, the support of parents or pedagogue is necessary for the download, installation and registration of the infant; for which, the name, sex and age are requested (Fig. 5a, b and c; respectively).

At the end of this process (Fig. 5d), it will be possible to identify and keep track of all users. To start using the app, a menu is displayed (Fig. 5e), where you will select the action to be carried out according to the ability to be reinforced (perception, attention, memory) and this is presented according to the age of the infant.

In addition, it was considered a motivating video to review the numbers in case there are still difficulties on the subject.

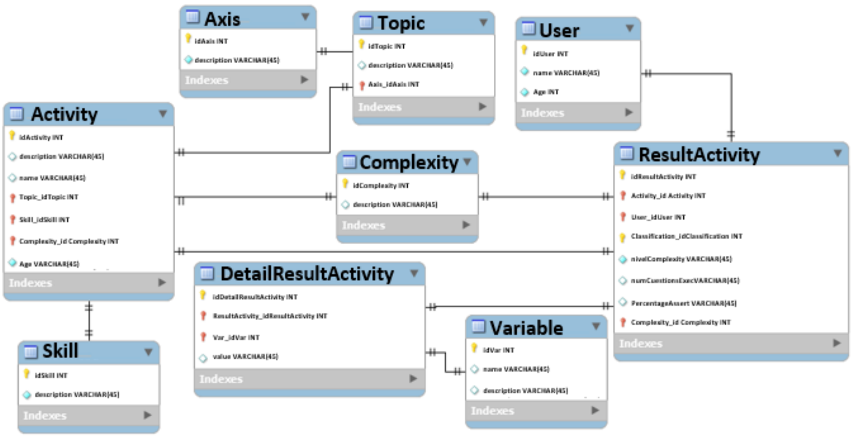


Fig. 4. Application E-R model.

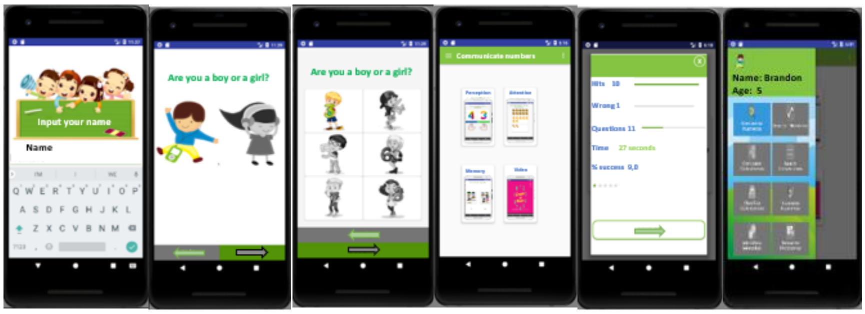


Fig. 5. Application interface (a) User registration, (b) Sex, (c) Age, (d) Complete registration, (e) Activities menu based on the 3 cognitive skills, (f) Final report, (g) Pending modules.

Once the interaction in each activity is finished, a summary is generated (Fig. 5f) of the errors, correct answers, percentage of success, among others. These are registered in the database to be analyzed.

B. Testing and Repository Generation

The tests were carried out on students of the Frida Kahlo Kindergarten with a current enrollment of 63 students in the 2018-2019 school year: 17 are 1st, 24 are 2nd and 22 are 3rd. Initially, 3 tests were carried out: two manuals (beginning and after 3 weeks) delivering 3 activities on paper and another with the app for the 3 grades; In each activity the three cognitive abilities (attention, perception and memory) are evaluated.

The tests with the application were carried out by requesting the tutors so that the students would carry out the tests using phones with the Android operating system in which the application was downloaded, for children from 3 to 6 to manipulate it, they generated 290 records in the BD.

In order for the ANN to obtain accurate results, it is necessary to perform preprocessing (debugging and normalization of the DB) to generate a repository in .csv format, for this it was necessary to carry out an analysis of the variables and records of the DB. In addition, the most useful characteristic features were recovered: age, correct answers, errors, question´s number, success percentage, number and activity duration, executions number per user, and the mastery of the knowledge level.

The classifier attribute (proficiency level) contains the grades proposed in the SEP curriculum, the value of this criterion is obtained in the app through (1).

C. ANN for Classification by Knowledge Level

For ANN, 9 attributes were considered, one of them corresponds to the class that determines the level of knowledge (NI, NII, NIII, NIV) that the child has; and it is interpreted as mastery achieved: poor (<= 5), basic (> 5 and <= 7), satisfactory (> 7 and <= 9) and outstanding (> 9); respectively).

Once the repository is standardized, training is performed with different classifying methods (Multilayer Perceptron (MLP), Nearest Neighbor (LinearNNSearch), Radial Base Functions (RBF), Support Vector Machines SMO and Neural Network with Dendritic Processing (NNMD)) to verify that the selected attributes are adequate, as well as identify which one presents better performance and is implemented in the app.

The criteria used for each classifying method are:

- *MLP*: the backpropagation algorithm was used, the body is evaluated with a learning rate of 0.3, and applied impulse of 0.2, 500 epochs to train, a validation threshold of 20, a total of 9 hidden layers.

- *LinearNNSearch*: A Euclidean distance search algorithm and K = 1 were used for this classifier group.

- *RBF*: hybrid learning algorithm, 2 clusters (groups of clusters), with a Gaussian activation function.

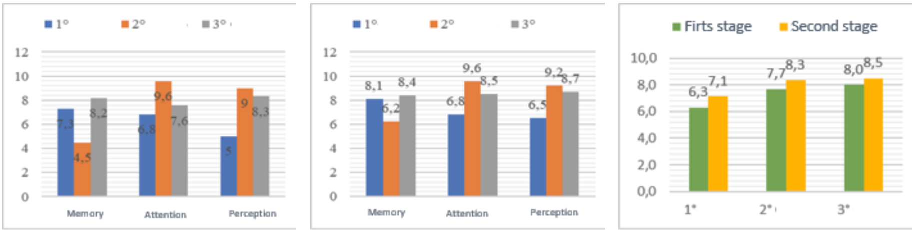
- *SMO*: complexity=1.0, tolerance=0.001, Epsilon=1.0E-12, polynomial kernel=1.

- *NNMD*: proposed by [25], the data percentages for testing were: 100%, 80%, 70%, 50%, generating 94, 35, 46 and 57 hyperboxes respectively.

4 Results

The present investigation is evaluated to demonstrate its functionality. In phase one, manual tests were carried out and of the total enrollment, only 86% of the students completed them, and it was observed that 1st year surpassed 2nd and 3rd in the first skill, 2nd year students obtained the highest score in attention and the success rate of 3rd in care was 8.3 (Fig. 6). In the second manual test (Fig. 6b), it is observed that in the children of the 3 degrees the attention does not change considerably.

According to the observations made by the teachers, the 3rd graders find it difficult to follow the instructions, the 1st graders completed the exercises without problems thanks to the teachers' support and the 2nd graders were more accessible to work.



(a) (b) (c)

Fig. 6. Phase 1 Results: (a) First evaluation, (b) Second evaluation, (c) when using the app.

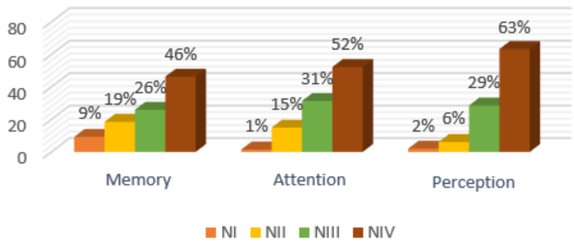


Fig. 7. Results by knowledge level and cognitive ability.

Table 2. Results of the training process with different classifier methods.

Classifier methods	Arithmetic mean	% correct classification			
		100%	**80%**	**70%**	**50%**
NNMD	99.75%	99%	100%	100%	100%
MLP	99.25%	100%	100%	99%	98%
SMO	96.25%	98%	98%	95%	94%
LinearNNSearch	96.75%	100%	98%	95%	94%
RBF	99.5%	100%	100%	100%	98%

The second phase only 68% downloaded and used the app, and compared to manual tests, its performance improved; increasing on average of the 3 skills the 0.8%, 0.7% and 1.8% in 1st, 2nd and 3rd; respectively (Fig. 6c).

So far, learning has been measured with (1), but the objective of this research is to measure the level and reinforce mathematical cognitive learning using Artificial Intelligence techniques. Therefore, the repository was evaluated with different classifying methods, using 100%, 80%, 70%, 50% of the samples for training and the remaining percentage for testing (Table 2.).

As can be seen in Table 2, the repository is well normalized, since the classification percentage of the selected methods is high, this will guarantee good precision in its implementation in the app.

Also, the level of knowledge was measured by cognitive ability, considering 290 records labeled by skill and mastery level and it was demonstrated how they were surpassing the skill obtaining until reaching an outstanding learning level (Fig. 7).

5 Conclusions and Future Perspectives

The education and comprehensive training of boys and girls will always be a transcendent factor in the world. The New Mexican School will only be a reality with the commitment and participation of all [3]. In the current context of Mexico, it is urgent to develop and apply strategies that promote the importance of complex cognitive development in students, from the basic level, so that the growth of our country is for the benefit of the whole society, and face the effects on education in Mexico by the COVID-19 pandemic.

The main contribution of this research was to achieve the interaction of Neuroscience, education, and current technology, to reinforce the basic knowledge of exact sciences, cognitive abilities (attention, perception, and memory), and infant´s skills; with this measure the mastery level of the study area through a NNMD. This work impacts public and private institutions in Mexico because the topics are focused on the current educational model proposed by the SEP.

We present a mathematical neurocognitive app that measures the level of knowledge acquired based on Artificial Intelligence techniques (DMNN). For future research, this will become a Brain-Computer Interface and by means of portable electroencephalography (EMOTIV EPOC of 14 channels), brain waves will be measured, in addition neurofeedback techniques will be implemented to stimulate the brain and with brain mapping to demonstrate that the child will reinforce learned, retaining it long term.

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