NEUROSCIENCE IN MATHEMATICS: AN ELECTROENCEPHALOGRAPHIC STUDY ON FRACTION LEARNING *

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Student achievement in mathematics and science has been given prominent attention as the nation's quest to achieve Vision 2020 and ability to face the challenges of globalisation are largely dependent on it. However, numerous studies have shown that achievement in mathematics has been less than satisfactory in both primary and secondary school levels and that many Malaysian pupils display phobia and anxiety in mathematics. Five hundred and twelve Primary 5 pupils from four randomly selected schools in Kuching city were administered the Fraction Diagnostic Test. The top 10% in achievement ranking were categorized as high fraction achievers while the bottom 10% as the low fraction achievers. 22 high achievers and 22 low achievers, randomly sampled from their respective groups, underwent an electroencephalographic test while answering fraction questions. This paper attempts to explore the differential utilizations of brain substrates during different fraction tasks by these two groups of pupils. The difficulties in learning fractions by the low achievers were explained in terms of mismatch of brain substrates and cognitive strategies.

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INTRODUCTION

The recent 1990's has been declared as the "Decade of the Brain." The rapid advancement of computer technologies and its capabilities has led to astounding discoveries of the structure and functions of the brain. The gadgetries of neuroscience have begun to reveal the bases and biological processes of the different elements of human behaviour. Investigations on the brain – at system, cellular and sub-cellular levels have resulted in a rich accumulation of knowledge and information about cognitive processes. This increased knowledge and understanding about the different cognitive processes that take place in the brain, among them, perception, vision, hearing, recognition of patterns, memory and moral decisions surely have broad implications in our classrooms.

Recent dramatic advances in cognitive neurosciences put the spotlight on the operations of the brain in the processes of learning. Brain science is now considered as one method to evaluate the teaching-learning processes and to identify and rectify learning and behavioral problems among pupils in schools. There will be less headway in our earnest search for effective teaching and learning strategies to help children in their learning if the neurological bases of where those particular learning takes place are not identified.

STATEMENT OF THE PROBLEM

Fractions, being cultural inventions and extensions of numbers, must involve hard work to learn as fractions have been consistently identified as one of the most difficult topics to teach and learn (Seth & Menon, 1990; Ong, Muhamad, Walaiporn, Wilai, & Wakidi, 1992). There exists a substantial amount of research evidence that shows that many pupils have consistently experienced significant difficulty in dealing with and applying the concepts of fractions. Although a rich store of personal meanings may be available for operating on fractions (Behr, Wachsmith, Post, 1985), it is not applied to the symbolic procedures used to solve fraction problems. In many instances, there have been unsuccessful attempts to construct fraction knowledge *in vacuo* (Ong et al, 1992). Ong (2001a) implicated the role of visual-spatial skills in fraction learning and proposed a relationship between visual-spatial ability and fraction achievement.

Many studies have shown that children process different sensory input in different manners, that is to say, different children employ different parts of the brain to process and provide meanings to different information (Gazzaniga, 1994). The brain hemisphericity theory (Sperry, 1974) besides highlighting the different functional roles of each of the hemispheres, also stresses on the ultimate interhemispheric integration in the processing of all kinds of stimuli. However, there are certain stimuli that demand differential hemispheric processing. Some stimuli, especially those that involve colour, visual-spatial characteristics, music, among others demand right brain processing. If children are made to make sense of these features with their left brains, then a *'conceptual mental block'* (Clements & Del Campo, 1987) will result.

Knowing that different children exhibit different learning styles in their constructions of different meanings in their learning activities (Riding, Glass, Butler, Phydell-Pearce, 1997), the researchers have hypothesized that these different learning styles and capacities are due to differential utilizations of different substrates in the brain. This study attempts to explore the use of electroencephalography (EEG) in elucidating the role of brain areas involved in processing different types of fraction knowledge on a combined spatial-temporal scale. It specifically seeks to explore the cerebral basis of individual differences in fraction learning by measuring EEG asymmetries of pupils with high and low fraction ability.

The EEG procedure was selected because:

1) its hardware, technologies and expertise are available for academic research;
2) it is non-invasive;
3) it gives a much higher temporal resolution than other brain imaging techniques;
4) it is very safe when stringent safety procedures are observed; and
5) it gives high reliability inferences and conclusions when stringent experimentation procedures are undertaken to effectively control artifacts.

The research question in the study was:

Using EEG power spectral parameters, what are the active areas in the cerebral cortex of the brain while learners of different ability groups are engaged in different fraction tasks?

METHODOLOGY

Research Sample

The research sample consisted of 512 Primary 5 pupils in four randomly selected schools in Kuching, Sarawak. From a battery of three separate fraction diagnostic tests, the highest 10% and the lowest 10% of the pupils in terms of the their total scores obtained were identified as high and low fraction achievers respectively. 22 high and 22 low achievers with no record of mental handicap (from consultations with teachers and pupils' records in schools) and were right-handers were randomly selected for EEG investigations. Informed and signed consent from parents or guardians was solicited prior to the investigations.

INSTRUMENTS

Handedness Inventory

The 'handedness' of the pupils was judged using the handedness inventory devised by McGlone and Davidson (1973). In this inventory, eight unimanual tasks (that is, writing a letter, brushing teeth, combing hair, cutting bread, drinking soup, striking a match, hammering a nail and playing badminton) were adopted. The pupils were required to act out the activities with the physical objects, that is, a pen, a toothbrush, a comb, a knife, a spoon, a match, a hammer and a racquet. This was to make certain that what they said was what they actually did. A demonstrated use of the right hand for writing and six of the seven other actions served as criterion for right hand preference.

Electroencephalographic Test

The electroencephalographic test consisted of fraction tasks which were developed using Visual Basic language. There were three different tasks:

a) Task A - questions about fraction representations in a discrete set model,

b) Task B - questions about fraction representations in a continuous region model, and

c) Task C - questions about fraction computations and comparison of magnitudes.

Each task had five trials and each trial had eight (8) questions of similar level of difficulty. Hence, there were a total of 40 questions in each fraction task. Table 1 shows the EEG task protocol. There was a rest period of at least 3 seconds between each trial. The questions were presented in a computer. Each question for Tasks A and B appeared on the screen for 2.5 seconds. Questions for Task C were presented for 3 seconds. These periods of presentation had been considered appropriate after a pilot test. Each question has 2 potential answers: A or B. Subjects needed to press the relevant key, marked as 'A' or 'B'. In all task conditions, the stimulus material and response mode remained the same throughout the experiment, thus controlling for stimulus and response-specific variation in the EEG.

Table 1
EEG task protocol

Task A (discrete set model) Convert diagram to symbol	Trial 1 (8 q)	Trial 2 (8 q)	Trial 3 (8 q)	Trial 4 (8 q)	Trial 5 (8 q)
Task B (region model) Convert diagram to symbol	Trial 1 (8 q)	Trial 2 (8 q)	Trial 3 (8 q)	Trial 4 (8 q)	Trial 5 (8 q)
Task C (problem solving) Convert diagram to symbol	Trial 1 (8 q)	Trial 2 (8 q)	Trial 3 (8 q)	Trial 4 (8 q)	Trial 5 (8 q)

Note: q = questions

(a) Electroencephalographic data acquisition

The Medelec DG Compact that was used for EEG data acquisition is a 32-channel digital electroencephalography machine in the Neurology Unit, Sarawak General Hospital. Its safety features conform to the International Standard for Medical Electrical Equipment IEC 601-1 Type BF (isolated patient connection), American Standard for Safety for Medical and Dental Equipment UL 544 (for isolated patient connection) and the BS5724 Part 1(British equivalent of IEC601-1) (Medelec Limited, 1993).

(b) EEG Pre-recording

A note informing the date and time of the EEG tests together with the following reminders were given to the subjects at least two days before the test:

1) to wash and shampoo the hair before coming for the test and not to use oils, spray or lotion on the hair;
2) to abstain from foods and beverages containing caffeine at least 8 hours before the test;
3) to take a small meal for lunch; and
4) to record and inform the investigator of any medications like anti-convulsants, tranquilizers, barbiturates or sedatives taken at least two days before the test.

(c) EEG Recording

Pivik, Broughton, Coppola, Davidson, Fox, & Nuwer, (1993) guidelines for the recording and quantitative analysis of EEG activity in research contexts, especially with regards to electrode types and application, derivations, grounding, calibration, filtering and digitization, were adhered to in this study.

All EEG recordings were done by a trained and qualified neurophysiology technologist at the hospital. Subjects were tested individually at the same time of different days (2.00 – 5.00 pm) as this helped to control the confounding variable of the time of day at which the EEG recordings were made. Many studies (Cummings, Dane, Rhodes, Lynch, Hughes, 2000) have shown the presence of a diurnal variation in the cortical quantitative EEG.

On arrival at the clinic, the subjects and their accompanying parents/ guardians were familiarized with the clinic surroundings, the experimental room and its set-up. As pupils' apprehension of the clinical structure of the test and its surroundings might affect their brain waves, all attempts were taken to make the pupils comfortable and calm. The test protocol and reward to be given (one sticker for every one right response to maintain motivation and vigilance in all the tasks) were explained to the subject. The EEG technologist was introduced to the child and parents/guardians who then described the electrodes and their functions. Subjects and parents/ guardians were later queried in a questionnaire about the subject's food and coffee intake for that day, medications intake and sleeping patterns in the past week, any serious illness during childhood and any known history of brain injury.

Subjects sat comfortably in a chair specially modified for the head and chin rest. These partially immobilized the heads to reduce movement artifacts and kept its distance from the monitor screen (size 25 cm x 15 cm) at an approximate 50 cm. The experimental room was sound-attenuated and moderately-illuminated. After prepping the scalp with Omni-Prep paste, 2 mm Ag/AgCl disc electrodes were mounted with adhesive Ten20 Conductive EEG paste at each of the eight (8) pairs of homologous sites of the left and right brains (a total of 16 sites), that is, Fp1, Fp2, F3, F4, F7, F8, C3, C4, P3, P4, T3, T4, T5, T6, O1 and O2 according to the International 10-20 System of Electrode Placement (Jasper, 1958) in a monopolar montage with Cz as reference (Fp – prefrontal, F – frontal, C – central, P – parietal, T – temporal and O – occipital). Odd-numbered sites are on the left brain and even-numbered sites on the right. Micropore adhesive strips were taped over the electrodes to hold them in place. A ground electrode was placed on the forehead. Impedances at all electrodes were maintained below 10 Kohms throughout the experiment. Figure 1 shows the electrode positions.

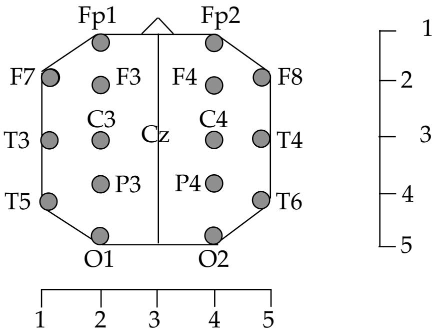

Figure 1: Electrode positions

Note: The head is seen from above, nose up, left ear left. Mapped area bounded by Fp1/2, F7/8, T5/6 and O1/2. The numbers identify the electrode positions of the international 10-20 system as rows (vertical, from anterior to posterior) and columns (horizontal, from left to right). The point (3,3) describes the location of Cz, the vertex.

A trial period was given to the subject to be familiar with the task structure and to practice the fingering for the pressing of appropriate keys in the keyboard – the left little finger to control 'A' key, right little finger for the 'B' key and the right thumb for the 'SPACEBAR' key.

The amplifier bandwidth was set between high pass filter with –3dB point at 1.6 Hz (3dB down at 1.6Hz) and low pass filter with –3dB point at 50 Hz (3dB down at 50 Hz). This would prevent aliasing of brain and muscle artifacts at frequencies beyond the cutoff. The automatic artifact rejection criterion was set at +105 microvolts. Fixed amplifier gain was set at x2000 with 15mV/mm sensitivity. Hamming and electromusculogram filters were set at 0.5 and 100 Hz. Using a 12 bit Analog to Digital Converter, the data was sampled at 960 Hz, sub-sampled at 240 Hz and then filtered to 100 Hz (-3 dB). The digitized signals were fed and stored in a 940 MB "write once read many" (WORM) non-erasable optical disk for off-line processing.

The EEG was first registered at rest with eyes closed for baseline data of at least 2 minutes, then with eyes open fixated at a black cross for at least 2 minutes to serve as a control condition for visual input and then during the three different fraction tasks. The tasks were always performed in the same order: Task A, Task B and Task C. The tasks were short, different in nature though equivalent in task demands and between each trial, there was a short rest time of about a minute so that fatigue and learning were not issues. Efforts were taken to get the subjects to relax to minimize muscle tension artifacts by soothing words of encouragement. The subjects took an average of one hour, including questionnaire administration, electrode placements and trial, to complete the session.

FINDINGS

Power Spectrum Analysis Of Electroencephalographic Data

Using the Medelec's Power Spectrum Analysis Program, the Fast Fourier Transform was applied to the EEG digital data to compute absolute power as a function of frequency. Absolute power is the intensity of energy at an electrode site in a specific frequency band and is measured in microvolts squared (mV^2) units. Frequency ranges set in the software included the standard and broad bands of delta (1 - 3.5 Hz), theta (4 - 7.5 Hz), alpha (8 - 12.5 Hz) and beta1 (13 - 18 Hz).

Two-tailed independent t-tests were used to investigate for differences in means of power spectral parameters between pupils of high and low fraction ability levels in all conditions, electrode positions and frequency bands. Figure 2 visually represents only those differences of means that were significant ($p < 0.05$).

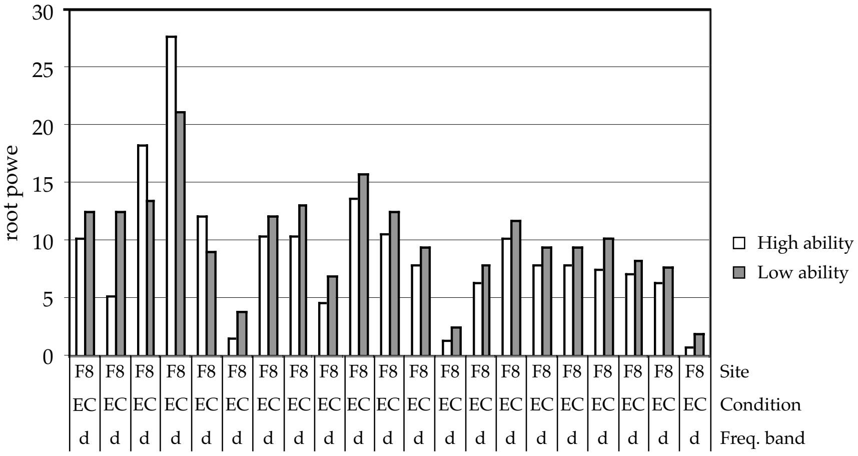

Figure 2: Histogram showing the differences in spectral parameters among the high-and low-ability pupils.

<u>Legend</u>: EC - eyes closed d - delta
EO - eyes opened t - theta
A - Task A a - alpha
B - Task B b1 - beta1
C - Task C

The analysis of power spectral metrics revealed that high fraction achievers as a group, demonstrated both left and right active hemispheres while the low fraction achievers as a group, demonstrated more active right hemispheres during baseline conditions with eyes closed and eyes opened.

Groups of high and low fraction achievers also employed different cortical substrates for the fraction tasks. Fraction Tasks A and B elicited significant differences in delta and beta1 output at left-hemisphere sites of Fp1, F7 and T5 between the two ability groups with higher values in the lower ability pupils, indicating greater mental effort here. Tasks A and B involve fraction processing in a discrete set and region model respectively and both demand visual-spatial operations of part: whole recognition.

Task C elicited significant differences in a wide range of frequency bands and sites. The lower ability pupils showed greater mental effort when the delta output was greater at the frontal sites of F3, F4 and F7, greater theta output at Fp1, F8 and O2 and greater beta1 output at F3. The higher alpha power at Fp1 which reflected lower activation most probably indicate some amount of guesswork among the lower able pupils in this task. As Task C was a problem-solving format involving computations of fractions, both the left and right-hemispheric sites were seen to be involved in both groups. Significant differences in the spectral output occurred mainly at the prefrontal, frontal and occipital sites.

Effects of control and experimental conditions on the locations of centers of electric gravity

In a second approach, the topography of each task-related map landscape was reduced to the location of the point of gravity of the absolute voltages within the map. This value is a conservative estimate of the mean location of the entire neuronal activity in two-dimensional space, and is known as "electric gravity center" (Pizzagalli, Koenig, Regard, Lehmann, 1998). Differences in electric gravity center location indicate activity of different neuronal populations. Thus, the spatial configuration of a momentary field configuration would be numerically expressed by two spatial co-ordinate values, x co-ordinate representing the left-right axis and y co-ordinate representing the anterior-posterior axis (Figure 1).

The following formulae were used to compute for these locations from the absolute power values of a particular frequency band [(Lehmann, 2000), personal communication)]:

X co-ordinate

$$= \frac{(F7+T3+T5)1 + (Fp1+F3+C3+P3+O1)2 + (Fp2+F4+C4+P4+O2)4 + (F8+T4+T6)5}{F7+T3+T5+ Fp1+F3+C3+P3+O1+ Fp2+F4+C4+P4+O2+ F8+T4+T6}$$

Y co-ordinate

$$= \frac{(Fp1+Fp2)1+ (F7+F3+F4+F8)2+(T3+C3+C4+T4)3+(T5+P3+P4+T6)4+ (O1+O2)5}{F7+T3+T5+ Fp1+F3+C3+P3+O1+ Fp2+F4+C4+P4+O2+ F8+T4+T6}$$

Two-tailed independent t-tests were used to investigate for differences in the locations of the centers of electric gravity between pupils of high and low fraction ability levels in all conditions, electrode positions and frequency bands. Figure 3 presents only those locations which were significantly different among the two groups of pupils ($p < 0.05$).

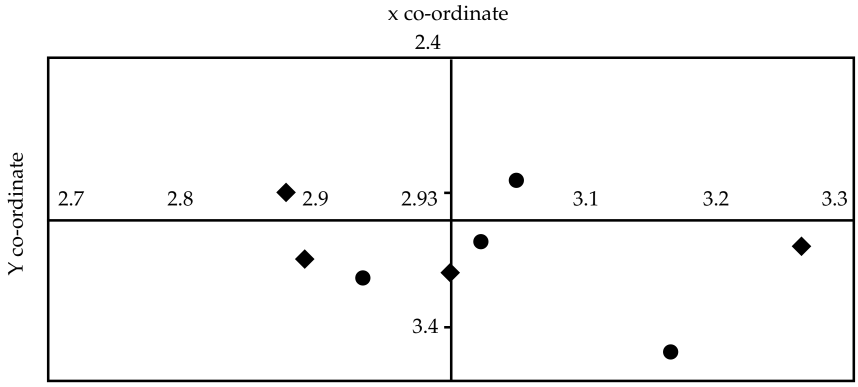

Figure 3: Locations of the brain's electric gravity centers (means across subjects in each ability group) during the eye open state and fraction task A.

Note: Circles, high ability group; diamonds, low ability group. The frame illustrates an area near the vertex, Cz (3,3) -the intersection point of the two axes.

1 - Alpha in eyes open state	2 - Beta1 in eyes open state
3 - Delta in Task A	4 - Theta in Task A

The low-ability pupils showed a more significant anterior and central location ($x = 3.0$, $y = 3.2$) of the center of alpha electric gravity than the high ability pupils ($x = 3.16$, $y = 3.5$) during the eyes-opened state ($p < 0.045$). However, the center of beta1 electric gravity demonstrated a more right location ($x = 3.26$) than the high ability group ($x = 2.94$, $p = 0.025$). Hence, the centers of electric gravity for the lower-ability pupils during the control condition tended towards a more central-right and anterior location when compared to the higher-ability group.

However, for Task A, the center of delta electric gravity tended towards a more left orientation in the low ability group ($x = 2.88$) when compared with the high ability group ($x = 3.05$, $p < 0.05$). Similarly, the center of theta electric gravity of the low achievers tended towards the left hemisphere ($x = 2.9$) whilst that of the high achievers tended towards the right hemisphere ($x = 3.02$, $p < 0.05$). As centers of electric gravity reflects the locations of points of gravity of the absolute voltages of the entire neuronal activity in two-dimensional space (Pizzagalli, Koenig, Regard, Lehmann, 1998), it can be implied from these findings that low achievers demonstrated a tendency to employ their left brains to process Task A while high achievers employed the more efficient right hemisphere.

CONCLUSIONS

The very suggestive findings from the EEG investigations revealed differential brain organizations among the high and low achievers towards learning fractions. These differential brain organizations may lead to (possibly qualitative) different cognitive strategies that each of this group of pupils employs to understand fractions. High achievers utilized both hemispheres, especially the right hemisphere actively in fraction processing. With the right hemisphere widely postulated in visual-spatial functions (Davidson, Chapman, Chapman, Henriques, 1990), high fraction achievers seemed to employ a more efficient and successful cognitive strategy in handling fraction tasks. When faced with the same fraction task, the low fraction achievers switched from an active basal right hemisphere to the left hemisphere. The left hemisphere seems poorly equipped for this task, and this mismatch of 'hardware and software' in computer lingo might constitute an 'invisible roadblock' in their learning of fractions. Ong (2001a) suggested that these pupils may have particular difficulty with the visual-spatial aspects of fractions, that is, the conception of a 'whole', mid-line segmentation and equi-partitioning. The inefficient cognitive strategy adopted by these low achievers might account for these difficulties and lead ultimately to poor performance.

A pertinent question to ask will be, "What triggers this switch?" An analogous situation will be the striker kicking goals during practice but was unable to find the net under match lights. During practice, the player was cool, calm and played intuitively (right brain mode) but under match conditions, play became analytical and measured (left brain mode) and that would be when forced errors and mistakes abound. Many different factors could have triggered the switch. Could it be that under situations of 'formal mathematics' where they have to do what the teacher said or did, when these weak pupils engaged the left-brain gear into activity? Or could it be that when faced with abstract and meaningless mathematical symbols and operations, the left-brain went into an overdrive? Or, could it be that these pupils, when faced with mathematics, attempted to retrieve information from rote memory? Seeking answers into these questions can be the quest for research and these are indeed exciting challenges of cognitive neuroscience research.

The different substrates used for fraction learning among different ability groups of pupils may indicate differential brain organisations which have led to the qualitative differences in their learning capacities and underscore the need to accommodate the diverse ways in which children learn. There is a need to acknowledge diversity and that every brain is uniquely organised. Hence, a universal instructional approach applied to all students in the learning of all subjects may not be appropriate. Not only different areas to be learned, but also different learners require the appropriate use of relevant and different teaching approaches.

The myriad of misconceptions, learning obstruction, inappropriate language and sophisticated coping strategies that low achievers demonstrated in Ong's (2001b) study clearly indicate that they need to approach the learning of fractions differently from the high achievers if they are to be successful. Naming halves as '*sepotong*' (a piece), '*separuh*' (a portion) or '*sedikit*' (a bit), not being able to represent thirds in a diagrammatic format or with a paper model, naming fractions in a part: part notation and adding fractions according to whole number rules after three years of instruction in fractions (from Primary 3 to Primary 5) speak volumes to the attention given to the different ways different children learn. There might be parents or teachers who might think that these children are stupid, however, the EEG findings here might convince them that they are not, only that they learn just differently from the better achievers.

Using the left brains for something that can be better done by the right brains is akin to using a blade to slice an apple. With a wrong tool, the final output of the job will fall short when compared to if a sharp kitchen knife was used. Likewise, encouraging low achievers to use their left brains by teaching fractions as a body of abstract symbols, rules and algorithms will only result in disappointment, both to the learners and the teachers. For these learners, such teaching that teaches them only how to manipulate abstract procedures without first establishing the deep connections between such procedures and the activities involved in the solution of practical and concrete problems is bound to fail. Teaching likewise to the high achievers will result in favourable learning as these high achievers, with their high visual-spatial ability, will be able to engage their right brains for the tasks. Clearly, low achievers cannot be taught using the same methods that have proved effective for their better counterparts. They need to be actively involved in their learning and be provided opportunities to explore, discover, discuss and apply mathematics in their world. In an attempt to engage both their right and left brains, they need to be exposed to a variety of materials and problem-solving opportunities that will allow them to understand relationships rather than to memorise steps. They should follow a learning sequence that moves from concrete materials to abstract symbols. Only through hands-on manipulations of materials and models can they have the opportunity to reflect and abstract the meanings of fractions. The findings of this study might imply that low achievers might benefit from a more visual-based pedagogical instruction strategy of using visual aids and hands-on activities rather than emphasis of algorithms and rules in fraction computations.

To sum up, the findings reported in this study add to the growing body of evidence of the importance of a multidisciplinary approach of cognitive neuroscience to the understanding and resolution of learning problems in the classrooms.

REFERENCES

Behr, M. J., Wachsmuth I. & Post, T. P. (1985). Construct a sum: A measure of children's understanding of fraction size. *Journal for Research in Mathematics Education, 16*, 120-131.

Clements, M. A. & Del Campo, C. R. (1987). Fractional understanding of fractions: variations in children's understanding of fractional concepts across embodiments (Grades 2 through 5) In J. Novak (Ed.). *Proceedings of the Second*

International Seminar on Misconceptions and Educational Strategies in Science and Mathematics, 3, pp. 98-110, New York.

Cummings, L., Dane, A., Rhodes, J., Lynch, P. & Hughes, A.M. (2000). Diurnal variation in the quantitative EEG in healthy adult volunteers. *British Journal of Clinical Pharmocology, 50*(1), 21-26.

Davidson, R. J., Chapman, J. P., Chapman, L. J. & Henriques, J. B. (1990). Asymmetrical brain electrical activity discriminates between psychometrically-matched verbal and spatial cognitive tasks. Psychophysiology, 27, 528 – 543. Cited in Ackerman, P. T., McPherson, W. B., Oglesby, D.M. & Dykman, R.A.. (1998). EEG power spectra of adolescent poor readers. *Journal of Learning Disabilities, 31(1),* 83 - 90. [Online] Available: http://www.ebscohost.com/cgi-bin/e…ecs=10/reccount=50/startrec=1/ft=1

Gazzaniga, M. S. (1994). Foreword. In H. J. Heinz, T. F. Munte & G. R. Mangun (Eds.). *Cognitive Electrophysiology*. Boston: Birkhauser.

Jasper, H. (1958). Report of the committee on the methods of clinical examination in EEG. *Electroencephalography and Clinical Neurophysiology, 10,* 370-375.

Lehmann, D. (2000). *Personal communication*. 15 September.

McGlone, J. & Davidson, W. (1973). The relation between cerebral speech laterality and spatial ability with special reference to sex and hand preference. *Neuropsychologia, 11,* 105-113.

Medelec Workshop Manual for D. G. Compact, U. K. (1993). Medelec Ltd.

Ong, P. H. (2001a). *Individual differences in fraction ability: Relationships with visual-spatial skills.* A paper presented at the National Conference for Postgraduate Research in Education, Universiti Putra Malaysia, 14 July.

Ong, P. H. (2001b). Mental blocks in Mathematics: Why underachievers cannot learn what others easily can. *A paper presented at the International Seminar on Learning and Motivation: Insights from Multiple Perspectives, Universiti Utara Malaysia, 8-10 October.*

Ong, P. H., Muhamad, B., Walaiporn, P., Wilai, A. and Wakidi, H.R. (1992). *Diagnostic assessment of teacher trainees' content abilities and perceptions of teaching fractions and decimals.* SEAMEO-RECSAM, Penang.

Pivik, R. T., Broughton, R. J., Coppola, R., Davidson, R. J., Fox, N. & Nuwer, M. R. (1993). Guidelines for the recording and quantitative analysis of electroencephalographic activity in research contexts. *Psychophysiology, 30,* 547-558.

Pizzagalli, D., Koenig, T., Regard, M. & Lehmann, D. (1998). Faces and emotions: brain electric field sources during covert emotional processing. *Neuropsychologia, 36*(4), 323-332.

Riding, R. J., Glass, A., Butler, S. R. & Pleydell-Pearce, C. W. (1997). Cognitive style and individual differences in EEG alpha during information processing. *Educational Psychology, 7*(1&2), 219-234.

Seth, S. & Menon, R. (1990). *Children's understanding of fractions and decimals: A Diagnostic approach.* Technical Report No. 3, Teaching-Learning Report, RECSAM.

Sperry, R. W. (1974). Lateral specialization in the surgically separated hemispheres. In F. O. Schmitt & F. G. Worden (Eds.). The Neurosciences. Third Study Program. Cambridge, Mass: MIT Press. Cited in Ehrlichman, H. & Weinberger, A. (1978). Lateral eye movements and hemispheric asymmetry: A critical review. *Psychological Bulletin, 85(5),* 1080-1101.