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Differential Brain Functioning Profiles Among Adolescent Mathematics Achievers

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...[O]verall performance in examinations is dependent on the child's mastery of his working language which is English, and Mathematics. The two subjects form the foundation for the child's progress in the education system Thus maintaining and improving the standard of English and Mathematics must be a primary task of the Ministry of Education. If levels of achievement in these two subjects drop, we will suffer an overall decline in the educational performance of our children which will have long-term adverse economic consequences for Singapore.

Dr. Tony Tan, former Minister for Education (1990, p.1).

This study is part of a funded research that investigates the relationship of adolescents' ethnicity, academic achievement, and mathematics achievement with their perception and processing of information and their brain functioning. One approach to the study of the normal brain forms the sub-field of neuropsychology called laterality. This particular paper looked into the adolescents' mathematics achievement against the backdrop of current brain research. It observed the subjects' underlying patterns of cognitive processing as identified by their brain functioning performance in lateralisation tests. Lateralization tests are used to assess subjects' performances on specialised cognitive functions in relation to their tendency towards performing tasks associated with the right and left hemisphere processes.

Rationale of Study

Fundamental in mathematics are mathematical facts, skills, concepts, principles, theorem proving, and problem solving. The gains embedded in these fundamentals are very significant in terms of transferability of principles and strategies, analytical powers, the application of analysis to diverse situations, the presentation of arguments and evidence to convince someone to accept the proof. All these processes require the operation of higher order thinking domains like

analysis, synthesis, evaluation, deductive and inductive reasoning, convergent and divergent thinking. If these processes are so significant, students cannot afford to enter secondary schools with a history of failure in mathematics. Least of all the argument that mathematics is for a few cannot be used to explain mathematics disabilities.

Mathematics, queen of the sciences, is an accurate and indispensable tool in social, economic, and technological development. Yet, it is one of the most feared and disheartening school subjects. Repeated failures lead to a common illness called *mathophobia* which is defined as an emotional and cognitive dread of mathematics peculiar only to this discipline and often verbalised with great frustration.

There is relatively little stigma attached to individuals' inability to do mathematics which is simply attributed to just not having a 'mathematical mind...or not being a numbers person.' What is this 'mathematical mind'? What is this attribute? Does this attribute embody cognitive processes suitable for the manifestation of the desired mathematical performances? Can this attribute for mathematics achievement be explained against the backdrop of current brain research? Can this attribute have an underlying pattern of cognitive processing recognisable by the students' brain functioning performance in lateralisatiaon tests?

Objectives

The objectives of the study are as follows:

1. To compare the brain functioning profiles among the adolescent mathematics achievers, namely the high, above average, average, and low.
2. To distinguish the brain functioning characteristics among the adolescent mathematics achievers.
3. To study the notion that cognitive profiling could be an important factor to predict mathematics achievement among Singapore adolescents.

To ask how students learn, acquire knowledge, and process information are ageless and always timely questions. Guilford's 'Structure of Intellect Model,' (Bell, 1978) characterised three variables for learning, namely: operations (set of mental processes used); contents (nature of the material being learned); and products (manner in which information is organised in the mind).

Cognitive Profiling

- Cognitive profiling finds out how individuals process information to obtain patterns of cognitive functions that are unique to individuals or groups of individuals. The cognitive functions are individuals' preferred self consistent modes of acquiring knowledge, learning, thinking, perception, information transformation, and utilisation of any kinds of information when they encounter a learning experience. The profile also reveals the cognitive obstacles that can inhibit their learning. Cognitive profiling is not about a 'better or worse' dichotomy on a test. Rather it is about a horizontal dimension of relative performance between two kinds of thinking.

- Cognitive profiling takes advantage of the anatomical organisation of the sensory and motor systems in order to 'trick' the brain into revealing the mode of operation to define patterns of cognitive functions unique to the individuals. Cognitive testing is gaining popularity in search of a qualitative picture of individual's strengths and weaknesses.

- Cognitive profiling describes habitual processes of thinking which are qualitatively distinct without a single entity. In contrast to intelligence where 'more' is better, cognitive processes are unobservable mental actions used to manipulate information to produce outcomes which may be manifested in performances.

- Cognitive profiling can be defined as the relation between the performances on right hemisphere tests to performances on left hemisphere tests. Hence it is a relative and not an absolute measurement.

Hemisphericity

> *[D]ominance is part and parcel of the normal human condition, ..as a result of this dominance, we are handed, footed, eyed, and in general sense 'brained'.*
>
> *(Herrmann, 1990, p.13)*

- There are a number of dimensions in cognitive profiling. The dimension selected for this study is hemisphericity, the newest element in cognition. It is defined as the tendency to use one side of the brain more than the

other. The theory behind this notion of cognitive profiling is from one of brain theory models, that of the 'Split brain model' by Dr.Roger Sperry. This model establishes association of the analytical, rational, methodical, verbal-sequential functions with the left cerebral hemisphere, and the non-verbal, imaginative, holistic, visual-spatial functions with the right cerebral hemisphere. Most early investigators based their conclusions about localisation of the brain function and hemispheric specialisation on studies of brain-damaged clinically dysfunctional subjects. Can their findings be safely generalised for the entire population?

- Psychologist Robert Ornstein in the 70's scientifically demonstrated that hemispheric specialisation was not limited to abnormal people but could be identified, predicted and measured in normal people. He was able to differentiate brain wave responses while subjects were engaged in simple tasks thus opening the way for lateralisation research into specialised brain functioning. Further new medical technologies (Nash, 1997) yielded masses of evidence in support of the concept of brain asymmetry - the idea that the two sides of the normal brain are different naturally, and that our mental abilities are lateralised, that is, the tendency to use one side of the brain more than the other.

- A left-brain approach to solving a problem would be fact-based, analytic, step-by-step favouring words, numbers, and facts presented in logical sequence. A right-brain strategy would weed out insight, images, concepts, patterns, sounds and movement, all to be synthesised into an intuitive sense of the whole (refer to Appendix A). So cognitive preferences, or preferred modes of knowing correlate strongly with what we prefer to learn and how we prefer to go about learning it.

- This performance bias towards the left brain functioning tasks or the right brain functioning tasks becomes a measure of hemisphericity. This interpretation of results in normal subjects becomes problematic as the hemispheres are connected via massive nerve connections, the largest of which is called the corpus collosum. The functions are not in an exclusive hemisphere. Rather, they are performed relatively better by a specific hemisphere. Currently the state-of-the -art is to assess brain functioning to understand the relative hemispheric capabilities.

Instrumentation

Lateralization tests were developed and used to assess subjects' performances on specialised cognitive functions in relation to their tendency towards performing tasks associated with the right and left hemisphere processes (Gordon, 1986; Torrance et. al., 1988; Herrmann, 1991; McCarthy, 1993).

1. ***The Cognitive Laterality Battery*** (Gordon, 1986) was selected for this study. A group administered battery of eight performance tests, the Cognitive Laterality Battery (CLB) was standardised from fourth grade through adult. The CLB consisted of four tests to measure the right hemispheric functions of visual-spatial abilities, and another four to measure the left hemispheric functions of verbal-sequential abilities.

To bring the assessment closer to the brain processes themselves, the CLB was taken directly or adapted from tests demonstrating left and right hemispheric superiority in brain divided patients and normal subjects. The data from these tests provided evidence that certain functions assessed by particular tests were attributable to the left or the right cerebral hemisphere. The CLB assessed subjects' performance on specialised cognitive functions through the use of 35mm slides syncronised with pre-recorded audio cassettes.

The brain lateralization tests assumed certain values:

- Propositional (P: verbal-sequential) is the value for the performances of the left brain functioning tasks.
- Appositional (A: visual-spatial) is the value for the performances of the right brain functioning tasks.
- Cognitive Performance Quotient (CPQ) measured the subjects' overall performances in the CLB. This value is obtained from (A+P)/2.
- Cognitive Laterality Quotient (CLQ) measured the subjects' cognitive profile. This value is equal to A-P. A positive CLQ indicates a right cognitive profile (visual-spatial). A negative CLQ indicates a left cognitive profile (verbal-sequential).
- By definition, a 'normal' score would be CLQ=0 with zero as the midpoint between the left cognitive profile (- CLQ) and the right cognitive

profile (+CLQ). This relationship is independent of the overall performance.

2. ***The Demographic Data Inventory*** (Yeap, Chong, & Low, 1995) is used to obtain student information on gender, academic achievement, mathematics achievement, like/dislike mathematics, and ethnicity. The data allows for the comparison of relationship among the variables. The data also allows the results from this study to be generalised to a larger population among Singapore adolescents having the same characteristics.

Sample

A total number of 1340 sixteen and seventeen year old Singapore adolescent mathematics achievers from 17 secondary schools were surveyed (see Table 1).

Table 1: Distribution of Mathematics Achievers by the Primary School Leaving Examination (PSLE)

Mathematics Achievers n = 1340	PSLE Maths Grades	n %
Low	D, E, & F	278 20.7%
Average	B & C	294 21.9%
Above Average	A	208 15.5%
High	A*	560 41.8%
Total		1340 100%

Research Questions

What is the trend of the hemispheric profiles among the high, above average, average, and low mathematics achievers?
Which brain functioning characteristics distinguish the adolescent mathematics achievers?

It is worrying that those who were poor in mathematics continued to be poor in mathematics even after three or four years of mathematics instruction? (Yeap, Chong, & Low, 1996). This trend has serious implications. While teachers may be able to recognise individual differences in the characteristic way students process their information, do they understand the basis of their differences? Are teachers knowledgeable about the dynamics of unobservable mental qualities crucial for pedagogical considerations that can positively or negatively affect the students' mathematics achievement? Are instructional strategies developed from certain psychological basis? Are they aware of differential brain functioning related to mathematics achievement performances?

Finding 1

The adolescent mathematics achievers (n=1340) process information differently using the two hemispheres but with a tendency to use one side of the brain more than the other. This analysis disputed the misconception that normal brain students process information with only one side of the brain (see Table 2).

Table 2: Performances (means) of A, P, CPQ, CLQ among Mathematics Achievers (n = 1340)

Cognitive Laterality Battery(CLB)	Means
A	Small 0.40
P	Big 0.75
CPQ	Average 0.58
CLQ	left -0.36

A = Appositional (visual spatial)
P = Propositional (verbal sequential)
CPQ = Cognitive Performance Quotient = (A + P) ÷ 2
= Overall Performance on the CLB
CLQ = Cognitive Laterality Quotient = A – P
+ CLQ = right cognitive profile
- CLQ = left cognitive profile

Mean scores	Scale
0.5 and below	small
0.51 to 0.7	average
0.71 and above	big

Finding 2

Students' performances in the right (A) or left (P) brain functioning tasks were directly related to their mathematics achievement. A and P scores increased with increasing mathematics achievement. There was significant difference among the four mathematics achievement groups in their performances of both the right (A) and left (P) brain functioning tasks (see Fig. 1).

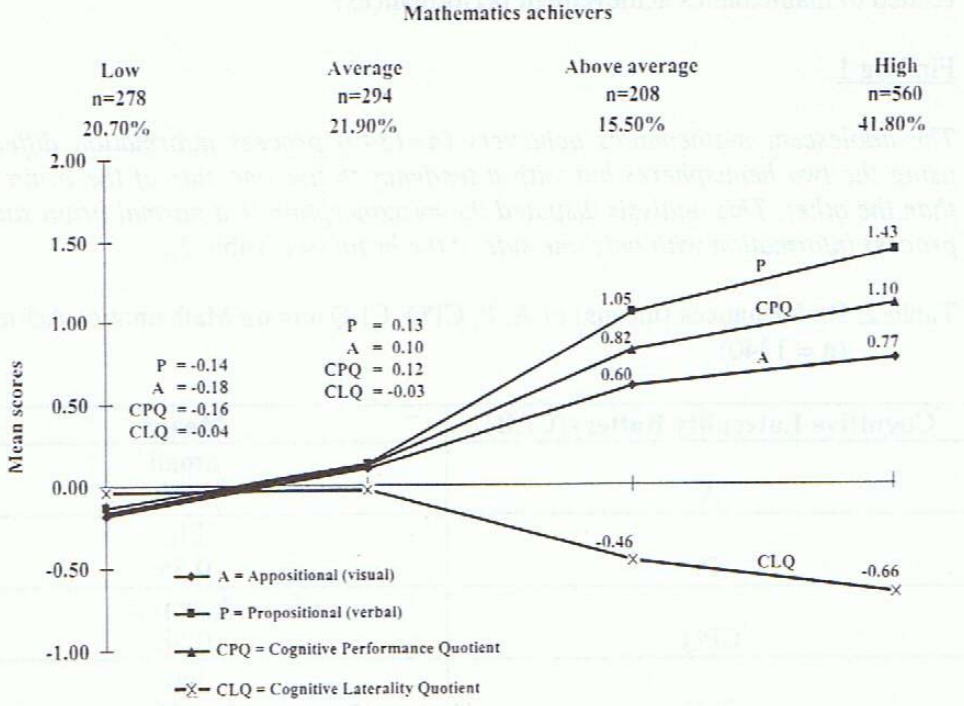

Figure 1: Mathematics Achievers (n=134) and Performance (means) in A, P, CPQ, CLQ

Finding 3

Adolescents' overall performances in the instrument, the Cognitive Performance Quotient (CPQ) was directly related to mathematics achievement. The higher the mathematics achievement, the better were the overall performances in the instrument (see Figure 1/Table 3).

Table 3: Performances (means) of A, P, CPQ, CLQ among Mathematics Achievers

Maths achievers	Low n=278 20.7%	Average n=294 21.9%	Above average n=208 15.5%	High n=560 41.8%	Total n=1340 100%
CLB A	Small -0.18	Small 0.10	Average 0.60	Big 0.77	Small 0.40
P	Small -0.14	Small 0.13	Big 1.05	Big 1.43	Big 0.75
CPQ	Small -0.16	Small 0.12	Big 0.82	Big 1.10	Average 0.58
CLQ	left -0.04	left -0.03	left -0.46	left -0.66	-0.36

A = Appositional (visual spatial)
P = Propositional (verbal sequential)
CPQ = Cognitive Performance Quotient = (A + P) ÷ 2
= Overall Performance on the CLB
CLQ = Cognitive Laterality Quotient = A – P
+ CLQ = right cognitive profile
- CLQ = left cognitive profile

Mean scores	Scale
0.5 and below	small
0.51 to 0.7	average
0.71 and above	big

Finding 4

Regardless of achievement groups, all the mathematics achievers had a left cognitive profile. The higher their mathematics achievement, the more left was the cognitive profile. There was a tendency towards the right cognitive profile among the low and average mathematics achievers (see Figure 1/Table 3).

Summary

> *We are biologically equipped to process information in two distinct and complementary modes that are developed in different manners and that these specialisations are not absolute but are rather a matter of relative predominance of one of the hemispheres.*
>
> *(Ornstein, 1972, p. 62)*

- It is the mathematics achievers' performances of the right (A) and left (P) brain functioning tasks that will distinguish the four groups of mathematics achievers. Performances in A and P are directly related to mathematics achievement. The performance scores increased with mathematics achievement. High mathematics achievers obtained high performance scores in A and P.

- The mathematics achievers' overall performances in the instrument measured as the Cognitive Performance Quotient, (CPQ) can also distinguish the four groups of mathematics achievers. CPQ is also directly related to mathematics achievement. High mathematics achievers obtained high CPQ scores.

- The cognitive profile measured as the Cognitive Laterality Quotient (CLQ) is another way to distinguish the groups of mathematics achievers. The higher the mathematics achievement, the more left was the cognitive profile. The low mathematics achievers, though also left in their cognitive profile, showed a movement towards a right cognitive profile. Ornstein (1997) observed 'that the left hemisphere is undeveloped in many students and both literacy and brain-based testing ought to be used to identify this deficit' (p.95).

- If performances in A, P, CPQ, and CLQ can distinguish the mathematics achievers, similarly these cognitive profiles and the performance scores can possibly predict mathematics achievement among the adolescents.

Using the CLB to measure the subjects differential performances in the lateralisation tests, studies were carried out in Nigeria (Gwany, 1985), Korea (Koh, 1982; Koh & Gordon, 1983), United States of America (Gordon, 1986, 1988), and Singapore (Yeap, 1989; Yeap et. al, 1997). All the studies showed that a certain type of cognitive profile, that of visual-spatial (A) could predict achievement performances of the subjects. A right cognitive profile (+CLQ) is not associated

with high achievement. A left cognitive profile (-CLQ) is. Instead high scores in the overall performances of the lateralisation tests (CPQ) were associated with high achievement scores.

Conclusion

> *People who approach learning with a left mode processing preference have beautiful gifts.*
> *People who approach learning with a right mode processing preference have beautiful gifts.*
> *People who access their whole brain flex and flow, they have both sets of beautiful gifts.*
>
> *(McCarthy, 1993)*

1. Adolescents learn differently, hence they should be taught differently. Cognitive matching tries to accommodate a learners' cognitive style with the delivery systems by formally or informally assessing individuals' cognitive profiles, and then deliberately matching the profiles with instructional intervention. (Jarsonbeck, 1984; Yeo, 1992). The challenge is to devise ways of studying the contribution made by each hemisphere to behavior in the intact brain.

High mathematics achievers would do well academically as they were more balanced in the functioning of both sides of the brain. With low mathematics achievers, there might be a need to deliberately create a learning environment where inter-hemispheric processing of information should be present. The gap between the right and left has to be narrowed as both hemispheres evidently contribute to the processing operation. Each hemisphere is restricted to a set of competencies and dominant functions. Whole brain learning may be better accomplished by different people with different methods. The Prime Minister, Mr. Goh Chok Tong's message (September 1996) was concerned with 'the future where growth will be driven by knowledge and innovation and the ability of the work force to think creatively and to generate and apply ideas' (p.3). This would call for 'wholeness' in the thinking process.

Guilford (Bell, 1978) identified four types of content in learning that match the two hemispheric functioning, namely figural (concrete shapes and forms, a right brain functioning); symbolic (symbols or codes representing concrete objects or abstract concepts, a left brain functioning)'; semantic (words and ideas which evoke a mental image, a left brain functioning); and behavioural (the way

people behave as a consequence of their own desires and the actions of other people).

2. There is the need to re-look into teacher education curriculum. Neuro-psychology is a new science relating brain functioning and behaviour to explain the 'why' of the types of behaviour. Educational psychology is about learning theories and behaviour. Neuro-psychologists provide the brain information, and educational psychologists apply the information to the learning settings. With the recent developments in brain research and technology (Nash,, 1997), it is imperative for educators to incorporate recent brain research findings to explain educational theories (Brooks et al, 1983; Kotulak, 1998).

One cannot predict what kinds of skills individuals will need in the next century, nor what kinds of jobs one will be required to do. Hopefully neuro-psychology will combine with learning theory and the emerging brain data to develop programs that can enhance the thinking strategies in problem solving, reasoning, decision making, and conceptualising.

A new science called *cognitive science* has emerged. It is a science that includes neuro-sciences, the behavioural sciences, social sciences, and computer sciences. A curriculum on the application of neuroscience on learning will re-focus the education profession from its traditional emphasis on the normative behaviour of a class to the developmental needs of different brains and styles, and to redirect the focus of teacher education from a predominantly educational psychology curriculum to include aspects of neuro-psychology (Yeap, Chong, & Low, 1997, April).

3. A serious significance is to realise that hemisphericity is not a stand alone construct. Its relationship to thinking directly (Yeap, Chong, & Low, 1997 June) shapes and enhances thinking strategies and skills. Thinking and hemisphericity were researched into independently during the developmental stages, but continuous research subsequently brought a closer relationship between them. (see Figure 2).

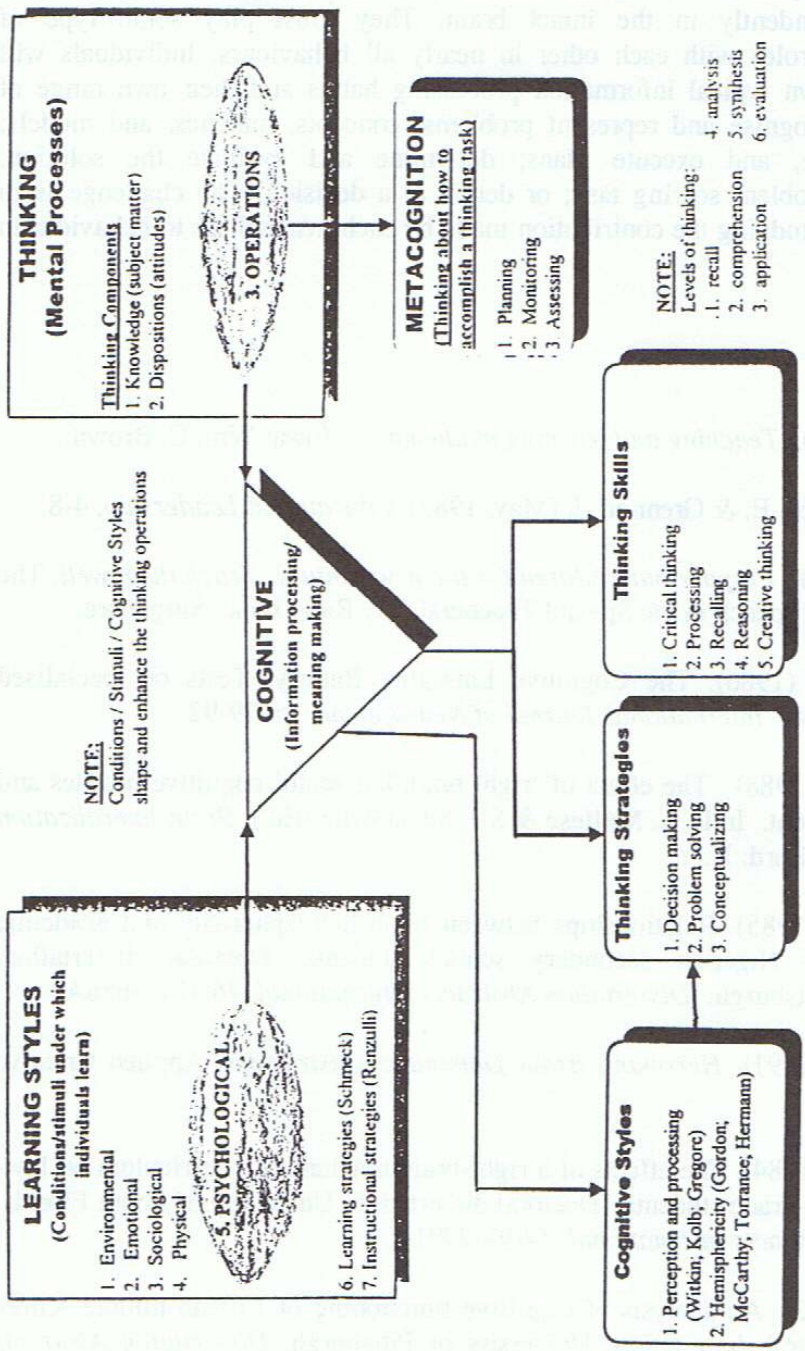

Figure 2: Yeap's Model linking Thinking, Learning and Cognitive Styles

Laterality is relative and not absolute. The two hemispheres are unlikely to function independently in the intact brain. They must play some type of complementary roles with each other in nearly all behaviours. Individuals will develop their own typical information processing habits and their own range of strategies to recognise and represent problems, concepts, hunches, and models; devise, generate, and execute plans; determine and evaluate the solution; accomplish a problem solving task; or derive at a decision. The challenge is to devise ways of studying the contribution made by each hemisphere to behaviour in the intact brain.

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