ENSCER
A neurocientific approach to teaching

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INTRODUCTION

Modern neuroscience is providing a new understanding of cognition and disclosing the properties of the neural circuits supporting language production and understanding, arithmetic calculations, etc. Brain imaging by non-invasive techniques such as fMRI, PET Scan, Magneto and Eletroencephalograpy are being used to investigate human reasoning in normal and pathological conditions. This new knowledge is changing the traditional view of the occidental culture about many cognitive functions and how children inherit and improve them by learning.

Arithmetic is now assumed to be a survival tool shaped by evolution allowing animals to quantify objects and events (Ashcraft, 1991; Butterworth, 1999; Dehaene, 1991, 1997; Fayol, 1990; Siegler, 1996; Wynn, 1998; 2000) in order to search for places where *more food is available and less enemies threaten life*. Neural circuits for quantification and calculation are known to be inherit by the newborn human (e.g., Butterworth, 1999; Wynn, 1998; 2000). Human language capability may know be understood as supported by some special types of neurons found also in other animals (e.g., Hustler and Gazzaniga, 1997; Perani et al, 1999; Rizzolati and Arbib, 1998; Rocha et al, 2001) and dependent on complex association of cells distributed almost all over the brain (Cabeza and Nyberg 2000; Cohen Let al, 2000; Federmeier et al, 2000; Holcomb et al, 1999; Kuperberg et al, 2000; Perani et al, 1999; Price et al, 1999; Raij, 1999; Tarkiainen et al, 1999).

Human bipedal posture was the best adaptation for the *Homo Sapiens*' survival when his ancestors left the trees for the savana. But this solution created new problems such the brain termodynamic adaptation to increased head temperatures due this upright position that changed the cerebral circulatory systme; the hip diameter reduction to provide faster running but that increased the difficulty for baby delivery at birth, etc. (e.g. Aiello, 1997; Orsntein, 1991). Birth was anticipated to facilitate the delivery; but this produced an immature brain. Cerebral immaturity however may enhance human learning capability and adaptation if the baby may receive better care from social tied parents and relatives. Not all knew problems were, however, very successfully solved by evolution, and many of them remain as important etiologic factors for brain damage during pregnancy, delivery and first infancy (e.g.; Baron-Cohen, 1995; Baron, Fennell and Voeller, 1995; Batchellor and Dean, 1996; Duane, 1991; DeFries and Gillis, 1995; Kuperberg et al, 2000; Lubs et al, 1995; Spreen, Risser, Edgell, 1955). Teaching children with special needs or learning disabilities demand an adequate knowledge of their brain functioning (Plomin, 1993)

The electroencephalogram (EEG) was the first non-invasive technique to be employed for the analysis of the human cognitive capabilities and continue to be a low cost/high benefit tool compared to PET Scan and fMRI use for the same purpose (e.g., Cabeza and Nyberg, 1997; Just et al, 1996; Hynd et al., 1991) when new brain imaging techniques (e.g., Dehane et al, 1999; Rocha et al, 2000; 2001; Stanescu-Cosson, et al, 2000) are deployed in the EEG analysis.

Averaged Event Related Activity (ERA for short) is a powerful technique for brain activity analysis. This type of EEG analysis had been proved as valuable a tool in the attempt to understand the brain as a distributed processing system and to study the cognitive functions supported by this type of system (e.g. , Deary and Caryl. 1997; King, Ganis and Kutas, 1998; Rocha, 1990). Using this technique, Rocha and associates (Rocha 1999; Rocha et al, 2000; 2001) developed a technique (Cognitive Brain Mapping – **CBM**) for brain mapping of cognitive functions, according to the following steps:

(a) ERA is computed in the case of different events associated to defined computer games;
(b) Linear correlation coefficients ($\mathbf{r}_{ij}$) are calculated for ERAs computed for the different site recordings ***i,j*** of the 10/20 system;
(c) Entropy indices of the brain activity are calculated using these $\mathbf{r}_{ij}$s to measure the possibility that neurons located in these sites exchange information, and
(d) The brain mapping supported by these indices may picture the distributed character of the cognitive cerebral processing.

Rocha and associates (Foz, F.B. et al, 2001; Leite, 2000; Leit et al, 2001; Machado et al, (2000); Ramazzini, 2000; Rocha, 1999; Rocha e Rocha; 2001; Rocha et al; 2000, 2001) have being using this technology to study different cognitive functions in normal and disabled children and adults, with the purpose to better understand language processing, arithmetic calculations and visual reasoning. The results of these investigations are being used to guide the production of **informatized educational activities (**IEA**)** for teaching children at the kindergarten and elementary school, and to develop new strategies to help children to do a better school learning. These are the main goals of the project **ENSCER®**.

According to this neurocientific view of teaching, learning is a cerebral process guide by both a phylogenetic inheritance of basic neural circuits for complex cognitive functions such as language, arithmetic, etc., and by external information provided both by experiencing and being taught, that modify these inherited circuits to adapt man to the conditions imposed by the environment.

ORGANING THE EDUCATIONAL ACTIVITIES

The teaching in the kindergarten or elementary school is proposed to be organized as an integrated sets of activities grouped according to the main subjects to be learned about language, mathematics, history, geography, etc. The program of each of these disciplines comprises, therefore, a collection of **projects** (Fig. 1), each project aimed to help the child to acquire competence in a series of subjects or **topics** of knowledge. For example, the project **DIMENSIONS** in **Mathematics** is designed not only to guide the learning of concepts such as height, width and length, how to measure them and how to do calculations with these measures, but also to teach the child to speak, read and write about these subjects. In this way the project integrate activities between two different disciplines: **Language** and **Mathematics**. **ENSCER®** developed 43 Projects of Educational Actitivities (**PEA**) about 218 different **topics** covering the entire curricula of the kindergarten and elementary school.

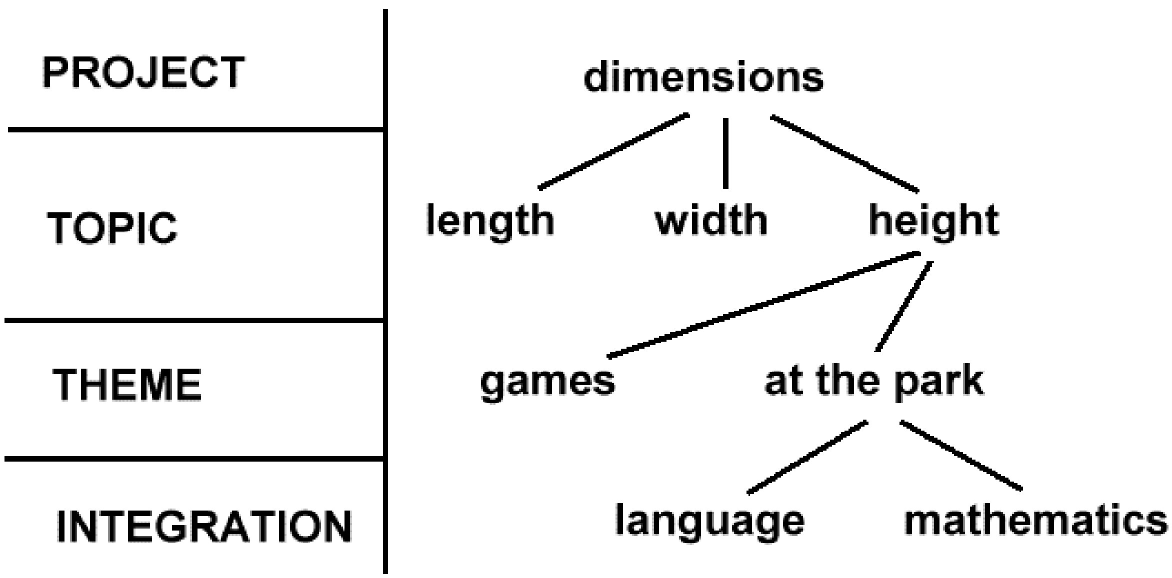

Fig. 1 – A Project of Educational Activities (PEA)

The teacher must introduce some initial knowledge about the topic to be developed, taking into consideration both inherited capabilities and the academic curriculum, to help the child to explore the subject in practical conditions of daily life. For instance, to introduce concepts about the dimension **Height** the teacher may use stories about going to a park, where fee entrance may be determined child's height (Fig. 2). Also, the child must be stimulated to experience measuring the space using his/her own body (Fig. 3), in order to discover important space properties.

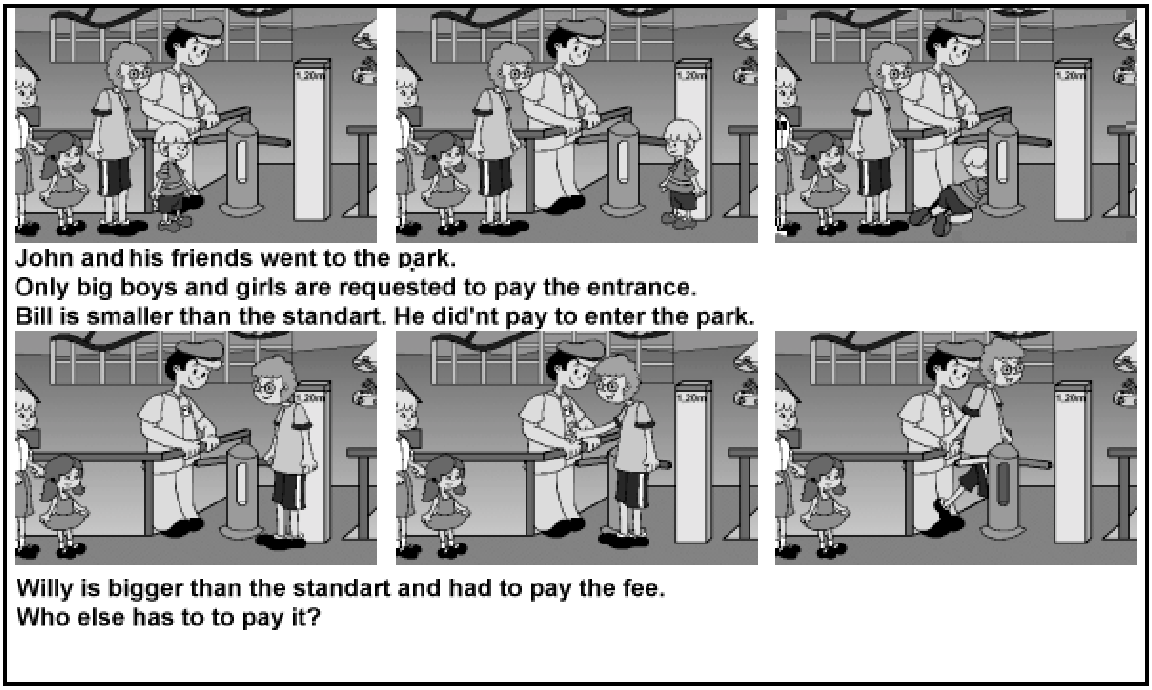

Fig. 2 – Project: Space Dimension
Topic: Height
Theme: At the park

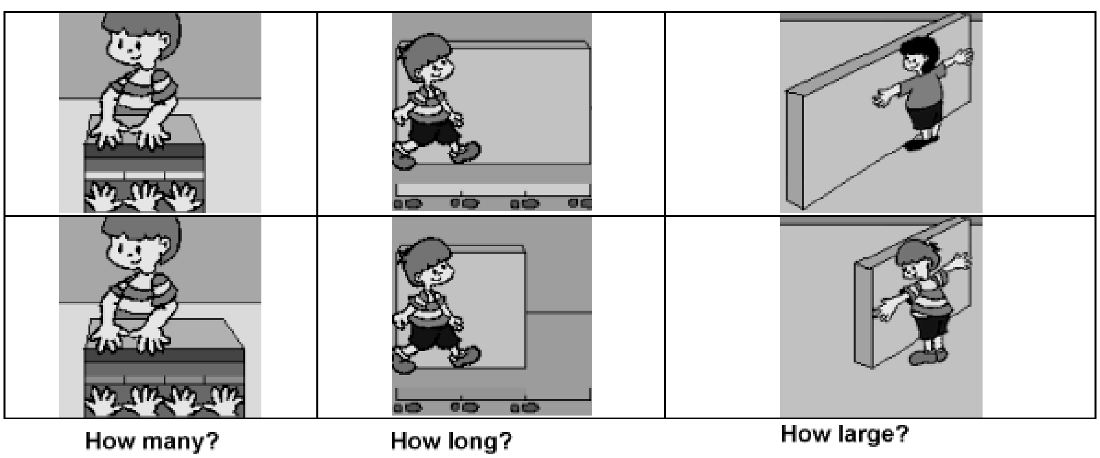

Fig. 3 – Project: Space Dimension
Topic: Length
Theme: Body measurements

Multimedia is used by **ESNCER®** to make learning of initial knowledge ease and more meaningful, since young humans are normally more proficient in visual reasoning than in processing the language that they are learning yet (e.g., Spreen et al, 1995). Initial knowledge is in general provided by stories about the themes of interest. **ENSCER®** uses 408 different themes to make learning pleasant. More than 130 stories introduces these themes.

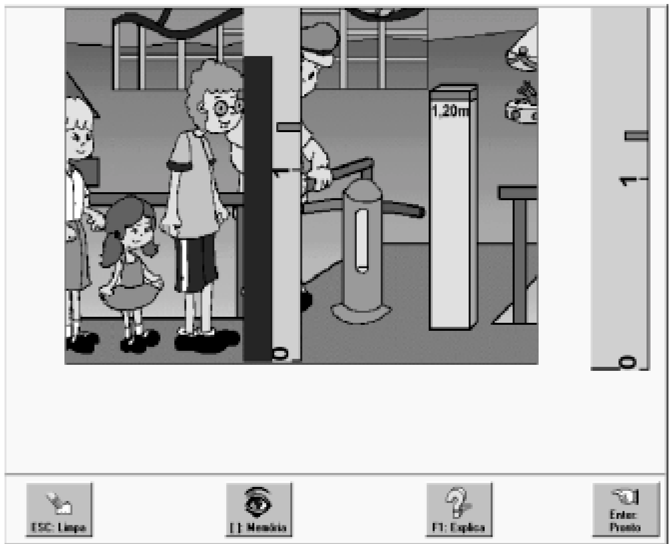

Fig. 4 – Project: Space Dimension
Topic: Height
Theme: At the park
Purpose: Learn about measurements

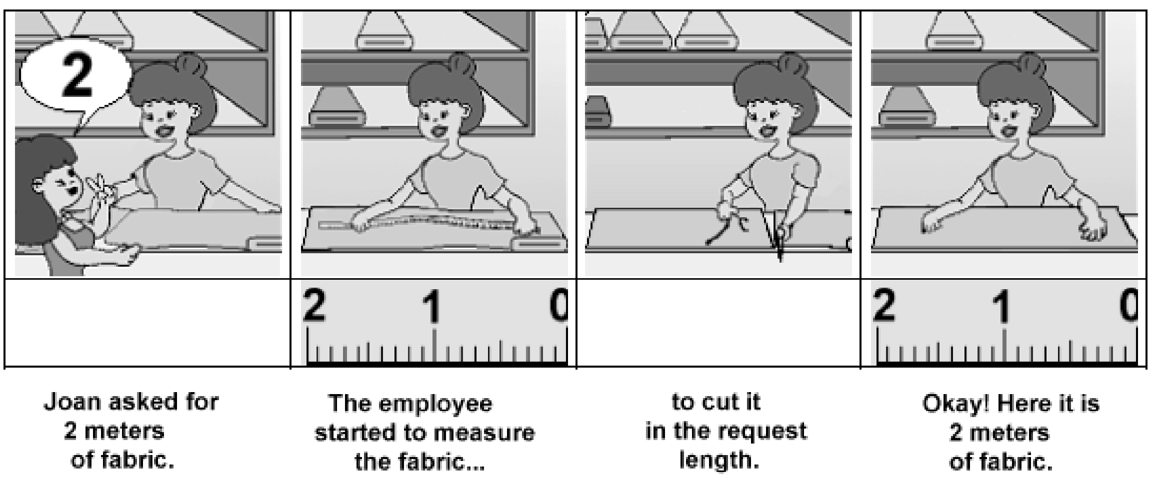

Fig. 5 – Project: Space Dimension
Topic: Height
Theme: At the park
Purpose: Learn speak about measures

Informatized activities are planned to propose different problems about the same subject: for instance how to measure and how to speak about this activity (Figs. 4 and 5). **ENSCER®** provides 25 different types of Informatized Educational Activities (**IEA**) and almost 50 different ways of using it to teach any subject of the kindergarten and elementary school curricula. A set of copyrighted characters (Fig. 6) were created in order to make **IEA**s more friendly to the children.

Fig. 6 – The characters: Juca, Laura and their parents

Sets of correlated **IEA**s are organized into **scripts** (Fig. 7) to explore a given subject to be learnt. The structure of the scripts provided by **ENSCER®** is optimized to provide a quick understanding and to maximize data association. Also, the complexity of the learning proposed by these scripts is organized according to the increasing complexity of the cognitive function of the developing children. Ease scripts are proposed at the first steps to be followed by others dealing with harder matters. More than 1500 scripts organize around 5200 **IEA**s for kindergarten and elementary school teaching.

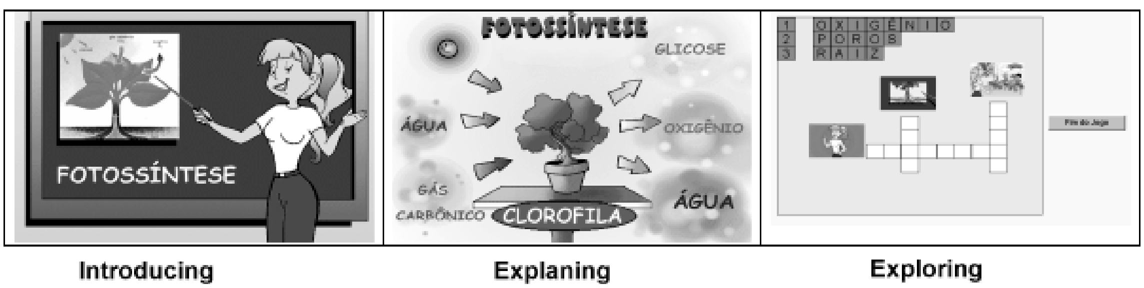

Fig. 7 – Project: Plants
Topic: Photosynthesis
Discipline: Sciences
Script: Chemical components

A set of services are also provided in Internet, at the address www.enscer.com.br, to support both the teacher and parents in dealing with their children learning at the school.

EXPLORING COGNITIVE FUNCTIONS

Special scripts were used to investigate the brain activity associated to the cognitive functions to be developed during the school age and to study brain functioning in normal and disabled people (Foz, F.B. et al, 2001; Leite, 2000; Machado et al, 2000 ; Ramazzini, 2000; Rocha, 1999; Rocha e Rocha; 2001; Rocha et al;

2000, 2001). The methods used for such a purpose and some of the results obtained form mental rotations and charade understanding with a group of mental deficient children are described in this section.

Each subject played a set of games while his/her EEG was registered (Fig. 8) with 20 electrodes placed according to the 10/20 system; impedance smaller than 10 Kohm ; low band passing filter 50Hz; sampling rate of 256 Hz and 10 bits resolution. Two networked personal computer were used: one for the EEG recording and the other for game playing. Timing of game events (E_1, E_2, ...) were wrote as corresponding marks (m_1, m_2, ...) in the file of the recorded EEG. The EEG was visually inspected for artifacts before its processing, and the events associated to a bad EEG were discarded. 2 second samples were selected in the recorded EEG before (r_1) and/or after (r_2) each selected mark for amplitude averaging referred to each EEG recording site or derivation $\mathbf{d_i}$, in order to generate the Game Event Related Activity (GERA) file for each game event and each volunteer. The analysis of correlation between the different $\mathbf{d_i}$s of each GERA allowed the computation of the associated mapping GERM according to eqs. 1-5 . This mapping is obtained by normalizing the entropy values calculated for each $\mathbf{d_i}$ and encoding high normalized entropy values in red and low normalized entropy values in black.

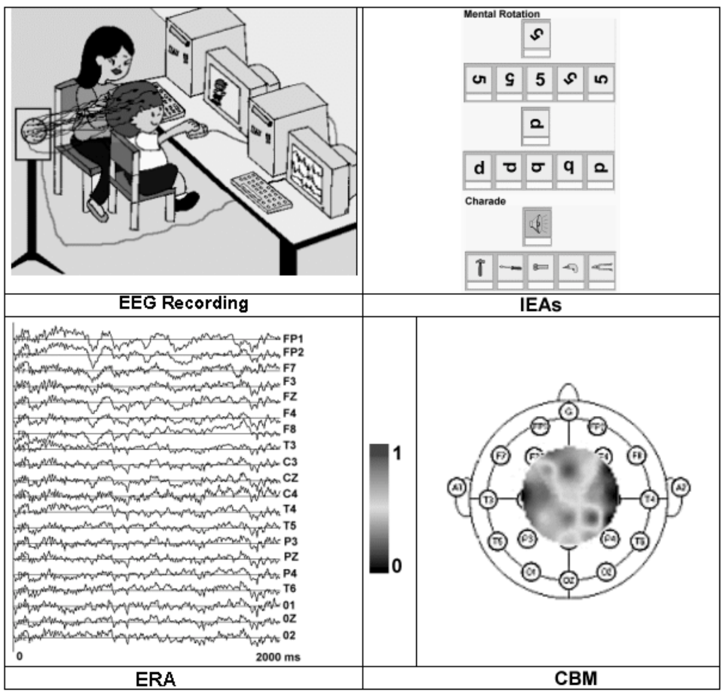

Fig. 8 – The experimental design

The rationale of this analysis is to obtain the $\mathbf{ERA_{i,j,k}}$ for each event **i** of game **j** and for each volunteer **k**, and to calculate the linear correlation coefficients $\mathbf{r_{i,j}}$ for the amplitude averaged activity at each recording site $\mathbf{d_i}$ referred to the averaged activity for each other 19 electrodes $\mathbf{d_j}$ for each $\mathbf{ERA_{i,j,k}}$. This $\mathbf{r_{i,j}}$ is considered a measure of the possibility ρ ($\mathbf{a_i,a_j}$) that neurons $\mathbf{a_i}$ at $\mathbf{d_i}$ are exchanging information with those neurons $\mathbf{a_j}$ at $\mathbf{d_j}$, therefore, the amount of communication resources $\mathbf{h(c_i)}$ allocated for this information exchange, is calculated according to (Rocha et al, 2000):

(a) the relational entropy $\mathbf{h(r_{i,j})}$ between $\mathbf{a_i}$ and $\mathbf{a_j}$ is calculated as:

$$h(r_{i,j}) = - \rho(a_i,a_j) \log_2 \rho(a_i,a_j) + \sim\rho(a_i,a_j) \log_2 \sim\rho(a_i,a_j) \quad (1)$$

$$\sim\rho(a_i,a_j) = 1 - \rho(a_i,a_j) \quad (2)$$

(b) the mean relational entropy $\mathbf{h_m(r_i)}$ of $\mathbf{a_i}$ is processed as

$$h_m(r_i) = -\rho_m(a_i)\log_2 \rho_m(a_i) - \sim\rho_m(a_i)\log_2 \sim\rho_m(a_i) \qquad (3)$$

$$\rho_m(a_i) = 1/n \sum_{j=1}^{n} \rho(a_i,a_j) \quad \text{and} \quad \sim\rho_m(a_i) = 1/n \sum_{j=1}^{n} \sim\rho(a_i,a_j) \qquad (4)$$

that is, $\mathbf{h_m(r_i)}$ is a function of the mean possibility $\rho_m(\mathbf{a_i})$ of $\mathbf{a_i}$ to communicate with the other agents $\mathbf{a_j}$**,** and

(c) the resources $\mathbf{h(c_i)}$ actually allocated by $\mathbf{a_i}$ to communicate with the other agents $\mathbf{a_j}$ is finally obtained as

$$h(c_i) = \sum_{j=1}^{n} h_m(\tilde{r_j}) - h(r_{j,j}) \qquad (5)$$

The game event related mapping $\mathbf{CBM_{i;j,k}}$ for the game player **k,** is the normalized plot of these calculated $\mathbf{h(c_{i,j,k})}$ for the event **j** of the game **i**. A grand average $\mathbf{CBM_{i,j}}$ for each event **i** of the game **j** is used to process $\mathbf{h(c_{i,j})}$ to generate the corresponding $\mathbf{CBM_{i;j}}$. The five highest entropy values for each $\mathbf{CBM_{i;j}}$ were used to a multiple correlation analysis between brain activity, school progress and performance in playing the games.

The games were:

a) Mental rotation (**Mr**): the correct solution is one among a set of pictures of the same object (boot in Fig.1) in different spatial orientations. The figure defining the correct response showed upper frame in the screen is randomly selected from the experimental set of figures, later displayed at bottom frames. The events of interest in this game for the EEG analysis are: the display of the visual information and the visual signaling of right and wrong decisions.

b) Charade solving (**Cs**): a three to four phrase description of a fruit or animal (e.g.; "My juice is delicious, my color is my name; ...") is provided 500ms before different pictures are displayed for decision making. Mean sound track duration for all charades is around 4 seconds.The events of interest in this game are the onset and the end of verbal sound listening, display of visual information and the signaling of right or wrong decisions

Performance in playing the games was assessed by computing errors and measuring the reaction time, that is, the time necessary for game decision making.

The **CBM**s were obtained for 35 mental deficient students enrolled in 2 kindergarten (**P1** and **P2**) and 2 elementary (**E1** and **E2**) classes. These **CBM**s (Fig. 9) were clearly different for:

1) Distinct IEAs: an important left hemisphere enrollment was observed in the case of charade solving, whereas mental rotation required more from frontal areas.

2) Different tasks of the same IEA: its seems that number rotation recruited neurons from right and posterior areas, whereas letters involved more left anterior regions.

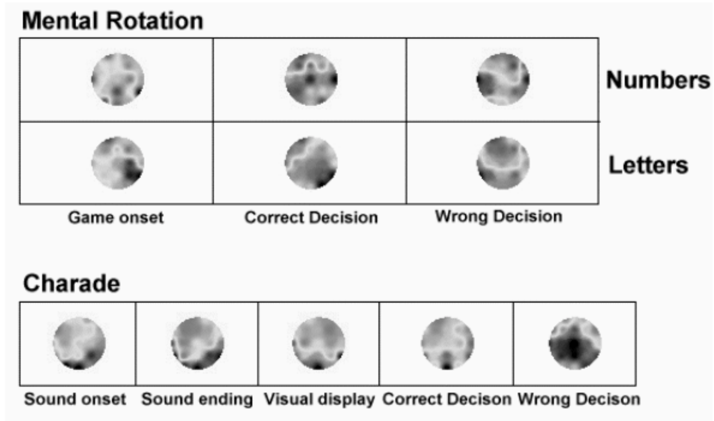

Fig. 9 – CBMs for charade unde rstanding and mental rotation

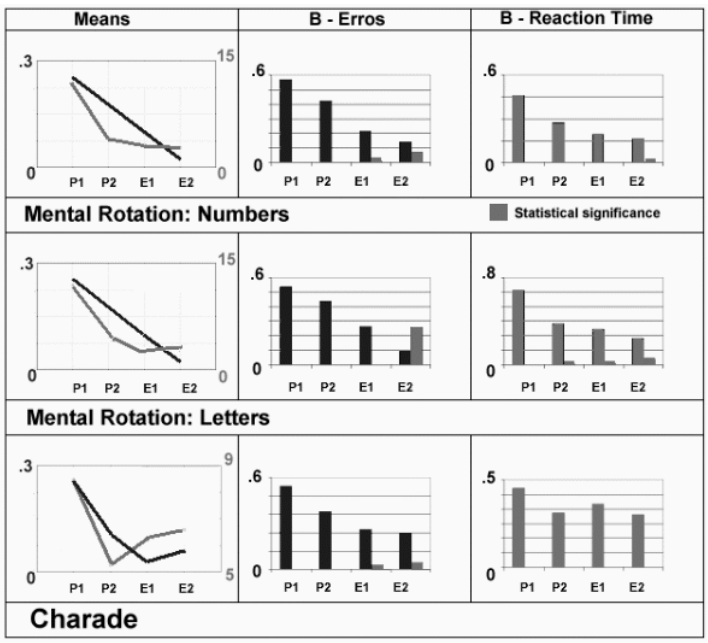

Fig. 10 – Performance and school progress

The performance in solving the **IEA**s accompanied the school progress (Fig. 10):

1) **Error rates decreased from P1 to E2:** error rate was a linear function of school progress, and

2) **Reaction time decreased from P1 to E2:** the required for game solving linearly decreased as the student progressed in the school.

The angular coefficients (**B**) of these functions systematically decreased from the first year in the kindergarten (P1) to the second year in the elementary school (E2). The statistical significance of these results was $p < .01$, except for Errors x P2 in letter rotation.

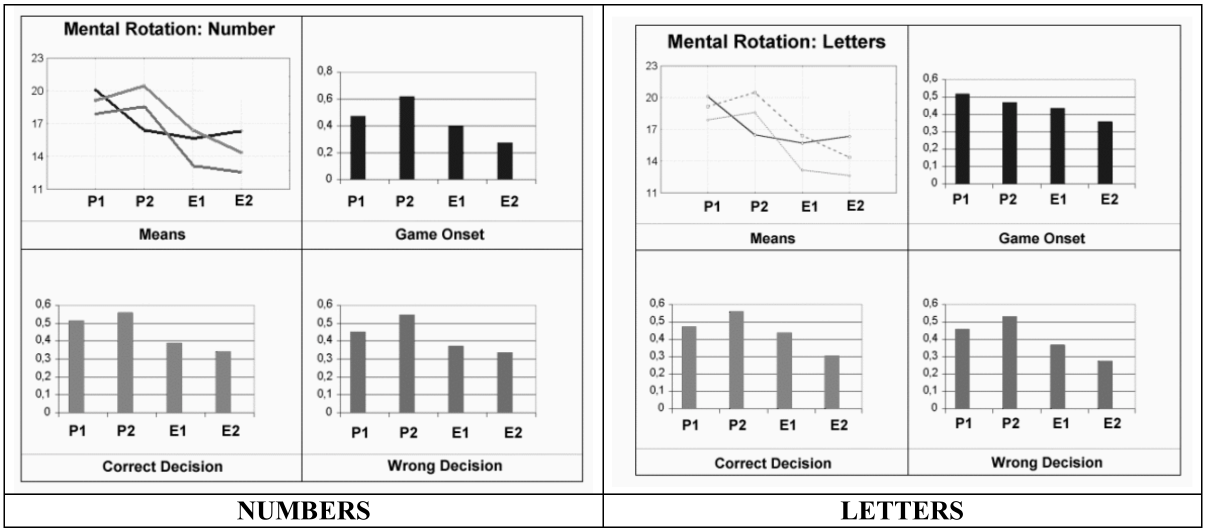

Fig. 11 – Brain entropy and school progress: Mental rotation

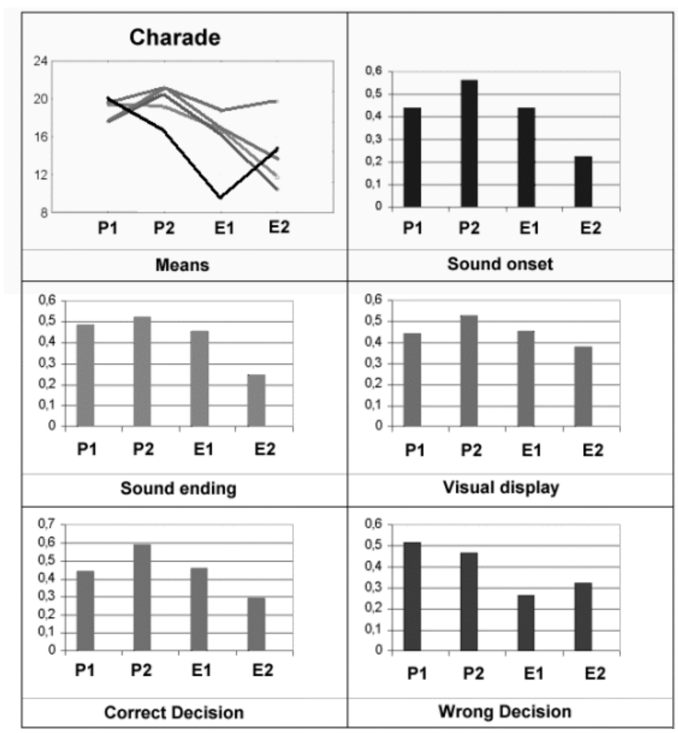

Fig. 12 – Brain entropy and school progress: Charades

School progress was accompanied by a reduction of the cerebral entropy associated to the different events of the number mental rotation activity (Fig 11). In the case of number rotation, the angular coefficients (**B**) of these functions systematically decreased from the first year in the kindergarten (P1) to the second year in the elementary school (E2), except for students attending P2. In the case of letter rotation. The angular coefficients (**B**) of these functions systematically decreased from the first year in the kindergarten (P1) to the second year in the elementary school (E2), except for students attending P2 and the decision making events. The statistical significance of these results was $p < .001$.

A similar reduction of the cerebral entropy with the school progress was observed also in the case of charade solving (Fig. 12). The angular coefficients (**B**) of these functions systematically decreased according to the sequence P2, P1, E1 and E2. The statistical significance of these results was $p < .001$.

It is possible to conclude from the above results that:

- error and time in solving the games decreased as students progresses from K1 to E2, and
- brain entropy decreases for all game events from K1 to E2.

and that mental deficient students

- improve their **IEA**s performance as they academic level increases, in the same way normal students do. Also, this
- performance improvement is associated to a reduction in the cerebral effort to solve the **IEA**s.

These results show that the **CBM**s not only disclose the brain areas involved with the solution of a cognitive task, but also that this activity and the task solution change with the age and school progress. Thus the brain maturation promoted by aging and learning (Chugani, 1999; MacKintosh, 1998; Thompson et al, 2000) is responsible for the school progress, even in the case of disabled children.

CONCLUSION

A new approach to teaching at the kindergarten and elementary school, supported by the knowledge about the neurophysiology of language, arithmetic and other cognitive functions, is used by **ENSCER®**. This approach has being successful in promoting learning by cerebral and sensory disabled children.

Mental impairment may or may not be due to structural cerebral lesion (Leite et al, 2001), but in any case the cerebral functions of most of this disabled children are not different from the so called normal people, since neural circuits for language, arithmetic and visual reasoning were shaped by evolution and phylogenetic encoded. Such a proposition is supported by some of the results discussed here, and also obtained by Rocha and collaborators (Foz, F.B. et al, 2001; Leite, 2000; Leit et al, 2001; Machado et al, (2000); Ramazzini, 2000; Rocha, 1999; Rocha e Rocha; 2001; Rocha et al; 2000, 2001) or described by other authors in the literature (Ashcraft, 1991; Butterworth, 1999; Dehaene, 1991, 1997; Fayol, 1990; Harley, 1995; Siegler, 1996; Wynn, 1998; 2000).

The new EEG brain imaging technology developed by the project **ENSCER®** allows the investigation of the cognitive functions to be developed in the school, to be performed in very natural condition, while the children are solving the same **IAE**s they deal with in the classroom. This pave the way for very interesting studies about the organization and maturation of the neural circuits supporting most of the cognitive functions used by children to learn at the school. It is also possible to follow this learning through out the changes of the brain activity associated to the school progress and biological growth. Such kind of research will certainly change the way our culture sees the school, teachers and students. **ENSCER®** provides a series of Internet services at the address www.encer.com.br, to promote these ideas.

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