Informing the facilitation of Mathematics in the senior phase using Herrmann's Whole Brain® theory

by

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DECLARATION OF ORIGINALITY

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DECLARATION

I declare that the thesis, which I hereby submit for the degree Philosophiae Doctor in Curriculum and Instructional Design and Development at the University of Pretoria, is my own work and has not previously been submitted by me for a degree at this or any other tertiary institution.

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ABSTRACT

This research innovation reports on the application of Herrmann's Whole Brain® theory in facilitating and assessing learning in Mathematics in the senior phase, Grades 7 - 9. It is a two-part interrelated initiative that seeks both to augment current Mathematics-specific educational theories to improve practice, as well as to reflect on ways that these theories impact on the teaching practice.

The literature review synthesises existing educational theories in terms of Herrmann's Whole Brain® model into a new proposed comprehensive Mathematics-specific Whole Brain® model. This synthesis of existing "good practices" in Mathematics education in terms of Herrmann's Whole Brain® model, supports the need for a Whole Brain® approach to teaching Mathematics. Furthermore, it hopes to be a user-friendly model with which teachers can plan and facilitate learning and assessment opportunities in Mathematics.

Data was collected on the thinking preferences of each Mathematics teacher participant, as well learners' perception of their teachers' thinking preferences. Both qualitative and quantitative data was used to report on the findings. Individual and collective reflective practices, situated in the framework of professional development and action research, were used to analyse and report on the findings. The reflective practice resulting from the initiative is in itself an outcome of the research, since "those teachers who are students of their own effects are the teachers who are the most influential in raising students' achievement" (Hattie & Yates, 2014, p. 24).

The degree to which the reflective process impacted on each participant's practice appears to be dependent on each teacher's level of professional development. Teacher participants engaging in post-graduate studies showed the ability to complement their "existing competencies with needed situational competencies" (Herrmann, 1996, p. 39), meaning that these teachers were not limited by their thinking preferences, but were able to employ lesser preferred preferences when needed.

Each teacher participant's unique set of thinking preferences was obtained using the Hermann Brain Dominance Instrument (HBDI®). When each of these unique profiles were combined, they produced a compound Whole Brain® profile. This supported Herrmann's (1990, p. 10) notion that every sizeable group would consist of a "composite whole brain", but also showed that there is no specific set of thinking preferences unique to a Mathematics teacher. The learner questionnaires also indicated a reasonably balanced Whole Brain® profile amongst learners, supporting the need for a Whole Brain® approach to facilitating learning and assessing in Mathematics.

The reflective cyclic process of theory informing practice and practice in turn informing theory is at the core of this research innovation. This cyclic process has become my living theory from which I hope to inspire others to engage in similar initiatives.

KEY WORDS

Herrmann's Whole Brain® Theory
Thinking preferences
action research; participatory action research
Facilitating Mathematics
Learning theories
Reflective practice; collective reflective practice
Informing theory through practice
Scholarly reflection

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To my husband, who knew about and believed in the HBDI® long before I did: thank you for reading this document so many times and for encouraging me to persist when circumstances were challenging. I am so blessed to have you in my life.

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LANGUAGE EDITOR DISCLAIMER

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TO WHOM IT MAY CONCERN

This is to certify that I have read and studied the PhD Thesis entitled "Informing practice in Mathematics in the Senior Phase through the use of Herrmann's Whole Brain® theory" by Elmarie Randewijk at her request.

I confirm that I have edited the work for correctness and appropriateness in term of its English language, grammar, punctuation, and spelling.

Michael King

Michael King

I hold a BA (English Hons) degree from Rhodes University, and MA degrees from the University of Cape Town and from Oxford University (UK)

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LIST OF ABBREVIATIONS

HBDI®	Herrmann Brain Dominance Instrument
CAPS	Curriculum and Assessment Policy Statement
NCS	National Curriculum Statement

CHAPTER 1

"If a child can't learn the way we teach, maybe we should teach the way they learn."

Estrada, (n.d.)

1.1 INTRODUCTION

This study is based on the premise that almost all learners can do Mathematics, if they are taught according to the way they prefer to learn. The hypothesis is that within each classroom learners with different thinking and learning preferences are present and that a teacher should cater to these differences. In this study I explore how Herrmann's Brain Dominance Instrument® (HBDI®) could be used to inform reflective practice amongst a group of senior phase Mathematics teachers to plan and facilitate Whole Brain® learning in their classrooms, through participatory action research, thus catering better for a variety of learning preferences.

Teaching Mathematics differs from teaching content-based subjects where teachers are more focussed on delivering content to be grasped and facts to be memorised. This study shows that 'teaching' Mathematics facilitates the process of inquiry and problem solving through active engagement. The Department of Basic Education (2011, p. 8) defines Mathematics as "a human activity that involves observing, representing and investigating patterns". It therefore requires teachers not to instruct or lecture, but to facilitate the learning process whilst learners are actively engaged in solving real-life problems (Slabbert, De Kock, & Hattingh, 2009). For this reason, the focus of this study is on 'facilitating of learning' in Mathematics and learning of Mathematics per se, rather than the 'teaching' of Mathematics.

To explore this notion of 'facilitation of learning' in Mathematics, Herrmann's Whole Brain® Model was proposed as a reflective foundation from which to initiate transformation of current practices in Mathematics in the senior phase. This study was conducted within an independent school[1] on the West Coast of South Africa.

1.2 MOTIVATION FOR THIS STUDY

I was introduced to the Herrmann Whole Brain® Model, by a Herrmann Brain Dominance Instrument® practitioner. The Herrmann Brain Dominance Instrument® (HBDI®) allowed me to set up conversations with other professionals on how one communicates and perceives information and constructs new meaning. This triggered my interest, since as a Mathematics teacher I have always been interested in the ways my learners think and learn and why some learners perceive Mathematics to be more difficult than others perceive it to be. Further reading into Herrmann's Whole Brain® Model showed the applications of the model in Higher Education (university) settings by Steyn and Maree (2003) with engineering students in their Engineering Mathematics course, as well as De Boer, Du Toit, Scheepers and Bothma (2013) in a more general Higher Education setting. Through an analysis of the literature, it became clear that to date, no research has been conducted on the use of the model at secondary (or high) school level and neither specifically in Mathematics at this level.

1.2.1 WHY HERRMANN'S WHOLE BRAIN® THEORY?

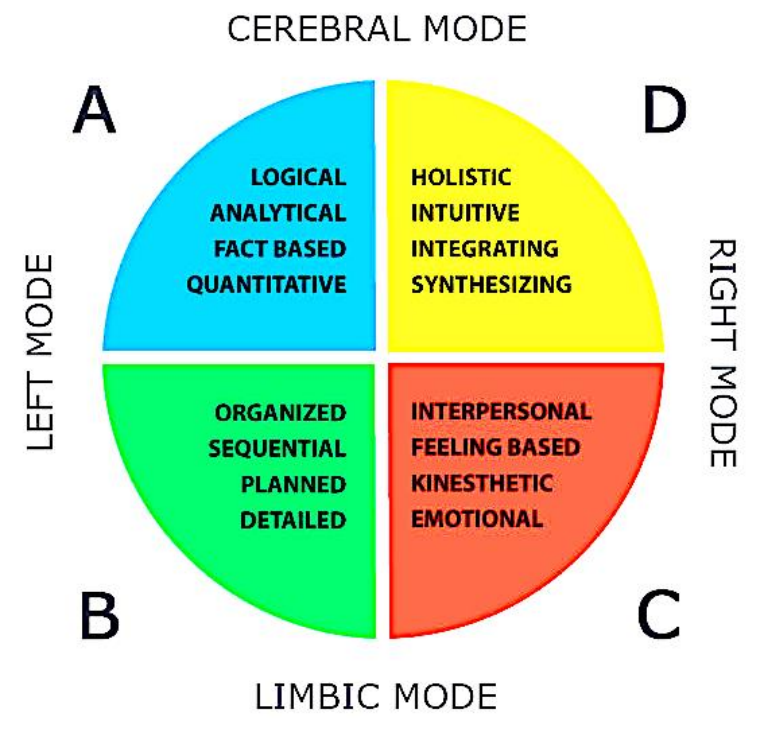
Herrmann's Whole Brain® Theory is based on Hermann's belief that certain modes of thinking are to be associated with certain parts of the brain and that each individual will have a preference for a certain set or sets of modes. This

[1] Independent schools are schools not funded by the Government, but have their own means of generating income and autonomy on ways of spending such income.

led Herrmann to create the four quadrant Whole Brain® Model, clustering similar modes together in each quadrant, as well as devising the Herrmann Brain Dominance Instrument® which tests an individual's preference for each of the quadrants. The Whole Brain® Model is the theoretical framework on which the Herrmann Brain Dominance Instrument® is based. Through the use of the Herrmann Brain Dominance Instrument®, an individual's preferences and aversions are quantified and mapped on the Whole Brain® Model. This representation is known as the individual's profile (Herrmann, 1995). Figure 1 below shows Herrmann's quadratic Whole Brain® Model as represented in De Boer, Du Toit, Scheepers and Bothma (2013, p. 4).

Quadrants A and B represent the modes typically associated with the left-brain, whilst quadrants C and D represent the modes associated with the right brain. The B and C quadrants together represent the limbic brain, whilst the A and D quadrants represent the cerebral brain. The model will be discussed in more detail in the next chapter.

FIGURE 1.1: HERRMANN'S WHOLE BRAIN® MODEL



THE WHOLE BRAIN® MODEL IS A TRADEMARK OF HERRMANN GLOBAL

Since the development of the Herrmann Brain Dominance Instrument (HBDI®) in the mid 1970's it has been used with great success to inform practice within corporations – from Herrmann's own management training at the GE Management Development Institute to companies such as Coca Cola, Shell and South Africa's own Tiger Brands (Herrmann International Africa, n.d.). Herrmann (1995) designed the instrument to inform planning, job design, supervising, teamwork, management training, corporate culture, communication, creativity and career aspirations. The success of Herrmann's brain dominance research and its application in corporations has sparked interest in its application for use in other fields, such as facilitating learning and professional development at higher education institutions.

For learners to actively engage in inquiry and problem solving in order to make sense of the mathematics involved in real-life problems – as proposed by Slabbert et al (2009) – teachers must be able to accommodate learners according to their unique thinking and learning preferences. I would like to advocate that the successes of the Herrmann Brain Dominance Instrument® would produce equally successful results for teaching teams in their creative planning and design of learning opportunities, in building a reflective culture and for effective communication within their community of practice. Wenger (2011, p. 1) defines communities of practice as "groups of people who share a concern or a passion for something they do and learn how to do it better as they interact regularly". This definition captures the intention of this study in terms of the research paradigm of praxis as well as the scholarly actions on which the Mathematics teaching team embarked.

Since the Herrmann Whole Brain® Model was essentially developed as an instructional model for training within a corporation, building on this model for teaching at secondary school level is therefore an extension to the initial intention of the model that is worth investigating.

The literature review shows how the pragmatic theories, such as those by Dewey (Mulcahy, 2007), cognitive psychology theory, such as those by Bruner (2009; Singer & Moscovici, 2008), and theories specific to facilitating learning opportunities in Mathematics, such as those by Dienes (1963; 1971) and Boaler (2008), can be mapped on Herrmann's Whole Brain® Model. Through mapping these theories on Herrmann's Whole Brain® Model, and based on the findings of my study I developed an integrated theory that aims to inform practice in Mathematics classrooms. Through this synthesising process, I aim to support the claim that Herrmann's Whole Brain® Theory can potentially benefit the planning and facilitating of learning opportunities in Mathematics.

1.2.2 Why research into Mathematics education in South Africa?

South Africa scored substantially less than the median in the 2011 Trends in International Mathematics and Science Study (TIMSS) in both the 4th and 8th grade Mathematics section (Mullis, Martin, Foy, & Arora, 2012). There are numerous factors contributing to South African learners' poor performance, such as a lack of resources, teaching (and assessing) being conducted in learners' second or third language as well as social challenges affecting schooling in many areas.

This study focusses exclusively on the professional development of Mathematics teachers as means of aiding learner achievement. According to Schoenfeld (2011, p. 464) teachers who are "more proficient at engaging their students, … spend less time on classroom management, both because they are better at it and because students who are actively engaged in doing mathematics do not need to be "managed" as much as those who are not productively engaged."

In order to focus on professional development of Mathematics teachers independently of the challenges mentioned above, this study is conducted in a privileged schooling environment. However, the study hopes to add to the body of knowledge of how Mathematics teachers in South African schools can be empowered to facilitate learning effectively, despite challenges.

The Department of Basic Education revised the National Curriculum Statement, which articulates the principles underlying the South African education system, in order to produce a detailed Curriculum and Assessment Policy (CAPS) for each school subject, specifying content to be taught and assessments to be conducted at specific intervals throughout the academic year. The policy states to serve "the purposes of: equipping learners, irrespective of their socio-economic background, race, gender, physical ability or intellectual ability, with the knowledge, skills and values necessary for self-fulfilment, and meaningful participation in society as citizens of a free country (and) providing access to higher education" (Department of Basic Education, 2011, p.4). Although the aims and skills specific to Mathematics is set out in the document, which will be further discussed in Chapter 2, the document seems lacking on *how* Mathematics can be taught in an equitable manner to all learners. Although the word 'equitable' refers to a wide range of opportunities, this study only focuses on facilitating equitable opportunities pertaining to learners' thinking and learning preferences, and more specifically in Mathematics. In this study I therefore argue that the need for personalisation of learning, as expressed in the Curriculum and Assessment Policy, can be addressed through the use of Herrmann's Whole Brain® theory.

Singapore scored first and second in the 4th and 8th grade TIMMS Mathematics study respectively, despite learners receiving their Mathematics lessons in English, with only an estimated 21% of these learners speaking English at home (Sriraman & English, 2007). For this reason the principles underlying the Singapore Mathematics curriculum should also be considered when planning on facilitating and assessing learning in Mathematics classrooms in South Africa where a majority of learners are also receiving their schooling in their second or even third language.

This study shows how the principles of the Singapore Mathematics curriculum are similar to those of the principles of Herrmann's Whole Brain® Model, therefore supporting the claim that South African schools could benefit from planning, facilitating and assessing learning based on this model.

1.2.3 Why senior phase Mathematics?

The focus of Mathematics in the South African curriculum for the intermediate phase, grades 4 to 6 (ages 9 to 12), is different from the focus of Mathematics in the senior phase, grades 7 to 9 (ages 12 to 15). The focus moves away from "numbers, operations and relationships" in the intermediate phase towards "patterns, function and algebra" in the senior phase. Where "numbers, operations and relationships" comprise 50% of the curriculum and "patterns, function and algebra' only 10% in grade 6, this gradually changes to "numbers, operations and relationships" comprising 15% and "patterns, function and algebra" 35% of the curriculum in grade 9 (Department of Basic Education, 2011).

Table 1.1 shows the weightings of the variety of mathematical content areas in the intermediate phase (Department of Basic Education, 2011, p. 17), and in particular the heavy weighting of time dedicated to basic number operations.

Table 1.1: Intermediate phase weighting of content areas

WEIGHTING OF CONTENT AREAS			
Content Area	**Grade 4**	**Grade 5**	**Grade 6**
Numbers, Operations and Relationships*	50%	50%	50%
Patterns, Functions and Algebra	10%	10%	10%
Space and Shape	15%	15%	15%
Measurement	15%	15%	15%
Data Handling	10%	10%	10%
	100%	**100%**	**100%**

*The weighting of Number, Operations and Relationships has been increased to 50% for three grades. This in an attempt to ensure that learners are sufficiently numerate when they enter the Senior Phase.

It is important to note that the content of the "patterns, function and algebra" in the intermediate phase only focuses on patterns and number sentences and that the use of variables are only introduced in grade 7 in the senior phase.

Table 1.2, shows weightings of content areas in the senior phase (Department of Basic Education, 2011, p. 16) with a clear decrease in time dedicated towards basic number operations along with an increase in time dedicated to algebra.

TABLE 1.2: SENIOR PHASE WEIGHTING OF CONTENT AREAS

WEIGHTING OF CONTENT AREAS			
Content Area	**Grade 7**	**Grade 8**	**Grade 9**
Numbers, Operations and Relationships	30%	25%	15%
Patterns, Functions and Algebra	25%	30%	35%
Space and Shape	25%	25%	30%
Measurement	10%	10%	10%
Data Handling	10%	10%	10%
	100%	**100%**	**100%**

Several research studies (Carraher, Schliemann, Brizuela, & Earnest, 2006; Kieran, 2008; Lodholz, 1990; Van Amerom, 2003) have indicated the difficulty learners experience when transitioning from a number-focused curriculum to an algebra-focused curriculum. Van Amerom (2003, p. 64) reports that the "discrepancies between arithmetic and algebra can cause great difficulties in early algebra learning (and that the) difficulty of algebraic language is often underestimated and certainly not self-explanatory". Lodholz (1990, p. 25) urges that "attention to the content, pacing and instructional methods during these transitional middle grades are, then, key components in the plan of 'algebra for everyone' ". Furthermore, the abstract thinking associated with algebraic thinking is not only limited to the content area of "patterns, function and algebra", but is also integrated into the variety of other mathematical content areas. There is therefore not only a shift towards conceptual abstract reasoning, but also integration and application of understanding.

An additional factor contributing to the difficulty of facilitating this transitional period is that the senior phase is traditionally split in South African schools, with the grade 7 year forming part of the primary school and the grade 8 and 9 years forming part of high schools. This physical divide makes the communication between Mathematics teachers in the senior phase very difficult. Even though the South African Curriculum and Assessment Policy (Department of Basic Education, 2011) for teaching Mathematics in the senior phase aids the process of content and pace, methods of facilitating and assessing learning can vary between teachers and between schools.

Since Herrmann's Whole Brain® Theory is used within corporate and higher education settings to improve communication within teams, the theory could therefore have potential benefits for improved communication within teams teaching at high school level planning for the critical transition towards Algebra.

1.2.4 WHY USE PROFESSIONAL DEVELOPMENT TO INFORM PRACTICE?

The minimum requirements for qualifying as a Mathematics teacher in the senior phase in the South African context can be achieved by following one of three course options: an undergraduate academic qualification, such as a three-year Bachelor of Science degree (BSc), followed by a professional qualification, such as an one-year Postgraduate Certificate in Education (PGCE); a four year professional qualification, such as a Bachelor of Education degree (BEd); or a technical diploma followed by a professional qualification, such as a Postgraduate Certificate in Education (PGCE) (Department of Higher Education & Training, Republic of South Africa, 2011, p. 17).

With an academic qualification, the focus is on specialisation and research within the chosen field, whereas a professional qualification has a focus on the application of the specific field. A teacher with an academic qualification (such as a BSc and PGCE) will have well-developed mathematical content knowledge, but might have limited mathematical application knowledge. Similarly, a teacher with a professional qualification (such as a BEd) will have well-developed application knowledge, but might lack proficiency in the mathematical content knowledge. Yet, a teacher in the field of Mathematics needs to fulfil the role of both a subject specialist and a designer of learning and assessment opportunities. The design of learning and assessment opportunities are also challenged by changes to the curriculum as well as the development of new technology which impacts on the way learners learn, access and engage with information.

The Policy on the minimum requirements for teacher education qualifications in the National Qualifications Framework (NQF) act 67 of 2008 (South Africa, 2011, p. 51), states the seven roles of a teacher, of which the above mentioned two roles form part, as being a "subject specialist", a "learning mediator", an "interpreter and designer of learning programmes and materials", a "leader, administrator and manager", a "scholar, researcher and lifelong learner", an "assessor" and a "community citizen practising pastoral care" role. Since professional development – at an intrapersonal level, where the individual takes responsibility for the development of self – is specified as one of these roles ("scholar, researcher and lifelong learner"), it seems appropriate to use professional development to inform practice, especially since the teacher is also a "learning mediator" and an "interpreter and designer of learning programmes and materials".

Job-embedded professional development was therefore used as the vehicle through which this study explored the practical application of Hermann's Whole Brain® Theory within Mathematics classrooms. According to Zepeda (2014, p. 99), "professional development embedded in practice creates the 'space' to engage in action research".

Professional development is used as the platform for action research in this research innovation. Furthermore, both action research as a research approach

(Greenwood & Levin, 2013) and mixed method research as a research strategy (Johnson & Onwuegbuzie, 2004) are pragmatic in nature. This interplay between paradigm, design and methodology therefore supports the outcomes of this study of informing practice.

Professional development in the context of this study should therefore be seen as both a means of informing practice and as a reflective inquiry regarding practice, true to the nature of action research. This idea is central to the methodology of this study.

1.2.5 In Summary

This study is based on Herrmann's (1990, p.10) belief "that composite whole brain learning groups represent the ultimate teaching configuration". This implies that although every learner in the classroom will have a different set of learning and thinking preferences, the class as a whole will have a collective whole brain profile. This implies that learners' learning preferences will be evenly spread across the four quadrants identified by Herrmann as displayed in the Figure 1.1. In order to facilitate and assess learning that is equitable and accessible to all learners, teachers should aim to incorporate aspects from all four quadrants. Furthermore, since Herrmann is of the opinion that every group constitutes a composite whole brain (1990, p. 10) the notion of the participating teachers being a composite whole brain scholarly community of practice is advocated.

This study proposes Herrmann's Whole Brain® theory as a means of addressing the challenges in Mathematics in the senior phase when learners progress from a number-focused curriculum to an algebra-focused curriculum. The study recognises that South Africa is faced with many challenges that impact on education, but proposes that professional development of teachers could positively contribute towards the improvement of the standard of facilitating and assessing the learning of mathematics. The Herrmann Brain Dominance

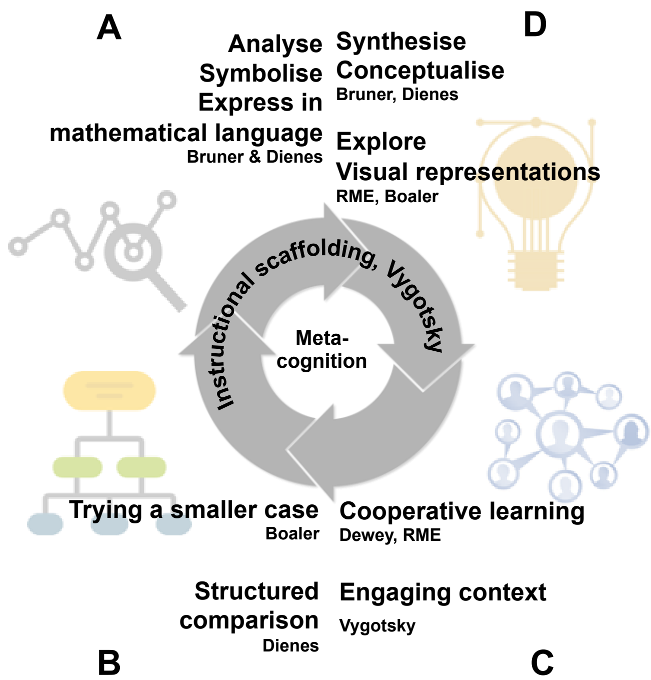
Instrument® was proposed as a means of initiating communication and reflection amongst a teaching practitioner group involved in teaching Mathematics in the senior phase and for the purpose of this study was trialled in an independent school on the West Coast of South Africa. The Herrmann Whole Brain® model is also proposed as foundation from which an integrated theory was developed to inform practice. The integrated theory draws on research that includes, amongst other theories, the psychology of learning, specifically a social constructivist approach to learning and assessing Mathematics as well as principles supporting local and international Mathematics curricula. These theories were mapped on Herrmann's Whole Brain® Model in order to create a comprehensive, Mathematics-specific model, that also forms the conceptual framework of this study.

1.3 CONCEPTUAL FRAMEWORK

In this study Herrmann's Whole Brain® Model is used as the foundation for a conceptual framework of facilitating and assessing Whole Brain® learning in Mathematics in the senior phase. Shields and Rangarajan (2013, p. 24) define a conceptual framework as "the way the ideas are organized to achieve the project's purpose". Therefore, the proposed model for facilitating learning opportunities in Mathematics proposes to organise the ideas applicable to the process of facilitating and assessing learning, using Herrmann's Whole Brain® Model as structural basis.

To validate the claim that the facilitation and assessment of learning in Mathematics must be a Whole Brain® endeavour, pragmatic and cognitive psychology theories, as well as theories specific to facilitating learning opportunities in Mathematics, were categorised according to the mode of thinking that it represents in Herrmann's four quadrant classification (as shown in Figure 1.1). In Figure 1.2, Herrmann's Whole Brain® model was therefore adapted to a Mathematics-specific Whole Brain® model, which also forms the conceptual framework of this study.

FIGURE 1.2: PROPOSED COMPREHENSIVE MATHEMATICS-SPECIFIC WHOLE BRAIN® MODEL FOR FACILITATING LEARNING IN MATHEMATICS AS CONCEPTUAL FRAMEWORK TO THIS STUDY



This model proposes an approach to facilitation and assessment of learning in Mathematics, where a teacher initiates thinking from an exploratory view of a given problem. By using a build-up strategy, which implies gradually adding thinking modes from all four quadrants, the teacher then guides learners towards a conceptual understanding of the problem. This build-up strategy, similar to Bruner's "spiral curriculum" (Bruner, 1999, p. 52), is not linear in nature, but requires constant interaction between thinking modes from all four quadrants. This approach is supported by the pragmatic and cognitive psychology theories of amongst others Dewey (Mulcahy, 2007) and Bruner (2009; Singer & Moscovici, 2008), as well as theories specific to the teaching of Mathematics, such as those by Dienes (1963; 1971) and Boaler (2008) and is also indicated on the Mathematics-specific model in Figure 1.2. Each of these theories is discussed in detail in Chapter 2 and analysed according to Herrmann's Whole Brain® Model. Chapter 2 therefore shows how the theory supports the need for a Whole Brain® approach and how it could be used to inform the facilitating and assessment of learning in Mathematics.

As mentioned before, the comprehensive Mathematics-specific Whole Brain® model aims to show that no educational theory should be grounded in a single quadrant since it will limit the quality of learning. The thinking modes associated with each quadrant are also in constant interaction with each other. Chapter 2 elaborates on this interaction as a vital component in developing a conceptual understanding of a given mathematical problem. This interaction between thinking modes is also part of the reflective nature of problem-solving which aids the process of learners becoming more aware of their thinking processes. For this reason, meta-cognition was positioned in the centre of the Mathematics-specific Whole Brain® model, since (as will be discussed in Chapter 2) meta-cognition is a Whole Brain® reflective endeavour.

Through the action research process of this research initiative, it will also be shown how the comprehensive model depicted above was developed and adapted from this initial representation, to the model represented in Figure 6.2. The adapted comprehensive Mathematics-specific Whole Brain® model is therefore proposed as a user-friendly model that can be used by Mathematics teachers in their planning and development of learning and assessment tools. The process of the model development also forms part of the reflective action research process that is reflected upon in Chapter 6. The conceptual framework is therefore also a product of this research innovation.

1.4 RESEARCH QUESTIONS

This study synthesised some of the main ideas highlighted in pragmatic and cognitive psychology research, as well as research into Mathematics educational reform into a multi-dimensional Mathematics-specific Whole Brain® model. These theories guided my own practice as well as the manner in which I planned to inform my colleagues practice through participatory action research by means of professional development. During the professional development process, the collective reflective practice of the teacher participants on the proposed theory, aided reflection on the theory itself as well how the theory informs the facilitating and assessing of Whole Brain® learning in Mathematics. Through this participatory action research process, the following research questions were explored.

How can the principles of the Herrmann Whole Brain® Theory be applied to inform practice in facilitation and assessment of learning in Mathematics in the senior phase?

In order to answer this question, the following sub-questions were considered:

1. How can Herrmann's Whole Brain® Theory be used as the foundation for a new integrated theory of practice, in the form of a comprehensive Mathematics-specific Whole Brain® model?

2. How can the Herrmann Brain Dominance Instrument® (HBDI®) profile of each teacher participant, along with learner feedback, be used to initiate collective reflective practice within a community of practice in a Mathematics Department?

Educational professional development was used as the vehicle through which these questions were explored. The community of practice, within which the professional development was conducted, therefore formed part of the research design of the study. Scholarship within the community of practice was in itself considered an overarching outcome of the action research and professional development process. Yet, for this study, the proposed Mathematics-specific Whole Brain® model for facilitating learning in Mathematics was used to aid communication, collaboration and reflective practice amongst Mathematics teachers specifically.

1.5 Research Setting

In order to address the research questions above, I conducted the professional development within my place of work and within the Mathematics department of which I am currently a member. As this is a participatory action research study, it requires that I am both a participant and a researcher in this study. I use the present tense here as action research is continuous in nature – indicating that self-monitoring of my practice is still executed, although the research that has been done is reported on in this thesis.

The Mathematics Department consisted of nine members of staff, all of whom taught both within the senior phase as well as the further education and training (FET) phase. Teachers ranged in experience as well as in their level of education. All teachers were university graduates holding a Bachelors degree along with a Post Graduate Certificate in Education, with two members holding a Masters degree and an additional member working towards a Masters degree. One of the teachers holding a Masters degree had also started a PhD during the time of the study. Two members were in management positions in addition to teaching Mathematics and a further two members were also involved in teaching Information Technology.

The school draws learners from mostly advantaged backgrounds from the local community and offers a school environment rich in technology. It is important to note that, different from most schools in South Africa, this school includes learners from grades 7 to 12 at the secondary faculty campus, therefore grouping learners in the senior phase (grades 7, 8 and 9) together on one campus. The same group of Mathematics teachers is therefore involved in teaching learners throughout the senior phase.

All learners in the school are required to have either a laptop or tablet for learning and teachers are required to integrate technology in their classroom practice. Professional development forms an integral part of the school system and an hour per week is scheduled into the school timetable for teacher professional development. The research innovation was often undertaken during this weekly slot by all members of the Mathematics department as part of the school's professional development programme.

1.6 Research Methodology

I started this chapter with a quote that has guided both my teaching and my academic inquiry: if my approach is ineffective, then it warrants change. This notion of informing my practice can be seen as both a philosophy and a methodology in itself. For this reason, I positioned myself within the paradigm of praxis, defined by Cohen, Manion and Morrison (2007, p. 301) "as action informed through reflection", and therefore I engaged in an action research design through a mixed method approach.

Mack (2010, p. 1) states it very simplistically when she defines ontology as "one's view of reality" and epistemology as "the view of how one acquires knowledge". Since action research is reflective in nature, and therefore threaded with my personal set of beliefs, I find it important to state both my ontological and epistemological view:

1.6.1 Ontological stance

I position my ontological stance in terms of my role as pragmatic action researcher. I have proposed the Herrmann Brain Dominance Instrument® as a tool for fostering communication and reflection within the Mathematics department, since I believe that a better understanding of oneself and how one relates to others, an understanding prompted by the HBDI®, could potentially lead to improved practice. This is in line with what McNiff and Whitehead (2002, p. 17) describe as the way action researchers see themselves: "honestly critiquing their practice, recognising what is good and building on strengths, as well as understanding what needs attention and taking action to improve it".

1.6.2 Epistemological stance

As with my ontological stance, I also position my epistemological stance in terms of my roles as action researcher. McNiff and Whitehead (2002, p. 18) state that "(a)ction researchers see knowledge as something they do, a living process". Since I wanted to inform my teaching practice through a process of reflective inquiry, I viewed my conceptual framework as merely a foundation for extrapolation, hence a "living process". In accordance with my ontological stance, I believe that my own reflective practice can initiate reflective practice within the community of practice. This is an opportunity for the participants to also challenge their understanding of their practice.

1.6.3 Research design

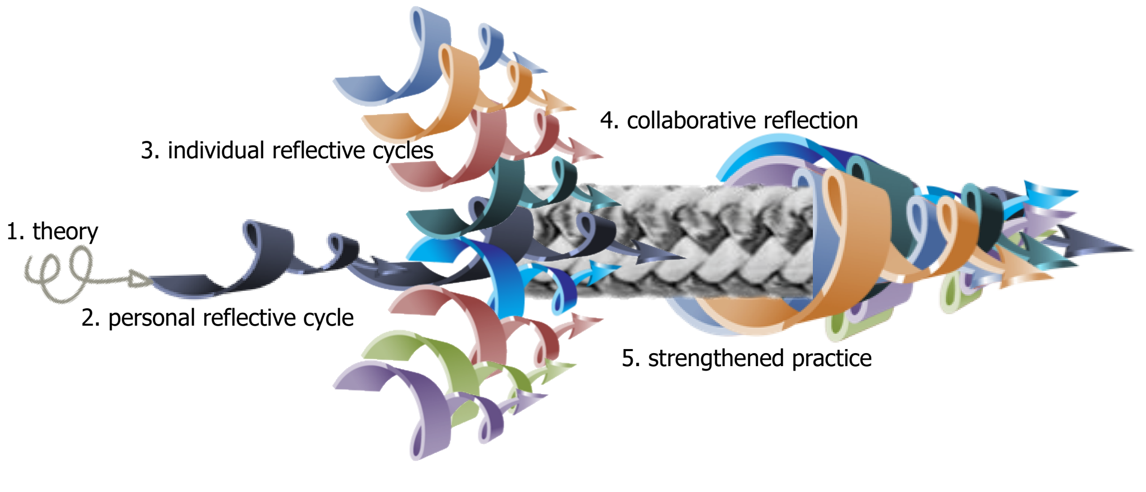
Although the research design is discussed in detail in Chapter 3, a short overview is included in this chapter in order to outline the design, methods and tools that were used in this research innovation.

Considering that the research aims to inform practice through reflective inquiry, it is clear that this study necessitates action research, defined fittingly by McNiff and Whitehead, (2002, p. 15) as "an enquiry by the self into the self, undertaken in company with others acting as research participants and critical learning partners. Action research involves learning in and through action and reflection".

Phelps and Hase (2002, p. 514) expand on the notion of reflection by adding that action research is a "cyclical process in which action contributes to knowledge and knowledge alters action, and members of the context are central to the research process".

The analytical, structured, collaborative, reflective and holistic approach of action research, which embraces the principles of Herrmann's Whole Brain® theory, therefore becomes a living theory.

FIGURE 1.3: RANDEWIJK ROPE MODEL DEPICTING THE REFLECTIVE NATURE OF PARTICIPATORY ACTION RESEARCH



In order to explain the action research cycles of this research innovation, I represented each of the 9 participants to this study, myself included, as a strand of rope as shown in Figure 1.3. With each reflective spiral (of action informing knowledge and knowledge informing action), the strand of rope is strengthened. But since each individual is also part of the community of practice, there is also the presence of collective reflective practice. This collective spiral can be seen as the strands of rope being interwoven into a rope, which forms the collective practice. Since Herrmann's Whole Brain® Theory has been used to inform the collective reflective practice, it can be seen as the strand of fibre at the core of the reflective process. Herrmann's Whole Brain® Theory is therefore at the core of this research innovation, as the theory informing the reflective practice cycles.

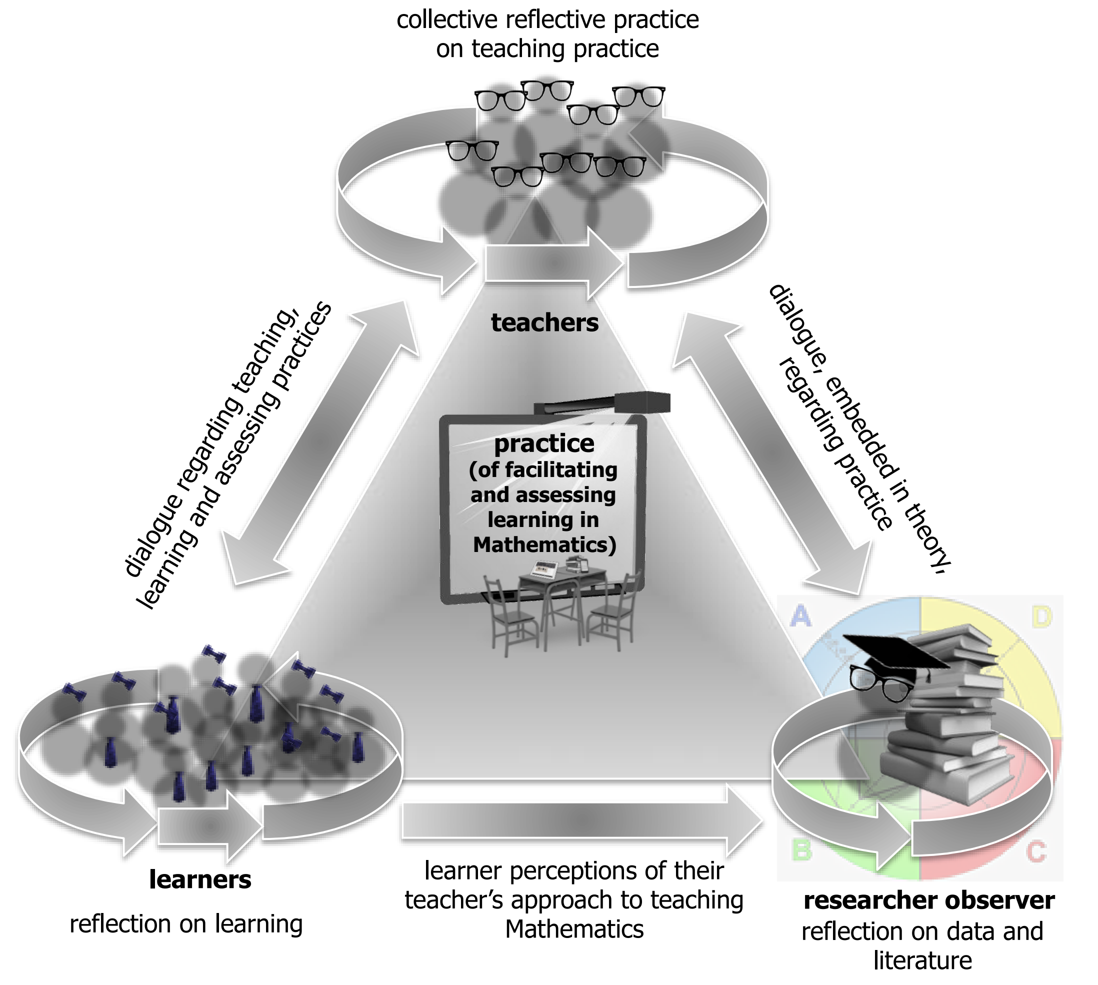
1.6.4 Research methods

McKernan (2016) advocates that the methods appropriate for action research should not be prescribed, but that they are dependent on what the action researcher deems valuable to the specific study.

The focus of this study is both on Mathematics education, as well as the reflective practice of the teachers facilitating the learning and assessment of the subject. In order to complement the quantitative nature of Mathematics, and the qualitative nature of teaching, and specifically a reflective teaching practice, I have chosen to follow a mixed methods approach. The Herrmann Brain Dominance Model® lists mathematical thinking as an A-quadrant (blue) thinking mode, whereas teaching and reflecting are classified as C-quadrant (red) thinking modes. Although seemingly opposing, this study will show the importance of interaction between these as well as the other two thinking modes. The mixed methods approach was therefore chosen "to legitimate the use of multiple approaches in answering research questions, rather than restricting or constraining research choices" (Johnson & Onwuegbuzie, 2004, p. 17).

Although this study focuses on the reflective inquiry of a teaching team, the teachers are inextricably part of the interrelationship between teachers, learners and the teaching material, as represented in Figure 1.4 below. Teachers receive information about the effectiveness of the practice through engagement with their learners and or the teaching material. Through the cyclic process of reflective action research, they may alter their practice, which will impact both learners and the teaching material use, resulting in teachers receiving new information regarding their practice. The triangulation therefore forms part of the action research cycle. Figure 1.4 represents this cyclic process of reflective action research between myself as the research observer, the teacher participants and learners.

FIGURE 1.4: REFLECTIVE NATURE OF PARTICIPATORY ACTION RESEARCH



A brief overview of the proposed research instruments and methods is captured Table 1.3. Although it is necessary for the timeline of this study to report on the results of the innovation, I would hope that the professional development innovation would continue beyond the period of this research. For this reason, the term *during innovation* was used instead of post innovation.

TABLE 1.3: PRE-INNOVATION RESEARCH INSTRUMENTS

PRE-INNOVATION RESEARCH INSTRUMENTS			AIM
Teachers	**Instrument**	**Methodology**	The questionnaire was designed to give insight into each teacher participant's perceptions regarding Mathematics, how it should be facilitated and assessed as well as the processes and thought patterns they value. Results were quantified according to each of the four quadrants.
	Questionnaire on current practice	quantitative qualitative	
Learners	Questionnaire on their teacher's perceived practice	quantitative qualitative	Learners were asked to comment on what they perceive their teachers to value in their facilitating and assessing of learning as well as what they perceive to be the main strengths of their teachers' practice. This was done in order to draw comparisons with the teacher participants perception of their own practice.

TABLE 1.4: INNOVATION RESEARCH INSTRUMENTS

INNOVATION RESEARCH INSTRUMENTS			AIM
Teachers	**Instrument**	**Methodology**	The instrument was used to determine each teacher's thinking preferences. The correlation between their preferences and the information gathered from the pre-innovation tools was used in further discussion throughout the reflective action research cycles
	Herrmann Brain Dominance Instrument®	qualitative	
	HBDI® Think Adventure (team-building activity)	qualitative	The HBDI® Think Adventure gave insight into the teaching team's dynamic as a group as well as the differences between individuals within the group.

TABLE 1.5: DURING-INNOVATION RESEARCH INSTRUMENTS

DURING-INNOVATION RESEARCH INSTRUMENTS			AIM
Teachers	**Instrument**	**Methodology**	The HBDI ® was used as a central theme for planning learning and assessment opportunities, which took place during weekly Mathematics meetings and informal discussions. Discussion were noted in my reflective journal.
	Observations and informal discussions	qualitative	
	Interview with teacher participants on reflective process as described in the reflective journal	qualitative	The interview gave feedback on the class visit and observations collected from the professional development process. It helped to determine the extent to which the professional development had impacted each teacher's practice.

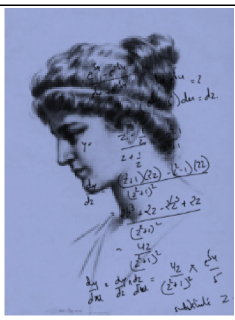
1.7 ADHERENCE TO ETHICAL CONSIDERATIONS

This study involves a great responsibility for the researcher to be both critically reflective and objective when gathering data. Although an action researcher's background, education and working environment can bring great richness to the study, it should not inhibit objectivity. I aim to be as objective as possible during this study.

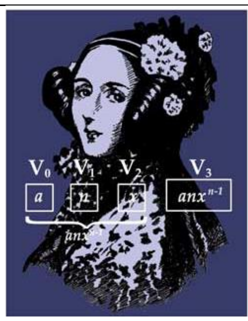
Permission from the Managing Director, Board of Directors, principal, parents and teachers involved in the study was obtained and is in accordance with the University of Pretoria's Ethics Department. Ethics approval for this study was obtained on 29 June 2016, reference: HU 16/06/02. See Appendix A and B for permission documentation.

Anonymity of all participants is insured by the use of pseudonyms for each of the eight participants. Names of famous mathematicians were assigned to each of the participants according to gender and certain characteristics.

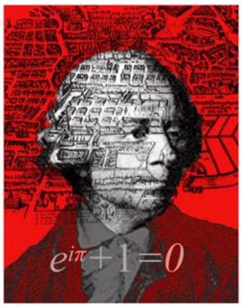
FIGURE 1.5: TEACHER PARTICIPANTS PSEUDONYMS

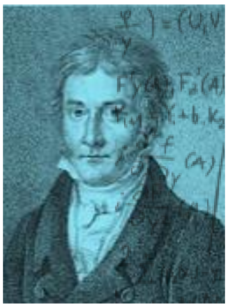

Hypatia

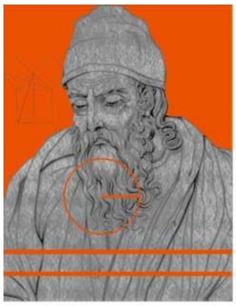

Sophie Germain

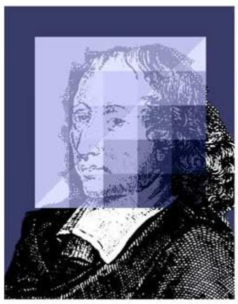

Ada Lovelace


Maria Agnesi


Leonhard Euler


Carl Friedrich Gauss


Euclid


Blaise Pascal

1.8 CHAPTER OUTLINE

CHAPTER 1

In this Chapter I gave an overview of the need for informed practice in facilitating learning opportunities in Mathematics in the senior phase. Herrmann's Whole Brain® model was proposed as the foundation for the conceptual framework of this study as well as an integrated theory to inform practice. The Herrmann Brain Dominance Instrument® functioned both as a data collection instrument and a method for fostering scholarly reflection within the community of practice. I have identified professional development as the vehicle for my research within the Mathematics department in which I operate, to facilitate learning opportunities in Mathematics in the senior phase.

CHAPTER 2

In contrast to traditional approaches to the literature review, this chapter starts with the foundation of my conceptual framework: Herrmann's Whole Brain® model. Herrmann's Whole Brain® model will be validated as an approach to teaching and learning Mathematics through an examination of pragmatic theories (Mulcahy, 2007), cognitive psychology theories (Bruner, 2009; Singer & Moscovici, 2008), cognitive domain knowledge by Bloom and Krathwohl (Bloom, 1956; Krathwohl, 2002) and theories specific to facilitating learning opportunities in Mathematics, such as those by Dienes (1963; 1971; Sriraman & English, 2007) and Boaler (2008) in terms of Herrmann's Whole Brain® model. This will allow for extrapolation towards an integrated theory of facilitating Whole Brain® learning opportunities in Mathematics. This integrated theory is not only the conceptual framework for this study, but is also proposed as a comprehensive Mathematics-specific Whole Brain® model, designed with the aim to inform practice beyond this research innovation.

Furthermore, it will be shown how the acclaimed Singapore Mathematics curriculum incorporates the four quadrants of Herrmann's Whole Brain® model into their pentagonal model, which again both validates Herrmann's Whole Brain® model as a teaching and learning approach which allows for extrapolation towards the integrated theory of facilitating Whole Brain® learning opportunities in Mathematics.

Lastly, professional development will be explored as a means of informing practice towards a Whole Brain® integrated theory of practice in Mathematics. Professional development will also be discussed as an integral part of the action research design of this study since it requires scholarly reflection of teacher participants.

CHAPTER 3

The idea of professional development as a part of the methodology of this study will be further explored in this chapter. The conceptual framework of this study is used as the foundation for the inquiry of the community of practice. The process of inquiry therefore aims to support the theory in order to develop a "living process" (McNiff & Whitehead, 2002, p. 18) of theory informing practice.

The development of the data collection tools and the process of reflective inquiry is discussed in terms of the pragmatic action research approach of reflective practice. It is also shown how the tools and data collection methods have Herrmann's Whole Brain® model as their foundation. The mixed methods approach aims to mirror the quantitative nature of Mathematics as well the qualitative nature of reflective teaching practice.

Chapter 4

This chapter starts with my personal reflection on my own HBDI® results, as this reflective data lead to the inception of this research innovation. The action research cycle of each participant is consequently reported by means of the data findings. Comparisons are also drawn between each participant's own perception on their teaching and their learner's perception of their teaching. The triangulation between the teacher's perception of their approach to facilitating and assessing learning in Mathematics, learner perceptions of this, as well as the HBDI® profile results, initiated my own reflective process which is discussed in chapter 5.

Chapter 5

My reflective process, strongly informed through the theory discussed in Chapter 2, aided my reflective engagements with the teacher participants, which in turn aided their respective reflective processes. This chapter therefore starts with my own reflection on the research innovation. The findings of the research innovation are reported both from both my own reflective perspective as well as the reflective perspectives of the teacher participants. The findings are therefore both a result of the innovation and a platform for further reflection.

Chapter 6

The final chapter is a reflection on the research questions discussed earlier in Chapter 1. Firstly, the extrapolation of the conceptual framework is explained. The conceptual framework, based on Herrmann's Whole Brain® theory, is also proposed as an integrated theory of practice in Mathematics. Secondly, the key findings from the research innovation are summarised and suggestions are made for further research as well as suggestions on how similar professional development endeavours could be undertaken.

1.9 Conclusion

This chapter considered my initial reflective action research cycle: from inquisitive teacher to reflective scholar.

The following chapters hope to build on this initial reflective cycle as well as report on the reflective cycles of my colleagues once they have been introduced to the Herrmann Brain Dominance Instrument® and the conceptual framework grounded in Herrmann's Whole Brain® model.

CHAPTER 2

“The whole art of teaching is only the art of awakening the natural curiosity of the mind for the purpose of satisfying it afterwards.”

France (2010)

2.1 INTRODUCTION

The structure of the literature review follows my own reflective process from inquisitive Mathematics teacher to reflective scholar. For this reason, I will start with an overview of Herrmann’s Whole Brain® theory. This specific theory forms the basis of the practise of the study as well as the theory that initiated my own reflective process.

Secondly, I will give an overview of emerging theories in education about the acquisition of knowledge and the process learners engage in when solving mathematical problems in terms of Herrmann’s Whole Brain® theory. This will be followed by a comparison between the acclaimed Singapore Mathematics curriculum (Lim-Teo, 2002) and Herrmann’s Whole Brain® Model (Herrmann, 1995). By mapping these theories onto Herrmann’s Whole Brain® Model I validate and justify the need for a Whole Brain® approach to facilitating and assessing learning in Mathematics. These theories also add to the comprehensive Mathematics-specific Whole Brain® Model that forms the conceptual framework for this study.

Lastly, I discuss the concept of professional development as the vehicle for metacognitive facilitation and assessment of learning. At this stage it is important to define what is meant by ‘metacognition’, since it forms the central theme of the comprehensive Mathematics-specific Model in this study. Simply stated, it is “the knowledge about and regulation of one’s cognitive activities in learning processes" (Veenman, Van Hout-Wolters, & Afflerbach, 2006, p. 3) which is central to a scholarly reflective practice.

Many of the emerging theories in education about the acquisition of knowledge and the process learners engage in when solving mathematical problems also advocate a collaborative approach. But collaboration is not only a cornerstone of the advocated Whole Brain® approach to facilitating learning in Mathematics of the study, but also of the approach to the participatory action research in which the teacher participants and I engaged in during this study. Marshall (2001, p. 443) states that "anyone engaging in collaborative research needs robust, self-questioning disciplines as their base".

Through the vehicle of professional development and the use of the Herrmann Brain Dominance Instrument®, this study established a community of reflective practitioners. It consisted of members who were encouraged to both practise and advocate collaboration, self-questioning and metacognition in terms of their approaches to facilitating and assessing learning. The literature discussed below proposes a synthesis of these concepts into a multi-dimensional theory of practice.

2.2 HERRMANN'S WHOLE BRAIN® THEORY

2.1.1 AN OVERVIEW OF HERRMANN'S WHOLE BRAIN® THEORY

Before Herrmann's Whole Brain® theory can be explained, two key features applicable to this study should be highlighted.

Firstly, it should be noted that Herrmann's Whole Brain® Model is merely a metaphorical representation of the brain. Herrmann (1995, p. 64) states that it is “a means of organizing and clarifying our thinking about modes of knowing”. It does not limit the specific thinking modes to a specific part of the brain.

Secondly, the Herrmann Brain Dominance Instrument® is not used as a test or a labelling tool and does not proclaim that one preference is better than another (Herrmann, 1995). Herrmann (1990) himself advocates heterogeneous groups since the “similarities and differences provide an opportunity for members of a group to learn from each other” (Bunderson, 1994). The Herrmann Brain Dominance Instrument® can therefore be seen as an instrument that produces results for reflection. Reflection includes both an individual reflecting on his or her individual practices or reflection on the functioning of a group as a result of individual differences or similarities.

Herrmann’s interest in the working of the brain grew out of his own seemingly opposing interests: arts and science. These interests prompted him to graduate with a dual degree in performing music and nuclear physics. This duality continued to interest him and his search for the cradle of his own creativity led him back to the human brain. He constructed a Model of the brain that incorporates both Sperry’s hemispheric left and right brain theory, with those of McLean’s triune brain (Herrmann, 1995). He proposed that not only can the brain be divided into a left and right hemisphere, but that each of the two hemispheres can also be divided into an upper cerebral and lower limbic brain (according to McLean’s triune brain structure of the reptilian, limbic and cerebral brain). He labelled the four quadrants as follows (Herrmann, 1995):

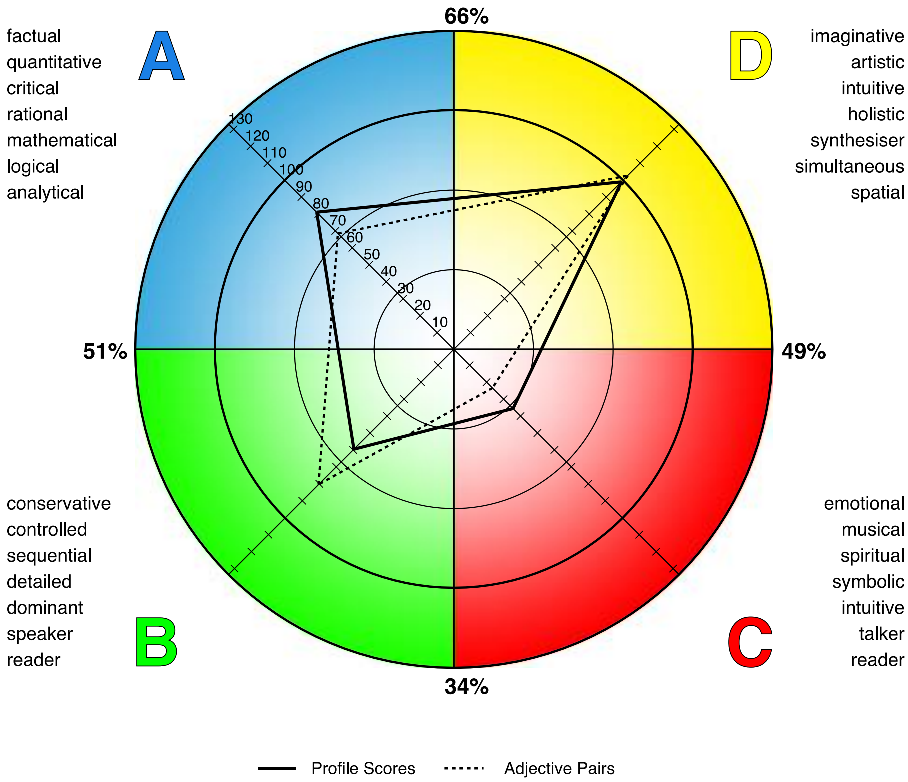
A. Cerebral left quadrant
B. Limbic left quadrant
C. Limbic right quadrant
D. Cerebral right quadrant

Herrmann developed both a Whole Brain® Model, summarising the thinking modes he attributes to each quadrant on a circular quadrant grid, as well as the Herrmann Brain Dominance Instrument® that determines an individual's preference for each of the respective thinking modes. This circular grid is shown in Figure 1.1.

With the use of the Herrmann Brain Dominance Instrument®, a profile of the individual's preferences is quantified and mapped on the quadrant grid to visually represent degrees of preference, as well as aversion for each quadrant (Herrmann, 1995). Figure 2.1 shows an example of an individual's HBDI® profile.

FIGURE 2.1: HERRMANN BRAIN DOMINANCE INSTRUMENT® PROFILE EXAMPLE

Quadrant :	A	B	C	D
Preference Code :	1	2	2	1
Adjective Pairs :	6	7	2	9
Profile Scores :	81	59	35	99



Both a ‘profile score’ (indicated as a solid lined quadrilateral) and an ‘adjective pair score’ (indicated as a dotted lined quadrilateral) is indicated on the visual representation. The ‘profile score’ indicates an individual’s thinking preference for each of the four quadrants under usual circumstances whereas the ‘adjective pair score’ is used to show the individual’s thinking preferences under stress (Bunderson, 1994). The profile score requires individuals to choose or rank thinking preference descriptors according to their personal preference. Score over 70 are deemed to be strong preferences whereas scores under 30 can be interpreted as aversions. In the HBDI® profile in Figure 2.1, both the A- and D-quadrant scores are over 70, meaning that this person tests with a double dominant profile.

The ‘adjective pair’ is, as the name suggests, indicative of the testing method, where individuals are given two adjectives at a time and are asked to choose between them. This forces an individual to choose one thinking preference over another even when both or neither of the options are preferred. The adjective pair score is therefore also known as the stress profile. The complete HBDI® is included in Annexure G. According to Herrmann International’s Profile Facilitator Guide (2006), the testing of an individual’s preferences as well as forced preferences, forms part of the instrument’s “built in validation”.

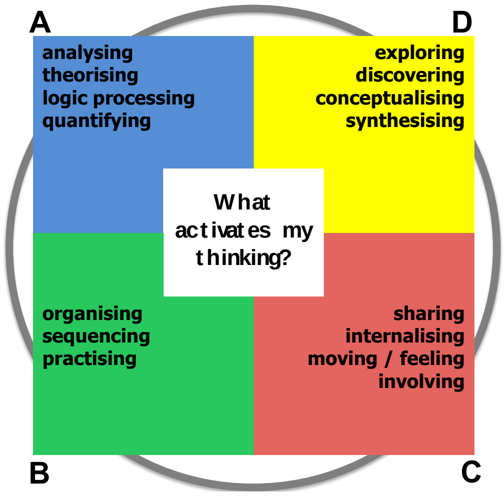
Because the Herrmann Brain Dominance Instrument® determines an individual’s thinking preferences, it can be seen as a process indicator of how an individual prefers to make decisions, rather than a product (or ability) indicator. For this reason Hall (2004, p. 92) “envisage considerable benefits to be derived from its use by policy-makers and course designers as well as in organisations concerned with education and training”. The benefits for a Whole Brain® approach to facilitating and assessing learning is also highlighted by De Boer and Van den Berg (2001, p. 125) in their research on the use of this approach in facilitating and assessing learning and state that “exposing learners to a variety of teaching methods – all focusing on the same key points, can facilitate effective learning”. Furthermore, Herrmann (1990, p. 13) himself states that "(t)he understanding of self — the discovering of self — can be greatly facilitated through whole brain approaches to learning".

It should also be noted that the Herrmann Brain Dominance Instrument® is not a personality test, but a measure of one's thinking preferences. It therefore aids an understanding of an individual's decisions or actions, but not their personality traits. It is also not binary as it does not force an individual to choose between opposing views and making classifications as a result. The Herrmann Brain Dominance Instrument® is designed to quantify the degree to which an individual has a preference for a specific quadrant and recognises that an individual could have preferences for seemingly opposing clusters of thought (Bunderson, 1994).

2.1.2 The use of Herrmann's Whole Brain® theory in facilitating and assessing learning

Herrmann (1996, p. 150) found that "(w)hen a large enough group of learners is considered as a whole, it inevitably comprises a composite whole brain". This means that in any given classroom, the likelihood is very high of having an even distribution of learners preferring each of the four thinking modes, but also an even distribution of thinking aversions. These aversions are almost of greater importance than their thinking preferences since they signal which approaches of facilitating and assessing learning will cause learners to become uninterested since a "turned-off learner is a waste of educational time" (Herrmann, 1996, p. 152). Learners with distinct preferences would be activated by learning tasks in line with their preferred thinking mode as depicted in Figure 2.2.

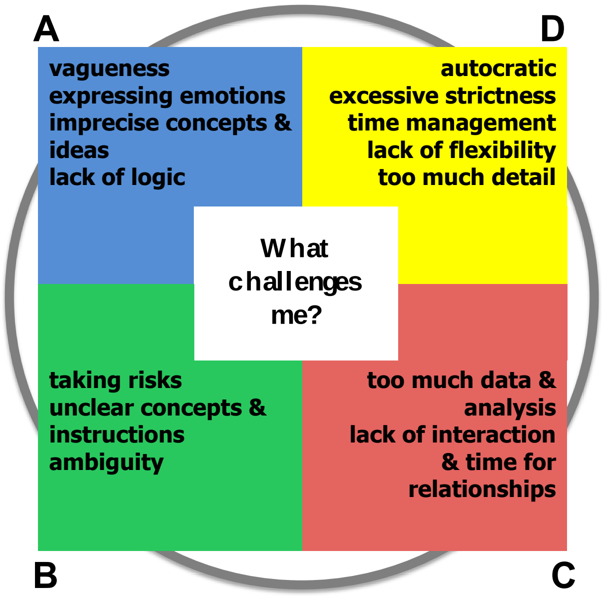
FIGURE 2.2: THE WHOLE BRAIN® MODEL ON LEARNING TASKS THAT ACTIVATE THINKING



Learners with an A-quadrant preference would find mathematical tasks focussing on analysing and logically processing problems more appealing and enjoyable. They might not be equally comfortable in sharing their ideas, as learners with a C-quadrant preference would be. Certain learners, showing a preference for the B-quadrant, might feel more comfortable if certain set rules and procedures are given in order to solve a problem – executing a task – whilst other learners, showing a preference for the D-quadrant, would rather like to explore possible solutions without a restrictive set of procedures. It should be noted that these views are not necessarily opposing. A teacher's goal should be to activate learners to explore and analyse problems, in an organised and logical manner, so that they can come to a conceptual understanding of the problem, which they would be able to communicate to others. Regardless of a learner's preference, they should be guided to develop a Whole Brain® understanding of Mathematics.

A learning opportunity, consisting of different tasks to be executed, will inevitably contain features that would not be of interest to learners. This will be different for learners with different thinking aversions, as depicted in Figure 2.3.

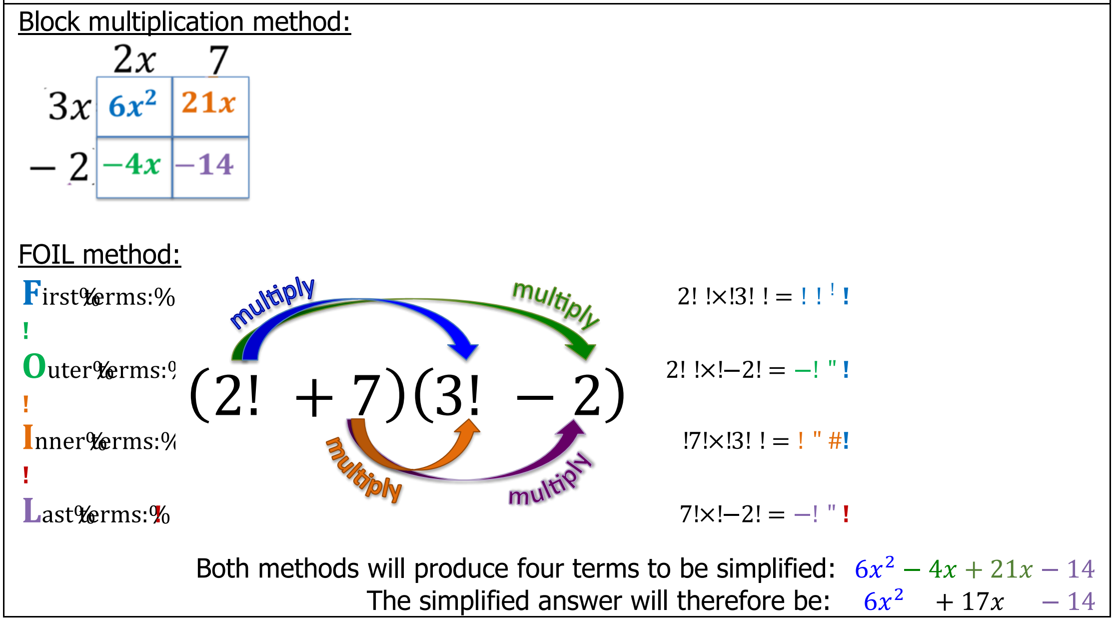
FIGURE 2.3: THE WHOLE BRAIN® MODEL ON TASKS THAT CHALLENGE THINKING



Since it is almost unavoidable for a lesson to contain features that would interest all learners, it is the responsibility of the teachers to find ways of working around these features and to create a balanced Whole Brain® classroom. It is very possible for a classroom to have strict rules and yet encourage free and exploratory thinking. Similarly, a classroom can encourage collaboration and interaction whilst learners are busy logically analysing and disseminating problems. Teachers can also facilitate discussions about different thinking and learning preferences in order to create an appreciation and understanding of these differences, with a view to promoting a whole brain culture of learning.

Learners all have different ways of learning. If we take the multiplication of two binomials as an example, certain learners might remember the acronym "FOIL" to help them memorise the procedure of multiplying the brackets (first, outer, inner, last); other learners might find it easy to draw the arrows between terms to visually show which terms should be multiplied by which; and yet another group of learners simply understand that each term in the first binomial should be multiplied by each term in the second binomial.

FIGURE 2.4: EXAMPLE OF MULTIPLYING TWO BINOMIALS IN VARIOUS WAYS

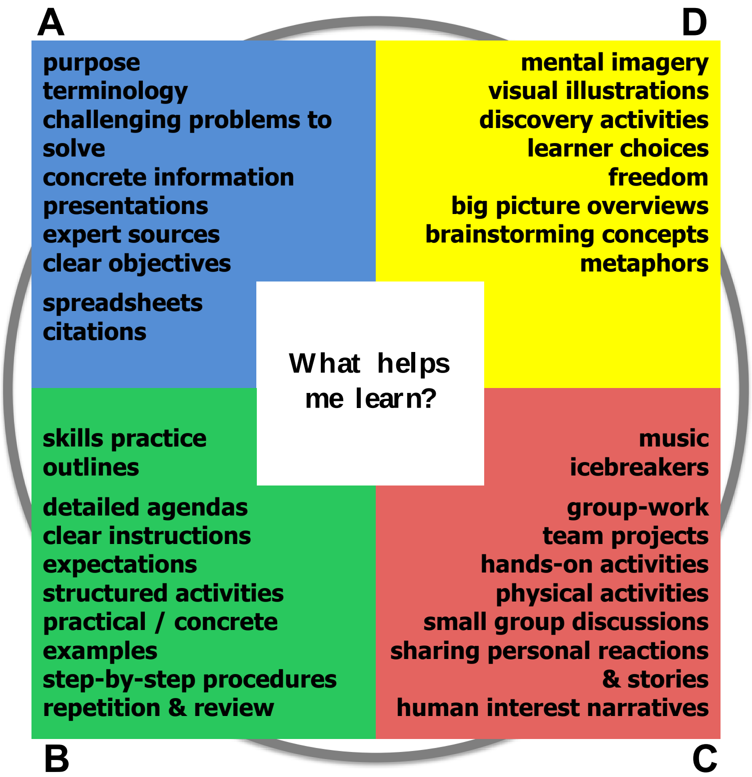


If teachers are able to facilitate learning in such a way that learners learn the same concept from different perspectives, it increases the likelihood that more learners will understand what is to be mastered. Figure 2.4 shows two ways of multiplying two binomials.

Since Herrmann's Whole Brain® Model classifies "quantitative" as an A-quadrant thinking mode, one can easily be mistaken for thinking that most mathematical tasks to be executed are to be approached from this quadrant. Figure 2.5 shows "solve", a term daily used in Mathematics classrooms, as one of the skills associated with the A-quadrant.

Solve, in a mathematical context, unfortunately is not a task that takes place in isolation from procedural instructions, examples, practice, summaries and comparisons and most of all, motivation. Engaging in the task of solving a mathematical problem, is a Whole Brain® endeavour.

FIGURE 2.5: THE WHOLE BRAIN® MODEL ON TASKS THAT AID LEARNING



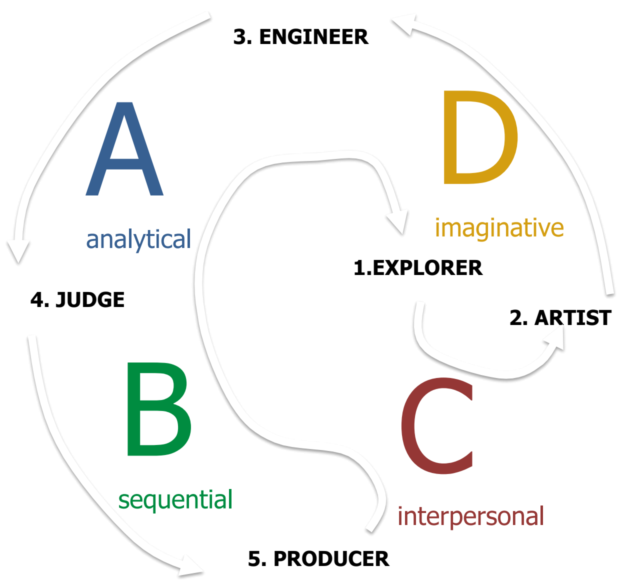
Learners with a B-quadrant preference, also known as the "safe-keeping self" (Hall, 2004, p. 77), might find comfort in a set of sequential procedures, followed by the opportunity to practise these procedures in order to solve a given problem. Learners with a D-quadrant preference might want to know how this mathematical competency relates to other competencies that were explored before, how it is different and how it is possibly the same. They have a need to build connections between skills and concepts in order to build a conceptual understanding of how these skills and concepts can be applied and used to make sense of new skills and concepts. Learners with a C-quadrant preference might find it necessary to share their understanding of the concept with those around them. They might find that by talking through the process, they understand the concept better. They might also be the learners volunteering to answer and explain the question on the board.

At this point it should be noted that all individuals have the ability to access all four quadrants, but that their preference for a specific quadrant will determine how they prefer to learn. One should never assume that learners with a preference for C- or D-quadrant thinking could not be mathematically inclined. Similarly, not all learners with A-quadrant preference will necessarily be brilliant mathematicians. What is of importance is that learners whose learning is not facilitated in a way that aligns with their preferences will not perform to their full potential. Taking this notion further, this research innovation advocates a Whole Brain® approach where learning is aligned with a learners' preference and augmented by the exposure to other preferences.

2.1.3 HERRMANN'S PROCESS OF CREATIVE PROBLEM-SOLVING

Lumsdaine and Lumsdaine (1995) explains the process of creative problem-solving according to the representation in Figure 2.6.

FIGURE 2.6: HERRMANN'S PROCESS OF PROBLEM-SOLVING



The process, which was born out of a short course for engineers on being more creative, starts with an exploratory view of the problem (D-quadrant). Herrmann likens the exploratory process to that of explorer or detective investigating what the problem is. The brainstorming of a multitude of ideas, known as the artist (C-quadrant), follows the first stage, but without testing the feasibility of any of these ideas. The engineer (A-quadrant) follows the artist and starts to formalise and synthesise ideas into a more practical course of action. Once a more practical idea is suggested, it is analysed and criticised by the judge (B-quadrant). The judgement process is the final step before implementation (B-quadrant), which can in itself be seen as another problem to be solved. The final stage, before the exploration process starts again, is called the producer (B-quadrant).

Herrmann initiated this method of creative problem-solving in what he calls a "contextual approach" in contrast to a more traditional "analytical approach" (Lumsdaine & Lumsdaine, 1995, p. 6). The differences between these approaches, as Herrmann used it in his workshop with the engineering students, is summarised in the table 2.1. The analytical approach focusses on knowledge, practice and clear procedures within defined parameters, whereas the contextual approach focusses on the contextualisation of knowledge in situations that are not clearly defined. For engineering students, an analytical approach meant that they experienced difficulty in applying their knowledge in industry when faced with problems that could have multiple possible solutions. The analytical approach did not equip the engineering students in dealing with failure, or for experimenting with innovative, multidisciplinary methods of solving problems.

The advantages of Herrmann's contextual approach with engineering students, as well as the use of the Herrmann's Whole Brain® theory in education in general is therefore well documented, but to date no study has focussed on the use of the Whole Brain® Model in facilitating learning and assessing in Mathematics at senior phase level. Many of the ideas captured in table 2.1 are echoed by other researchers in the remainder of this literature review.

TABLE 2.1: HERRMANN'S CONTEXTUAL APPROACH IN COMPARISON TO AN ANALYTICAL APPROACH	
ANALYTICAL APPROACH	**CONTEXTUAL APPROACH**
1. Students must know the fundamentals	1. Students must know the fundamentals
2. Minimal computer use	2. Extensive computer use
3. Artificial, neat problems	3. Real-life, "messy" problems
4. Problems are fully defined	4. Problems are open-ended
5. Students' time is spent substituting into equations (plug-and-chug)	5. Students' time is spent on critical thinking and on asking "what if" questions
6. Only one "correct" solution expected	6. Multiple solutions/alternatives expected
7. Right-or-wrong answers	7. Contextual problem-solving
8. Narrow focus on course or discipline	8. Multidisciplinary focus
9. Pure analysis – no design content	9. Application to design is central
10. Students work alone	10. Students work alone and in teams
11. Learning is teacher-centred	11. Learning is student-centred
12. Students fear risk; failure is punished. Learning from failure does not occur	12. Students examine causes of failure for continuous improvement
13. Quick idea judgment	13. Deferred idea judgment

Although problem-solving is a key component of facilitating and assessing learning in Mathematics, the purpose of solving a given problem is more often than not to come to a new understanding or a set of beliefs. Problem solving is therefore the vehicle for learning. The solution to the problem is merely part of the learning process. For this reason a process more specific to facilitation and assessment of Mathematics learning is needed. A different route, to that of the creative problem-solving approach, needs to be mapped and followed on the Whole Brain® Model in order to facilitate learning in Mathematics.

At this point it is important to clarify what is meant by *understanding* Mathematics. Skemp (1976, p. 20) makes a distinction between "instrumental understanding" and "relational understanding" in Mathematics. The former refers to a process of memorising rules and procedures without comprehending the reasons, application or interconnectivity of these rules and procedures. Relational understanding, however, is when learners can explain their reasoning as well the interconnectivity between concepts, rules and procedures, and are able to apply what they have learnt. Hence, when referring to understanding in this study, a relational understanding is implied, but more so, a Whole Brain® meta-cognitive understanding – all of which will be elaborated on in the remainder of this literature study.

2.2 EDUCATIONAL THEORIES IMPORTANT FOR FACILITATING AND ASSESSING LEARNING OF MATHEMATICS

Looking at research conducted specifically in the field of Mathematics Education, many of the theories can be mapped on Herrmann's Whole Brain® Model. Uribe-Flórez (2009, p. 13) notes that Mathematics "education has been influenced by advocators of learning through experience such as Dewey, Bruner, and Dienes". The findings of these pragmatic and constructivist researchers are therefore included in this study and they link very closely to Herrmann's contextual approach to problem-solving. In my analysis of each of these theories, I show how each theory can be mapped on Herrmann's Whole Brain® Model in the process of developing a comprehensive Mathematics-specific Model for facilitating and assessing learning in Mathematics, with specific reference to the senior phase.

Through the process of exploring how educational theories can be mapped onto Herrmann's Whole Brain Model®, I have concluded that, as an extension to Herrmann's modes of creative problem-solving, the final stage of problem-solving in Mathematics should not be limited to producing a solution, but coming to a new understanding through a process of synthesis.

Since the Herrmann Brain Dominance Instrument® is considered to be a cognitive process indicator, the co-action between Herrmann's Whole Brain Theory® and that of Krathwohl's "six major categories of the Cognitive Process dimension", a revision of Bloom's taxonomy (1956), is included in this study and supports the claim of synthesis as the objective of problem-solving.

2.2.1 John Dewey's theory in terms of Herrmann's Whole Brain® Model

Dewey was one of the earliest advocates for constructivism and noted that the human mind constantly strives towards making connection between past experiences and new information or encounters. Dewey (1975, p. 20) states that there is a "necessary relation between the processes of actual experience and education." Mulcahy (2007, p. 67) explains that Dewey stresses the importance of "relevance, purpose and connection of the curriculum" to a learner's surroundings, unlike de-contextualised curriculum proposed by behaviourists. He also states that as a pragmatist, Dewey proposed "that theory is meaningless without action, that reason and emotions are interwoven, and that knowledge and intelligence are to serve living" (Mulcahy, 2007, p. 67). Not only do these convictions fit into this study's paradigm of praxis, but also support the claim of a Whole Brain® approach to learning.

Dewey explains the "act of thought" (Mulcahy, 2007, p. 69) as a process consisting of five stages: Firstly, a person encounters a problem to be dealt with. Secondly, the problem and its possible causes are identified as well as the context of the problem. Thirdly, a range of viable solutions is considered. In the fourth stage, a possible solution is chosen and the consequences of the solution considered. Lastly, the solution to the initial problem is executed and its viability analysed (Mulcahy, 2007). The process of problem-solving encompasses a number of skills: inquiry (obtaining knowledge), interpretation, analysis, reflection and validation, similar to Herrmann's explorer, artist, engineer, judge and producer process discussed earlier. Dewey's process therefore also entails that learners are active and engaged in the learning process.

IQ (intelligence quotient) and other ways of ranking were considered by Dewey to be undemocratic and not designed to take into consideration cooperative and social skills. The child's experiences determine how information will be received and processed and therefore test scores could be influenced by a multitude of factors affecting the child. This active and cooperative engagement in the learning process is what Dewey labelled as progressive education. The principles of Dewey's progressive education are similar to that of Herrmann's contextual approach in the sense that it focusses on problems that are real and relevant and requires active participation in order to find multiple possible solutions or applications. Progressive education has the following six key features (Mulcahy, 2007):

1. The purpose of education should be centralised around the child and must aim to incorporate learning tasks that are relevant to the life, the actions and the needs of the child.
2. Children are not passive receivers of information, but should be active participants in their learning, in the same way that they learn through their participation in learning tasks in and around the home.
3. Teachers should be enablers of learning through learners' active participation and facilitate the actions towards a desired outcome.
4. Through active participation in learning tasks that are both relevant and interesting to learners, the school should become a safe and small-scale version of the bigger society – the real world that requires authentic learning (Slabbert et al 2009).
5. Since learners will be required to solve problems rather than memorise facts in the bigger society, problem-solving skills should be developed within the small-scale society of the classroom.
6. The school should endorse democratic and cooperative principles of living within all aspect of school life to prepare learners for the bigger society that is run on these principles.

This is in line with the critical cross-field outcomes as set out in the National Curriculum Statement (NCS) as well as in the Curriculum and Assessment Policy Statement (CAPS) for Mathematics in the senior phase (Department of Basic Education, 2011, p. 5) stating that learner should:

1. “Identify and solve problems and make decisions using critical and creative thinking.
2. Work effectively with others as members of a team, group, organisation and community.
3. Organise and manage themselves and their activities responsibly and effectively.
4. Collect, analyse, organise and critically evaluate information.
5. Communicate effectively using visual, symbolic and/or language skills in various modes.
6. Use Science and Technology effectively and critically showing responsibility towards the environment and the health of others.
7. Demonstrate an understanding of the world as a set of related systems by recognising that problem-solving contexts do not exist in isolation.”

Both Dewey’s progressive education as well as Herrmann’s contextual approach are also relevant to the Mathematics specific aims as set out in CAPS for Mathematics in the senior phase (Department of Basic Education, 2011, p. 8).

1. “a critical awareness of how mathematical relationships are used in social, environmental, cultural and economic relations
2. confidence and competence to deal with any mathematical situation without being hindered by a fear of Mathematics
3. an appreciation for the beauty and elegance of Mathematics
4. a spirit of curiosity and a love for Mathematics
5. recognition that Mathematics is a creative part of human activity
6. deep conceptual understandings in order to make sense of Mathematics
7. acquisition of specific knowledge and skills necessary for: the application of Mathematics to physical, social and mathematical problems; the study of related subject matter (e.g. other subjects); further study in Mathematics.”

Active participation, both by the individual learner and within a group, aids the process of knowledge, skill, understanding and even appreciation acquisition. Dewey's focus on active participation of learners in the learning process impacted several research trends in later years, including South Africa's National Curriculum Statement. Caine and Caine (1991, p. 8) argue for brain-based learning, which they refer to as a process of making connections, rather than memorising individual sets of facts and describe this process of learning as:

1. "Designing and orchestrating lifelike, enriching and appropriate experiences for learners."
2. "Ensuring that students process and experience in such a way as to increase the extraction of meaning."

Dewey's focus on content that is 'relevant' to learners also ties in with the Realistic Mathematics Education (RME) theory of the Dutch Mathematician Freudenthal. He believes that Mathematics is a 'human activity' and that learners should be activated by teachers to make sense of (carefully selected) real world problems in order to make apparent the underlying Mathematical schemes (Gravemeijer, 1999).

Also important to note about the Realistic Mathematics Education is the notion of "progressive mathematizing" (Gravemeijer & Doorman, 1999, p.111). This approach has a strong exploratory approach to problem-solving and make use of representing and communicating answers through the use of visuals and diagrams. Although this approach was originally designed for primary school Mathematics, Gravemeijer and Doorman (1999) also showed how the RME approach can be used for in the design of a calculus course.

The RME is in line with the NCS critical outcome of "Communicate effectively using visual, symbolic and/or language skills in various modes" (Department of Basic Education, 2011, p. 5). This forms the foundation for problem-solving until formal algebraic symbolisation is introduced and is always proposed as initial strategy when engaging with problems. This approach is also in line with the work of Dewey as well as research by Bruner (2009), Dienes (Sriraman & English, 2007) and Boaler (2008) which are subsequently discussed.

Vygotsky also supports Dewey's view that the nature of the problem to be solved, should be relevant and engaging to learners, but suggests that content should be unfamiliar (and the context familiar) so that learners can gain a higher level of (relational) understanding either through cooperative learning or scaffolding (O'Hara, 2007).

Cooperative learning, also known as collaborative learning, implies that classrooms should be set up in such a manner that dialogue is promoted. The developmental potential that exists within the individual when he or she works in cooperation with others, was labelled by Vygotsky as the zone of proximal development. O'Hara (2007, p. 242) defines the zone of proximal development as "the concept that a child will accomplish a task that he or she cannot do alone, with help from a more skilled person".

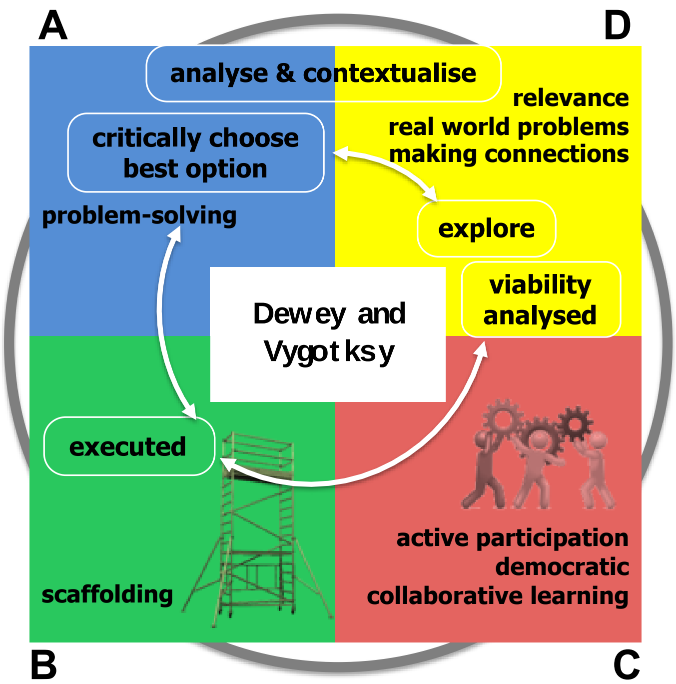
This does not imply that learners continuously work at small clusters of desks with a fixed group of peers; it implies that learners have an opportunity to share their ideas, whether with a small group or with the whole class as the situation arises. Stevenson and Lee (1995) found when comparing East Asian classrooms with American classrooms, that East Asian teachers spent a considerable larger percentage of each lesson on whole group instruction than that of their American counterparts. Yet, the interaction between students and teachers during whole group instruction in East Asian classrooms was also more frequent than those in American classrooms. East Asian teachers called on their students more often to supply answers to questions and gave immediate feedback on different responses. These teachers were also prepared to point out common misconceptions and addressed potential errors prior to learners attempting any problems on their own. East Asian teachers were therefore using Vygotsky's principle of scaffolding even though it was a class discussion and not peer discussions. There is awareness with East Asian teachers of the learning process and where learners might experience difficulty. This notion links with Hattie's research on factors most beneficial to student achievement. Hattie and Yates (2014, p. 24) state that "those teachers who are students of their own effects are the teachers who are the most influential in raising students' achievement". This awareness is also recognised as reflective practice. In their research Hattie and Yates conclude that learner feedback is the most beneficial factor to student achievement. Feedback to teachers on their thinking preferences as well as how learners perceive their teaching, was therefore a used as foundation for teachers' reflective practice for this study. The objective is that teachers who reflect on their own practice, will also be more aware of the needs of feedback to learners about their learning.

Scaffolding can also be understood as a process through which collaboration mostly precedes problem-solving, and that is aided through structured-instruction, such as defining, demonstrating and supporting (Bukatko & Daehler, 2011). Vygotsky therefore reiterates Dewey's notion of interconnectivity between collaboration and structured analysis when solving problems.

The need for structured and collaborative learning fits with Herrmann's limbic B- and C-quadrant thinking preferences. Structuring the curriculum aids learners in ordering their thinking and building on existing knowledge structures, whereas collaboration with others aids the reflective processes involved in thinking and learning. Both scaffolding and collaboration aids the thought process of relevant problems being analysed and contextualised, possible solutions being explored, the best solution being critically chosen and executed where after the viability is analysed according to the context of the given problem.

Both Dewey and Vygotsky's research allows us to infer the need for a Whole Brain® approach to facilitating and assessing learning in Mathematics. Their research in terms of the Whole Brain® approach is summarised in Figure 2.7.

FIGURE 2.7: DEWEY AND VYGOTSKY'S THEORIES IN TERMS OF THE WHOLE BRAIN® MODEL



Vyogtsky's notion of scaffolding was further developed by Jerome Bruner, who coined the concept of "instructional scaffolding" (Conway, 2007, p. 243).

2.2.2 JEROME BRUNER'S THEORY IN TERMS OF HERRMANN'S WHOLE BRAIN® MODEL

Bruner's idea of scaffolding included a new notion of thought, which, to a certain degree, is in contrast to Piaget's levels of cognitive development. Bruner believed "that the foundations of any subject may be taught to anybody at any age in some form" (Bruner, 2009, p. 12). Whereas Piaget attributed certain skills to an approximate age (Saran, 2007), Bruner believes that higher order thinking skills could be presented in such a manner that it could even be accessible to younger children. This notion also forms the foundation for the acclaimed Singaporean approach to teaching Mathematics, and, as will be discussed below, also feeds into the comprehensive Mathematics-specific Whole Brain® model.

Bruner's research has four general premises for facilitating and assessing learning: structure, scaffolding, intuition and motivation (Bruner, 2009):

1. The curriculum should be carefully structured in such a manner that the fundamental principles of the subject are used to make the subject more comprehensible; to deduce simplified representations (such as formulae) which is easy to remember; to assimilate[2] the knowledge to similar situations and as foundational knowledge for further in-depth studies in senior years.

   Specifically appropriate to this study is the idea that young learners are already familiar with certain algebraic constructs, for example finding the value of a missing number, often presented as an open square (☐) in primary schools. By working backwards, they are using inverse operations to calculate the unknown. They might not know the terminology of their exploratory actions, but they are developing a key mathematical skill on which teachers, facilitating algebra learning in the senior phase, can build. This notion links to the idea of scaffolding and can be situated in Herrmann's B-quadrant.

2. Scaffolding allows for facilitating and assessing learning of advanced concepts to young children with the guidance of the teacher within a structured curriculum. Bruner refers to it as a "spiral curriculum" (Bruner, 2009, p. 52) where fundamental concepts are introduced from a young age, at an age-appropriate elementary level, and revisited at an increasingly more advanced levels in proceeding years.

[2] Piaget "implied the term assimilation to explain the complex process of learning that occurred with the help of prior knowledge" (Saran, 2007, p. 193).

3. Fostering a culture where intuition is encouraged and rewarded is a challenging endeavour for teachers. Intuitive thought requires an intricate mixture of creative thought and self-confidence, since creative answers are proposed without a thorough analysis of their viability and should be presented without fear of being corrected. Bruner (2009, p. 68) explains that "it requires a sensitive teacher to distinguish an intuitive mistake, an interestingly wrong leap, from a stupid or ignorant mistake, and it requires a teacher who can give approval and correction simultaneously to the intuitive student". Intuitive thought does not guarantee correct answers, but it does explore creative solutions that could be confirmed through methodical, analytical procedures. Bruner (2009, p. 58) states that "intuitive thinking rests on familiarity with the domain of knowledge involved and with its structure, which makes it possible for the thinker to leap about, skipping steps and employing short cuts" to obtain a possible answer. The creative nature of intuition therefore only leads to correct answers when learners are familiar with the rules of the mathematical concept they are busy exploring. This importance of intuition not only links to Herrmann's artist stage of creative problem-solving, but also to the work of Dienes (1971) and his levels of engagement which are consequently discussed.

4. Closely linked with the notion of intuition, is motivation. Few students find joy in a subject in which they only experience continuous failure, and this is especially true in Mathematics, when answers are seemingly more important than the thinking process leading to it. Mathematics teachers are role models for the beliefs they wish to establish with their learners: "Somebody who does not see anything beautiful or powerful about mathematics is not likely to ignite others with a sense of the intrinsic excitement of the subject" (Bruner, 2009, p. 90). Both the inter- and intrapersonal aspect of facilitating and assessing learning seems apparent, but places an enormous responsibility on teachers and more

specifically on Mathematics teachers. Herrmann's inter- and intrapersonal C-quadrant stands opposite to the logical A-quadrant. Although both the A- and C-quadrants are needed for facilitating and assessing learning of Mathematics, the seemingly contrasting approaches can create conflicting views, especially since Mathematics is often perceived to be a purely A-quadrant proficiency.

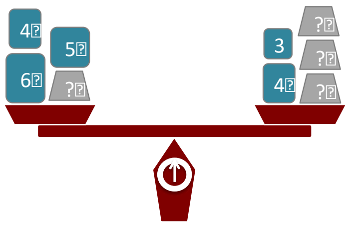
Further to the premises of facilitating and assessing learning discussed above, Bruner, as Piaget, also constructed levels of understanding, namely enactive, iconic and symbolic. Unlike Piaget's levels, Bruner suggests that upon learning a new concept, a person comes to a new set of beliefs by working through all three stages (Conway, 2007).

The enactive level refers to hands-on inquiry through play. A primary school child might be "playing" with a balancing scale in order to determine the weight of an object, without being able to explain concepts of equivalence or solving equations – an important algebraic concept introduced in the senior phase of Mathematics. Once the child is able to find the weight of an object without the use of a scale by, for example, making a drawing of the scale, as in Figure 2.8, they are reasoning at an iconic level. Only once the child can write a formal equation, solve it using mathematical reasoning and explaining this reasoning, is the child at the symbolic level.

This process is not linear in nature and restricted to certain age periods as Piaget's cognitive levels suggested. Bruner argues that one reverts to the use of enactive and iconic means of understanding when presented with a challenging problem, creating an almost circular process of coming to a new understanding. Bruner therefore suggests that through active participation, the child could be activated towards a conceptual understanding (Conway, 2007).

A learner in the senior phase might use "sophisticated" mathematical procedures for solving a problem such as $2x + 3 = 13$, but might need to revert to drawing a scale to solve a more complex problem such as $15 + x = 7 + 3x$. The drawing aids a conceptual understanding of the question.

FIGURE 2.8: A SCALE DRAWING OF THE EQUATION $15 + x = 7 + 3x$



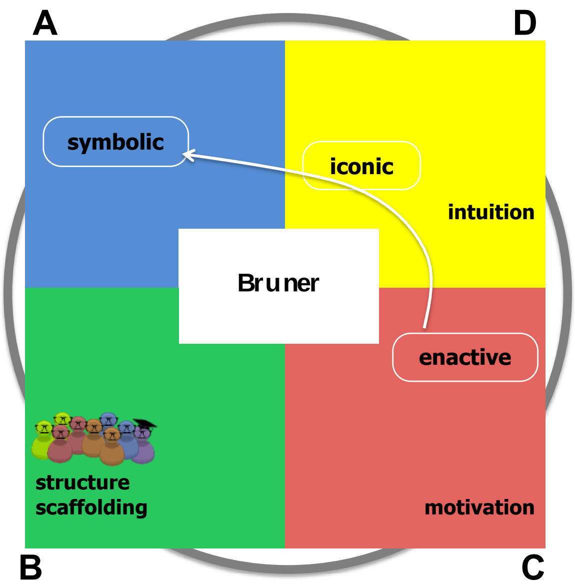
Similar to Skemp's (1976, p. 20) notion of "relational understanding and instrumental understanding", Rittle-Johnson and Alibali (1999, p. 175) define conceptual knowledge, similar to relational understanding, as an "explicit or implicit understanding of the principles that govern a domain and of the interrelations between pieces of knowledge in a domain". This is in contrast to procedural knowledge, similar to Skemp's instrumental understanding, which is often taught in schools as an "action sequence for solving problems" (Rittle-Johnson & Alibali, 1999, p. 175). The action sequence is executed without an understanding of why it is suited to the specific problem or how it has come to be. Bruner supports the importance of a conceptual understanding by emphasising the process of coming to a new understanding. He advocates that active inquiry helps learners to become familiar with the underlying principles of a topic and helps them to assimilate, rather than accommodate, principles of the topic into their existing knowledge bank.

Piaget distinguishes between these two processes of adaptations. Where assimilation involves a person relating new knowledge to existing or prior knowledge structures, accommodation involves one changing one's existing understanding or knowledge structures to come to a new set of beliefs. Piaget "implied the term assimilation to explain the complex process of learning that occurred with the help of prior knowledge" (Saran, 2007, p. 193) When there is an imbalance, or lack of equilibrium, between a child's current understanding or knowledge structure and information received from the environment, there is a need for better understanding. This self-regulatory activity of obtaining equilibrium is the motivation for a child to learn. The accommodation process does not necessarily lead to sound new beliefs and should the new information challenge the learner's current understanding, carefully scaffolded facilitating of learning is needed. Piaget also noted that children accommodate knowledge according to their individual cognitive structures and within a classroom environment we therefore find that children accommodate and assimilate the information being taught completely differently (Saran, 2007)

Singer and Moscovici (2008, p. 1616) describe Bruner's approach to learning as an "interactionist research methodology… based on exploration and inspection of phenomena, where a theoretical model is constructed and continually reconstructed during the study". The learner therefore participates in the learning experience as a researcher, with his or her peers as the research team, with the goal to construct meaning from emerging ideas. This description reinforces Herrmann's process of problem-solving, but places the emphasis on the construct of meaning rather than on the execution of a proposed solution to a problem.

Bruner's theory of learning formed the basis of the acclaimed Singapore Mathematics curriculum, which is also included in this study (Naroth & Luneta, 2015). The analysis above aims to show that Bruner's theory of learning Mathematics could be situated within the Whole Brain® approach to teaching Mathematics advocated by this study. Yet, although great emphasis were given by both Bruner and Vygotsky in terms of the scaffolding and structures teachers should create in order to aid the learning process, in comparison, little has been said about learners creating their own structures during the learning process. The learning process through the enactive, iconic and symbolic phase could therefore be interpreted as a process where structure is created for learners rather than learners creating structures themselves as part of the learning process. Bruner's enactive, iconic and symbolic stages can be mapped on Herrmann's Whole Brain® Model as follows: enactive, as a C-quadrant process of inter- and intrapersonal inquiry; iconic, as a D-quadrant process exploring representations and using intuition to build connections with prior knowledge structures; and lastly symbolic, as an A-quadrant process where ideas are analysed, formalised and represented mathematically.

FIGURE 2.9: BRUNER'S THEORY IN TERMS OF THE WHOLE BRAIN® MODEL



Where Bruner merely implied thinking modes of the B-quadrant, namely structure and scaffolding, Dienes extended on Bruner's three-stage process by including three more levels to the problem-solving process.

2.2.3 ZOLTAN DIENES' THEORY IN TERMS OF HERRMANN'S WHOLE BRAIN® MODEL

Dienes is said to be the father of the relatively new field of study, psychomathematics, meaning the psychology of mathematics learning (Sriraman & English, 2007). Dienes believed that children should experience mathematics in order to develop abstract and symbolic reasoning. Dienes (1963) therefore equates exposure to mathematical experiences with development of mathematical ability.

Dienes (1971) differentiates between six levels of engagement:

Level 1: Trial and error or free play

In order to engage with a problem that one does not know, a person's first attempt of engaging with the problem is often trial and error. Although a primitive approach by nature, it is even used by sophisticated mathematicians when exploring concepts that they are unfamiliar with. "Playing" with ideas helps one to explore methods of solving the particular problem.

Level 2: Play by rules

At the second level one realises that there are certain conditions for the situation and that certain rules would apply. The free exploration becomes limited to the boundaries of the conditions or rules that apply to the situation. It might be necessary for example, to make all units of measure the same before one can attempt to do any calculations.

Level 3: Comparison

When finding commonalities and differences between sets of problems, it focuses one's attention on the structure of the problem and the specific set or rules that apply to the problem. Typical questions that are often asked are: Have I done a problem like this before? Is it the same or is this problem perhaps slightly different? Is it a combination of problems I have attempted before?

Level 4: Representation and structuring of information

Drawing or representing the problem by means of a diagram, table or any other applicable representation, helps to structure the given information. A diagram can help to illuminate the unnecessary information to help one focus on what is given and what is needed. A table of given values, for example, can eliminate the context of the situation for a moment, so that one can focus on determining the pattern of the values in the table.

Level 5: Symbolisation

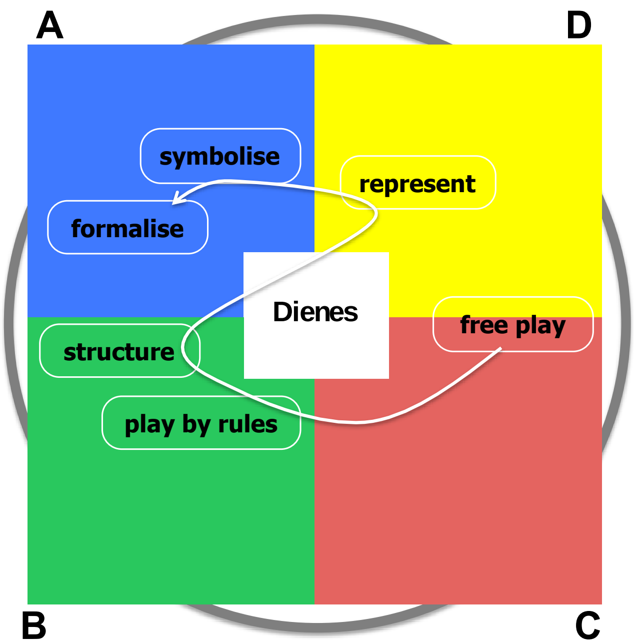
On communicating one's finding after analysing the structure, one is required to express one's finding in some sort of symbolic representation. This symbolic representation can be elementary in nature since at this level one is merely trying to summarise the findings before deducing a formal proof.

Level 6: Formalisation

The last level involves a more sophisticated approach whereby a formal proof is derived from one's elementary descriptions.

Dienes's levels reveal a distinct similarity to Herrmann's creative problem-solving process, the levels of Piaget as well as that of Bruner's enactive, iconic and symbolic levels of understanding. Dienes, Herrmann, Piaget and Bruner, through different classification systems, outline the process of coming to a new understanding through a process of initial primitive exploration to sophisticated analysis. Unlike Bruner and Vygotsky, Dienes makes apparent that learners have to work through a process of rules and structure of the given problem in order to come to a more appropriate representation, symbolisation and ultimately, formalisation of the problem. If we map this onto Herrmann's Whole Brain® Model, in Figure 2.10, free play, like Bruner's enactive stage, also starts within the C-quadrant, but then detours through the B-quadrant through a process of structured dissemination of the problem which aids the exploration, building of connections and visualisation (or representation) process within the D-quadrant. As with Bruner's symbolic stage, Dienes also concludes the process in the A-quadrant with symbolisation and formalisation.

FIGURE 2.10: DIENES'S THEORY IN TERMS OF THE WHOLE BRAIN® MODEL



Dienes's process of problem-solving also bears similarities to the Hungarian mathematician Pólya's heuristics approach to problem-solving, and forms the basis for the inquiry-based learning promoted by Boaler. Boaler simplifies the problem-solving process to "drawing the problem, making a chart with the numbers (and) trying a smaller case" (Boaler, 2008, pp. 185-186).

2.2.4 JO BOALER'S APPROACH TO TEACHING MATHEMATICS IN TERMS OF HERRMANN'S WHOLE BRAIN® MODEL

The British born Professor of Mathematics Education at Stanford University in the United States of America, has and still plays a key role in the controversial math reform or inquiry-based learning in the United States. Boaler describes traditional teaching, as teaching students through "passive approaches (to) follow and memorize methods instead of learning to inquire, ask questions, and solve problems" (Boaler, 2008, p. 40).

Boaler has conducted a multitude of longitudinal studies on various strategies American teachers and students employ in learning Mathematics. She has several recurring themes in her research: talking about mathematics, memorisation versus problem-solving and the organisation of ideas, subsequently discussed.

2.2.4.1 Talking about Mathematics

Through her interaction with students, many have reported that the passive approach to traditional teaching have left them uninterested in Mathematics and that the focus on memorisation of procedures, without understanding, has led them to believe that Mathematics does not require any thought at all (Boaler, 2008). This passive approach is in sharp contrast to the methods of learning proposed by Dewey, Bruner, Dienes and Realistic Mathematics Education, discussed earlier, all promoting active participation in the learning process.

Active participation involves educational discourse and Boaler’s studies indicate that talking about mathematics is a beneficial process of reflection. Although the mathematically talented students in her study at first resisted explaining problems to their peers, they soon realised that they “learned more and more deeply from having to explain work to others” (Boaler, 2008, p. 115). This notion of social collaboration is synonymous with Vygotsky’s research and is also supported by the research of Bruner, Dienes and Herrmann. Through the process of collaboration Boaler encourages exploration of structures and mathematical patterns. It is also a means of activating learners’ thinking about their thinking, also known as metacognition.

2.2.4.2 Memorisation and problem-solving

This active participation promoted by education specialists and teachers sparked a great deal of resistance in America and is misinterpreted by many as “just talk(ing) about math” (Boaler, 2008, p. 33). Although the approach encourages conversation, as an approach of deepening understanding, it is far more than mere talking about Mathematics. It still requires rigour and even some memorisation. Boaler describes it as the "secret that good mathematics users know… that only a few methods need to be memorized, and that most mathematics problems can be tackled through the understanding of mathematical concepts and active problem-solving" (Boaler, 2008, p. 41). She therefore acknowledges the importance of students memorising basic concepts, such as times tables, but states that bigger mathematical ideas, such as Algebra, should be introduced through engaging with mathematical problems.

In an interview with Steven Strogatz, a Cornell University Professor of Applied Mathematics, about the resistance against Boaler's inquiry-based learning, he defends the approach as follow:

"If we only teach conceptual approaches to math without developing skill at actually solving math problems, students will feel weak. Their mathematical powers will be flimsy. And if they don't memorize anything, if they don't know the basic facts of addition and multiplication or, later, geometry or still later, calculus, it becomes impossible for them to be creative. It's like in music. You need to have technique before you can create a composition of your own. But if all we do is teach technique, no one will want to play music at all" (Lahey, 2014, p. 1).

This notion of understanding basics before exploring more conceptual ideas, was what Dienes (1971) referred to as playing by the rules. It is only when learners can use numbers adaptably, that they are able to decompose and recompose them (Boaler, 2008).

Let us consider the following example of decomposing and recomposing: When calculating a 20% discount on an item of R350, it is fairly easy to know that 10% of the amount would be R35. The discount offered would therefore be R70, since 20% is double 10%.

Similarly, when calculating 99 x 7, one could calculate it as follows: 100 x 7 = 700, but that is 7 too many.

Therefore 99 x 7 = 700 – 7 = 693

Many learners are unable to break a question up into simpler parts and keep to memorised methods such a long multiplication shown in Figure 2.11.

FIGURE 2.11: EXAMPLE OF LONG MULTIPLICATION

$$\begin{array}{r} 99 \\ \underline{\times \quad 7} \\ 63 \\ \underline{+\ 630} \\ 693 \end{array}$$

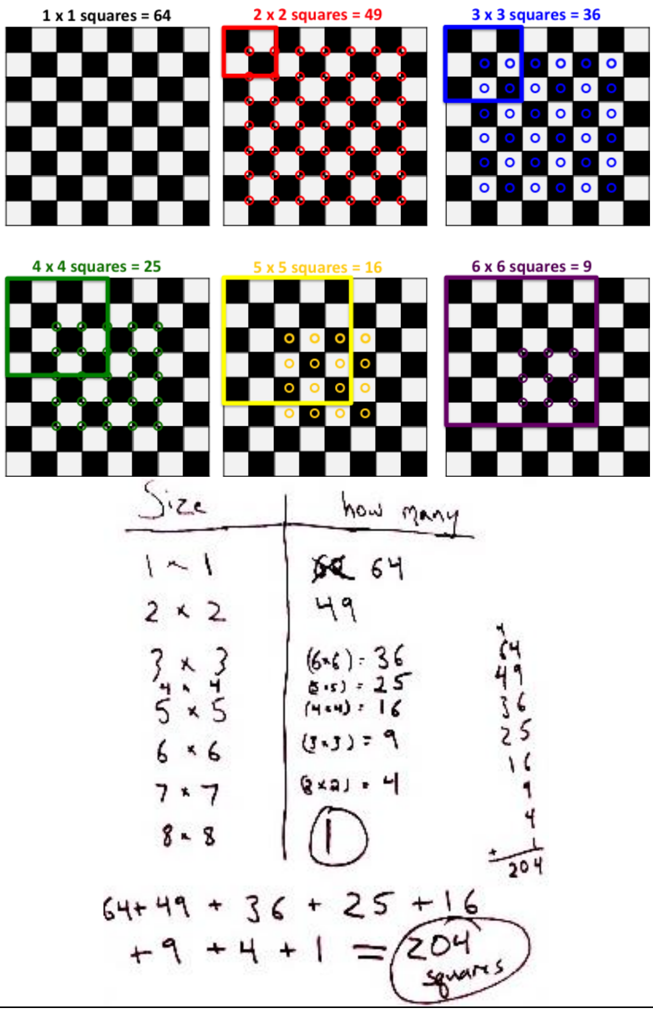
Memorisation in conjunction with problem-solving also forms an important part of a Whole Brain® approach to facilitating learning in Mathematics as it aids learners in working with numbers, and later also variables, in an adaptive manner.

2.2.4.3 ORGANISATION OF THOUGHTS

Boaler suggests that "low-achieving students" find it difficult to follow a structured approach to solving problems and that they are hesitant to draw the problem, try smaller cases and record their findings in a table or chart. Through her research "it became clear that one of the main things that was hurting the performance of the low achievers, in many features of their work, was the lack of careful recording or organisation of ideas" (Boaler, 2008, p. 190).

To illustrate this, Boaler gave students the problem of counting the number of squares, of different size, on a chessboard. The "low-achieving students… started counting them in a disorganized way and did not get them all" (Boaler, 2008, p. 190). One of Boaler's students, named Ella, followed a very systematic approach whereby she drew a circle in the middle of each square she counted and by doing so she discovered the following pattern and made the following chart to explain her finding and calculate a final answer (Boaler, 2008, p. 190) as shown in Figure 2.12.

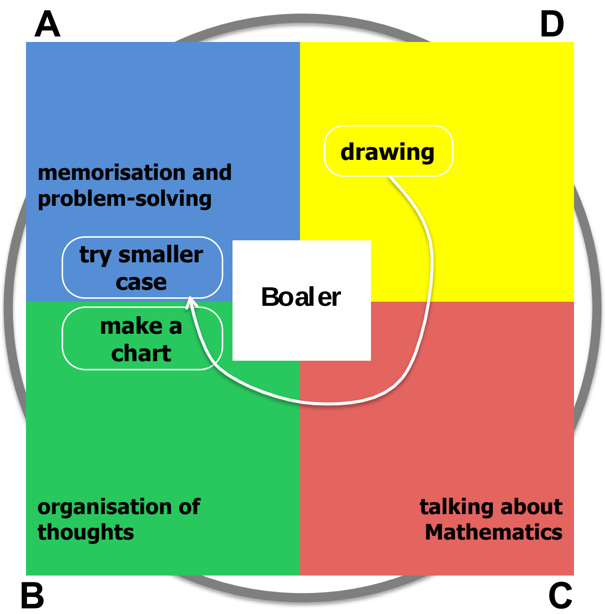
FIGURE 2.12: ELLA'S PATTERNS FOR COUNTING SQUARES ON A CHESS BOARD



By working systematically, looking for patterns and having knowledge about square numbers (1, 4, 9, 16…), Ella could come to a conclusion relatively quickly. As mentioned earlier, Boaler explains the process of organisation as "drawing the problem, making a chart with the numbers (and) trying a smaller case" (Boaler, 2008, pp. 185-186), exactly as Ella did it in the question above.

Boaler's idea of drawing the problem is both a means of exploring and representing the problem and for this reason I situate it in the D-quadrant. It could also be viewed as a means of getting an overview of what is being asked which aids in translating the problem into a simpler format from where it could be analysed, structured and formalise. This structured analysis, is what Boaler describes as making a chart and trying a smaller case which can be situated in the B- and A-quadrants respectively. This process becomes a Whole Brain® activity when learners are encouraged to talk about their thinking. Talking aids reflection, which I have situated in the C-quadrant. This movement between the quadrants is shown in Figure 2.13.

FIGURE 2.13: BOALER'S THEORY IN TERMS OF THE WHOLE BRAIN® MODEL



2.2.5 SCHOENFELD'S APPROACH TO PROBLEM-SOLVING

Schoenfeld has conducted extensive research into problem-solving in Mathematics. Through his university course on problem-solving, he has come to the belief "that much greater attention will have to be paid to "metaheuristics" or managerial actions in classroom instruction, if we are to be successful in teaching problem-solving skills" (Schoenfeld, 1988, p. 3).

Schoenfeld (1992, p. 356) posed the following three questions to his students during the problem-solving course as he walked around observing them whilst engaging a given problem:

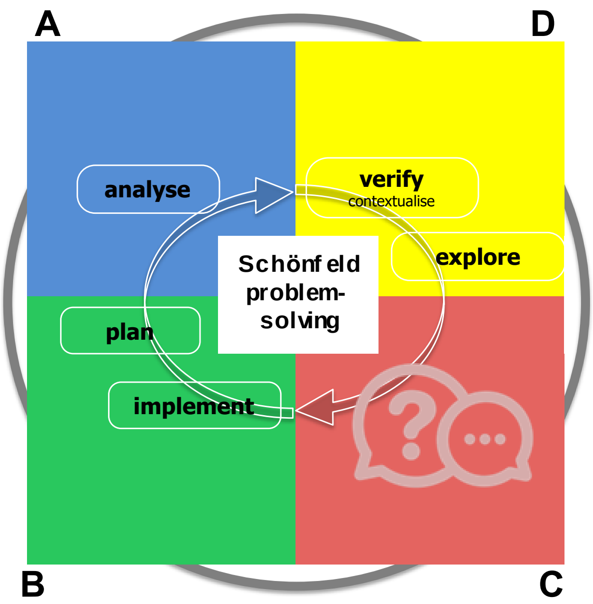
“What exactly are you doing? (Can you describe it precisely?)”
“Why are you doing it? (How does it fit into the solution?)
“How does it help you? (What will you do with the outcome when you obtain it?)”

Initially, students were bemused by these questions, but as they came to expect it, they began a habitual process of posing these questions to themselves or within the group they were working in. As a result of this process, his students moved from a problem-solving approach that was almost entirely exploratory in nature, to an approach that also includes analysis, planning, implementation and verification (Schoenfeld, 1992). The initial reflection, extrinsically provided by Schoenfeld, becomes an intrinsic process that transforms the heuristics into metaheuristics. The communication between Schoenfeld and his students and later between the students themselves, therefore aided the development of metacognitive strategies.

Schoenfeld, as Boaler (2008), therefore places an important emphasis on effective communication in Mathematics classrooms in order to establish a culture where learners are able reflect on their thinking and thereby managing their thinking process. Both the interpersonal as well as the intrapersonal reflection is therefore vital in developing a Whole Brain® meta-cognitive understanding of Mathematics. Schoenfeld’s research can therefore also be mapped on Herrmann’s Whole Brain® Model.

Whereas Boaler’s approach promotes a strategy where a learner systematically works through the four quadrants, starting at the D-quadrant and ending in the C-quadrant, Schoenfeld approach is more cyclic in nature. The process is initiated by the teacher (or lecturer) asking questions directing learners to activity think about their thinking. This initial communication, is a C-quadrant construct. The process following this is not necessarily linear in nature and learners are encouraged to *reflect* on every step of the process. The analysis process, which is situated in the A-quadrant, is therefore grounded in reflection situated in the C-quadrant. Similarly, the planning and implementation process, situated in the B-quadrant, is grounded in reflection, as so also the verification and exploration process, situated in the D-quadrant.

FIGURE 2.14: SCHOENFELD'S THEORY IN TERMS OF THE WHOLE BRAIN® MODEL



2.3 BLOOM'S REVISED TAXONOMY

Firstly it should be noted that Bloom's well-known cognitive taxonomy is part of "a complete taxonomy" consisting of "three major parts – the cognitive, the affective, and the psychomotor domains" (Bloom, 1956, p. 7). Bloom (1956, p. 7) describes the affective domain as "changes in interest, attitudes, and values, and the development of appreciations and adequate adjustment". Herrmann's Whole Brain® Model includes both the cerebral (thinking) as well as the limbic (feeling) modes, and it is therefore important that whilst relating Bloom's cognitive taxonomy with Herrmann's Whole Brain® theory, we do not completely exclude the affective domain.

Krathwohl's (2002) revised version of Bloom's taxonomy contains four instead of three knowledge dimensions as was used in Bloom's original taxonomy. With increasingly more research being conducted showing the importance of metacognition, metacognition was introduced as the fourth knowledge dimension along with factual, conceptual and procedural knowledge (Krathwohl, 2002).

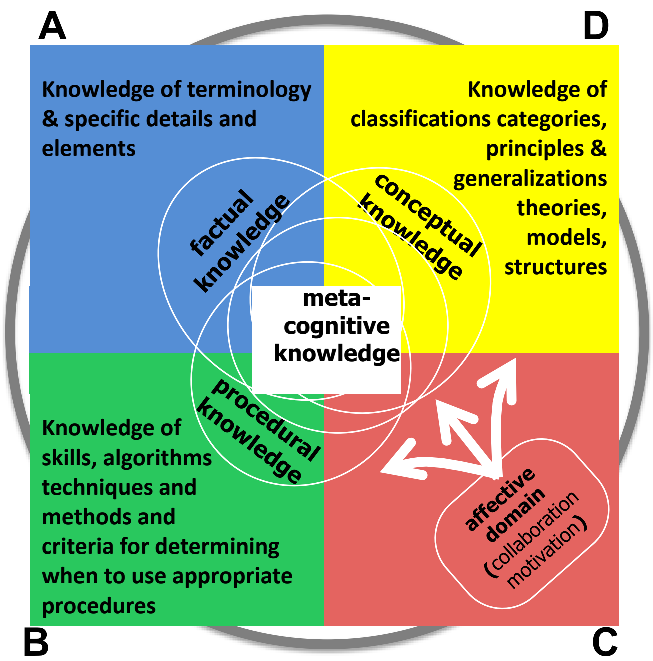
Whereas metacognition is seen as the reflective process, metacognitive knowledge is defined as knowledge about "what factors or variables act and interact in what ways to affect the course and outcome of cognitive enterprises" (Flavell, 1979, p. 907). Metacognitive knowledge is therefore the thoughts an individual has about his or her factual, conceptual and procedural knowledge.

In Figure 2.15, I have classified factual knowledge as an A-quadrant type of knowledge, since it is regarded as "knowledge of terminology", "specific details and elements" (Krathwohl, 2002, p. 214). I classified procedural knowledge as a B-quadrant type of knowledge since it involves "methods of inquiry, and criteria for using skills, algorithms, techniques, and methods" (Krathwohl, 2002, p. 214). I classified conceptual knowledge, an important level of understanding in Mathematics, as a D-quadrant type of knowledge, which centralises around the "interrelationships among the basic elements within a larger structure that enable them to function together" (Krathwohl, 2002, p. 214) or in short, synthesising. Where conceptual knowledge and the ability to synthesise knowledge was always seen as the highest level of understanding, the metacognitive level of reflection upon the process of coming to know is now considered to be the highest level of understanding.

Factual, conceptual and procedural knowledge, in interaction with the affective domain, therefore feeds the development of metacognition. Since metacognition is a reflective process that considers all these different thinking processes, and modes of thinking, it can therefore be considered a Whole Brain® process. This reinforces the foundation of this study: that in order for learners to have a higher level of understanding of Mathematics, or more specifically, a meta-understanding of Mathematics, the process of coming to this understanding must be a Whole Brain® facilitated process.

Although Krathwohl separates the cognitive domain from the affective domain, the research of Dewey, Vygostky and Boaler discussed earlier, have shown the importance of motivation and collaborative learning to move an individual beyond his or her current ability as well as their current mode of thinking. For this reason I included the affective domain in the diagram below since, from a constructivist approach, this domain is vital for the development of metacognition and more specifically, a metacognitive understanding of Mathematics.

FIGURE 2.15: KRATWOHL'S KNOWLEDGE DOMAINS IN TERMS OF THE WHOLE BRAIN® MODEL



The intersections between domains above suggest the continuous process of co-action between the different thinking modes associated with each of the four quadrants. This coaction supports Herrmann's (1995, p. 6) notion of problem-solving that should be the exploration of "messy" problems, which entails a process of solving that is not linear in nature, but equally "messy".

Kratwohl (2002) distinguish between Knowledge Domains and Cognitive Process Dimensions, the latter for whom Bloom is better known and which is used extensively in the design of assessment opportunities. Kratwohl's revised Cognitive Process Dimension Taxonomy, shown in Table 2.2, like Bloom's Taxonomy also includes six main categories. However, the names of these main categories have been changed to verbs.

TABLE 2.2: STRUCTURE OF THE COGNITIVE PROCESS DIMENSION OF THE REVISED TAXONOMY
1.0 Remember - Retrieving relevant knowledge from long-term memory. 1.1 Recognizing 1.2 Recalling **2.0 Understand -** Determining the meaning of instructional messages, including oral, written, and graphic communication. 2.1 Interpreting 2.2 Exemplifying 2.3 Classifying 2.4 Summarizing 2.5 Inferring 2.6 Comparing 2.7 Explaining **3.0 Apply -** Carrying out or using a procedure in a given situation. 3.1 Executing 3.2 Implementing **4.0 Analyze -** Breaking material into its constituent parts and detecting how the parts relate to one another and to an overall structure or purpose. 4.1 Differentiating 4.2 Organizing 4.3 Attributing **5.0 Evaluate -** Making judgments based on criteria and standards. 5.1 Checking 5.2 Critiquing **6.0 Create -** Putting elements together to form a novel, coherent whole or make an original product. 6.1 Generating 6.2 Planning 6.3 Producing

Any of the outcomes in the revised Cognitive Process Dimension Taxonomy can be classified as Factual-, Conceptual-, Procedural or Metacognitive Knowledge. This led Kratwohl to design a two-dimensional Taxonomy Table as shown in table 2.3. In this table I also assigned quadrants to both the knowledge dimension as well as the cognitive process dimensions.

TABLE 2.3: KRATWOHL'S TWO-DIMENSIONAL TAXONOMY TABLE

The Knowledge Dimension	The Cognitive Process Dimension					
	Remember A-quadrant	Understand A-quadrant	Apply D-quadrant	Analise A-quadrant	Evaluate B-quadrant	Create D-quadrant
Factual knowledge (A-quadrant)						
Conceptual knowledge (D-quadrant)						
Procedural knowledge (B-quadrant)						
Metacognitive knowledge						

Many of the theories discussed in this chapter are well-known and are used to some degree when designing learning and assessment opportunities in Mathematics. Since all these theories substantiate the claim that a Whole Brain® approach is needed to facilitating learners in Mathematics, the following section will discuss how a Whole Brain® could be introduced into the South African Curriculum.

2.4 SOUTH AFRICA'S CURRICULUM IN COMPARISON TO INTERNATIONAL TRENDS

The Department of Basic Education, in the Curriculum and Assessment Policy Statement (CAPS) for Mathematics in the senior phase, state that "formal assessments should cater for a range of cognitive levels and abilities of learners" (Department of Basic Education, 2011, p. 156) and prescribe four different cognitive levels for formal assessments in Mathematics: knowledge, routine procedures, complex procedures and problem-solving. This is similar to Krathwohl's knowledge dimensions and we can equate the four levels as follows:

- Knowledge, similar to Krathwohl's factual knowledge, can be situated in the A-quadrant.
- Routine procedure, similar to Krathwohl's procedural knowledge, can be situated in the B-quadrant.
- Complex procedures, similar to Krathwohl's conceptual knowledge, can

be situated in the D-quadrant.

- Problem-solving, similar to Krathwohl's meta-cognitive knowledge, can be situated in all four quadrants as a Whole Brain® endeavour.

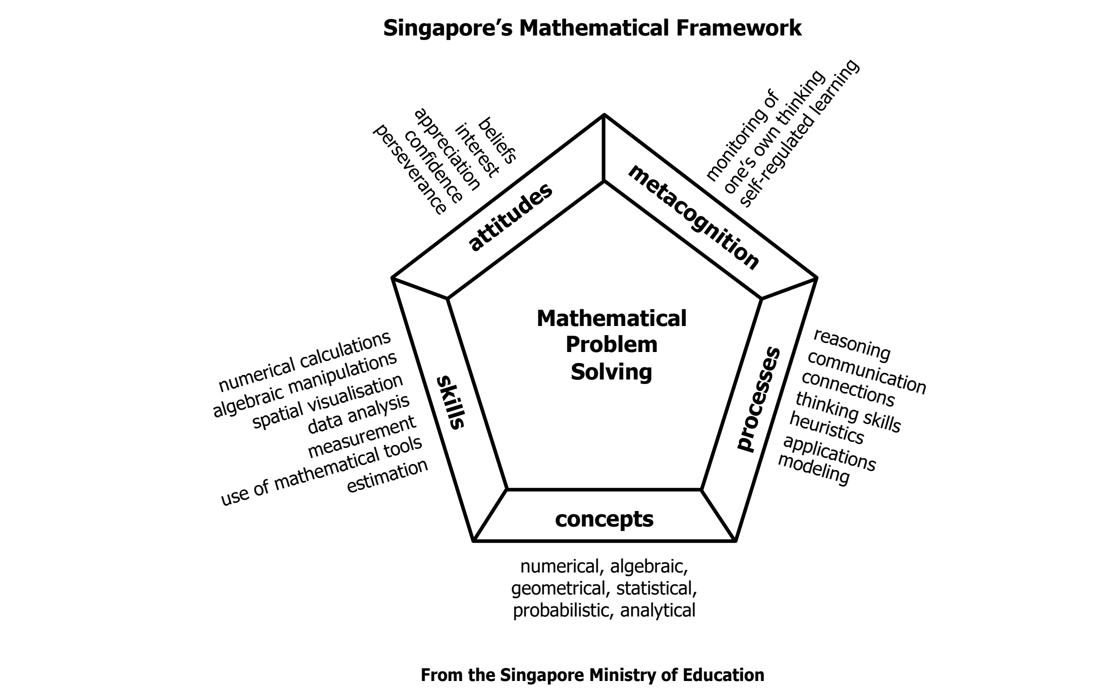
Further to this, the Department of Basic Education provide a definition in the CAPS document explaining Mathematics both as a language and a science (Department of Basic Education, 2011, p. 10), supporting the notion proposed in this study of Mathematics as a Whole Brain® undertaking:

> "Mathematics is a language that makes use of symbols and notations to describe numerical, geometric and graphical relationships. It is a human activity that involves observing, representing and investigating patterns and quantitative relationships in physical and social phenomena and between mathematical objects themselves. It helps to develop mental processes that enhance logical and critical thinking, accuracy and problem-solving that will contribute in decision-making."

The definition set out in the Curriculum and Assessment Policy Statement focus mainly on attitudes towards the study of Mathematics. Together with the assessment cognitive levels, the CAPS provide a fairly balanced approach to Mathematics, however, specifics on how the different mental processes should be developed are limited in the document.

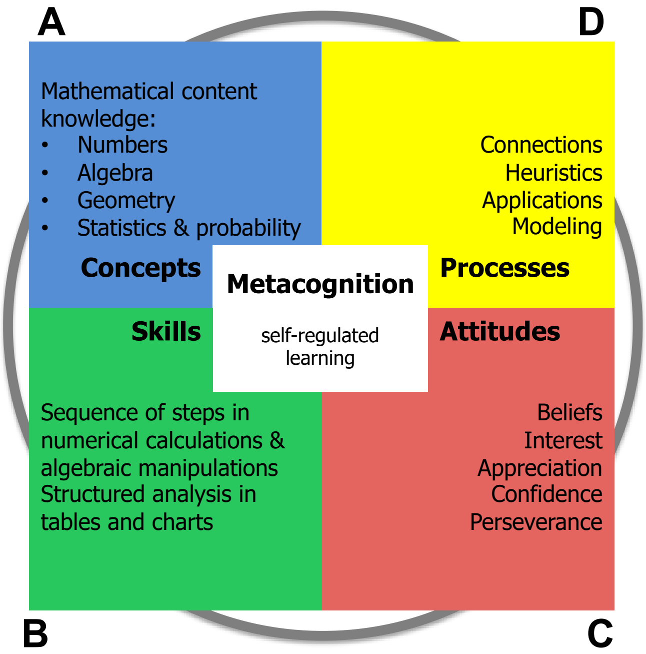
In contrast with the South African CAPS, the framework for the 1990 Singapore Mathematics curriculum (Lim-Teo, 2002, p. 5) below shows a summary of approaches to be followed by teachers in order to support learners to reach the objectives set out in the syllabus. Although minor changes had been made since the introduction of the Singapore Mathematics Curriculum Framework since 1990, the pentagonal model, in Figure 2.16, has remained unchanged. Although creating meaningful learning opportunities is never a simple task, the model provides a simple frame of reference for the planning of learning opportunities and facilitating learning based on concepts, skills, attitudes, processes and the importance of metacognition in solving problems.

FIGURE 2.16: THE SINGAPORE MATHEMATICS FRAMEWORK



This study proposes that the comprehensive Mathematics-specific Whole Brain® Model for facilitating learning in Mathematics, which is similar to the Pentagonal Model of the Singapore curriculum, could provide a framework for South African Mathematics teachers in the planning of learning opportunities as well as the facilitation and assessment of learning in Mathematics. As with the Singaporean Pentagonal Model, the comprehensive Mathematics-specific Whole Brain® Model is supported and built on existing research, with an aim to activate learners to develop a Whole Brain® metacognitive understanding of Mathematics. This becomes clear when mapping the constructs of the Pentagonal Model on Herrmann's Whole Brain® model, as seen in Figure 2.17.

FIGURE 2.17: THE SINGAPOREAN FRAMEWORK FOR MATHEMATICS IN TERMS OF THE WHOLE BRAIN® MODEL



Concepts can be ascribed to the A-quadrant due to the focus on knowledge of concepts. Skills, that are required through following a sequence of steps, or by means of analysis using table and charts, are seen to be B-quadrant thinking processes. Attitudes, which includes beliefs, interests, appreciation, confidence and perseverance falls within the C-quadrant. Processes of making connections and applying concepts and skills, along with the use of heuristics and modelling, is classified as D-quadrant thinking processes.

Flavell (1979, p. 908) states that metacognition "can lead you to select, evaluate, revise, and abandon cognitive tasks, goals, and strategies in light of their relationships with one another and with your own abilities and interests with respect to that enterprise". Hence, due to the nature of metacognition as a self-regulated reflective process, I placed it in the centre of the model in Figure 2.17, as it requires reflective thought on the concepts, skills, processes as well as attitudes of the individual engaging in the mathematical process.

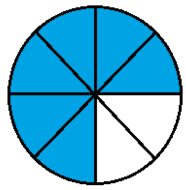
SINGAPORE'S MULTI-MODAL STRATEGY

The Singapore Mathematics curriculum team adapted Bruner's enactive, iconic and symbolic approach in the early 1980's to that of concrete, pictorial and abstract, or in short the CPA approach. The CPA approach formed the basis of a set of teaching materials and textbooks at primary school level, which became renowned in several countries outside of Singapore. Towards the end of the previous century, Wong (2015) extended this three-stage approach to six stages, or more appropriately referred to as six modes, for facilitating and assessing the learning of Mathematics at a high school level. Known as the Multi-Modal strategy (MMS), it was developed in order to "promote deep understanding" in Mathematics at higher grade levels (Wong, 2015, p. 43). Whereas Bruner's approach is often misinterpreted as a chronological progression, possibly as a result of Bruner's use of the word *stage*, Wong uses the word *mode* to imply the different representations, rather than stages of development (Hoong, Kin, & Pien, 2015). The six modes, briefly discussed below, are identified according to action words in order to simplify the process for both teachers and learners, namely: do, communicate, calculate, visualise, manipulate and apply (Wong, 2015).

Similar to that of the enactive (or concrete) stage, the Multi-Modal strategy starts with the action word *do*. This first stage requires active participation of learners in the manipulation of objects and not merely observing the manipulation being done by a teacher or peer. This stage can be associated with Herrmann's C-quadrant as it is a hands-on approach to learning.

The second mode is *communicate*. Being fluent in Mathematics is not as simple as being fluent in English or any other language in which one is learning. It is true that a sound understanding of the language in which one studies Mathematics definitely aids one's understanding of the subject matter, but it is still necessary to translate certain linguistic expressions into mathematical expressions and visa versa. Communication about a mathematical problem, allows a learner to make sense of what is being asked. For example, if the size of a pizza slice is one eighth of a whole pizza, how many slices, of this size, can be cut from three quarters of a pizza?

The first step to interpreting this question, might be to ask how many ⅛'s would fit into ¾'s? Depending on the learner's grasp of fractions, they might either use repeated addition or division to solve the problem, as seen in Figure 2.18.

FIGURE 2.18: REPEATED ADDITION IN COMPARISON TO DIVISION	
$\frac{1}{8} + \frac{1}{8} = \frac{1}{4}$ $\frac{1}{8} + \frac{1}{8} = \frac{1}{4}$ $\frac{1}{8} + \frac{1}{8} = \frac{1}{4}$ therefore 6 slices make ¾ of a pizza	$\frac{3}{4} \div \frac{1}{8} = \frac{3}{4} \times 8 = 6$ slices 
REPEATED ADDITION	DIVISION

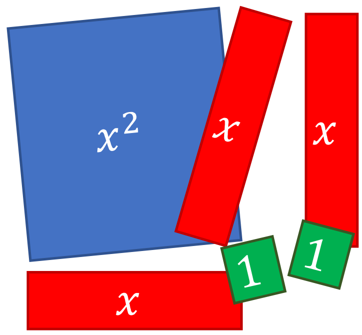
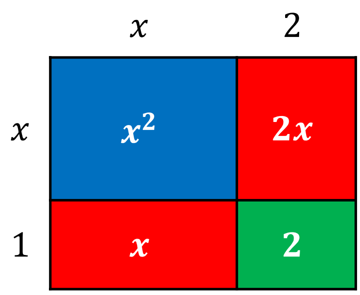
Rephrasing the questions aims to help learners understand the situation and prevent them from trying to guess which of the four operations (multiply, divide, add or subtract) are appropriate for the situation. This stage links closely to the emphasis placed on communication, cooperative learning and the zone of proximal development by Vygotsky as well as Herrmann's C-quadrant focus of sharing and internalising. A learner might not be able to "translate" the problem into something meaningful for him- or herself, but with the assistance of a peer, they might be guided to form a better understanding once they have been assisted in the translation process. This process can take place between learners, between a learner and teacher or even individually in the form of written communication. Communication therefore not only precedes the iconic and symbolic stages, but communication can also transpire into these representations of thought.

The third mode is when learners *calculate* a given problem, after they have communicated or translated the problem. The calculation stage can also be used to make sense of algebraic rules, since these rules are based on number properties. In Figure 2.19 it shown how the multiplication exponent rule needed in Algebra build on number properties. Translating their knowledge of number properties to their understanding of algebraic exponent rules, will aid an understanding for the rules. Calculate, is a skill associated with Herrmann's A-quadrant as it is part of quantifying.

FIGURE 2.19: ALGEBRAIC EXPONENT LAWS BUILDING ON NUMBER CONCEPTS	
$\boldsymbol{x^3 \times x^7 = x^{3+7} = x^{10}}$ because: $(x \times x \times x) \times (x \times x \times x \times x \times x \times x \times x) = x^{10}$	$\boldsymbol{2^3 \times 2^7 = 2^{3+7} = 2^{10}}$ because: $(2 \times 2 \times 2) \times (2 \times 2 \times 2 \times 2 \times 2 \times 2 \times 2) = 2^{10}$
EXPONENT RULES IN ALGEBRA	NUMBER PROPERTIES

The fourth mode is to *visualise* and refers to the use of different visual representations. As with communicating about a given problem, seeing the problem represented in different formats can also aid a better understanding. Patterns, for example, can be formed using concrete objects (or manipulatives), representing the number relationships in a table or flow diagram format, by writing number sentences or formulas. These different representations of patterns are widely used in South African textbooks and even stipulated in the Curriculum and Assessment Policy Statement (CAPS) for Mathematics in the senior phase. Visual representations in other areas of the curriculum are limited and almost not specified in the CAPS document. Bruner and Kenney (1965, p. 56) state the importance of "giving a child multiple embodiments of the same general idea" in order to aid their abstraction process. This idea of visual representations and multiple embodiments, were explored by Hoong, Kin and Pien (2015, p. 13) upon introducing students in Singapore to factorisation. In Figure 2.20, it is shown how the concept of factorisation could be explained through the use of AlgeCards. These cards are physical cards (manipulatives) that learners can use to help them factorise an expression. It is based on the idea of a trinomial as the area of four different rectangles. Although learners initially physically build and manipulate trinomials with the different AlgeCards, it aids them in developing abstract manipulation skills. Fitting with Herrmann's Whole Brain® approach, these multiple embodiments give learners with different thinking preferences an opportunity to explore the same concept in multiple ways in order to develop a conceptual understanding of the specific topic. It can therefore be associated with Herrmann's D-quadrant.

FIGURE 2.20: MULTIPLE EMBODIMENTS

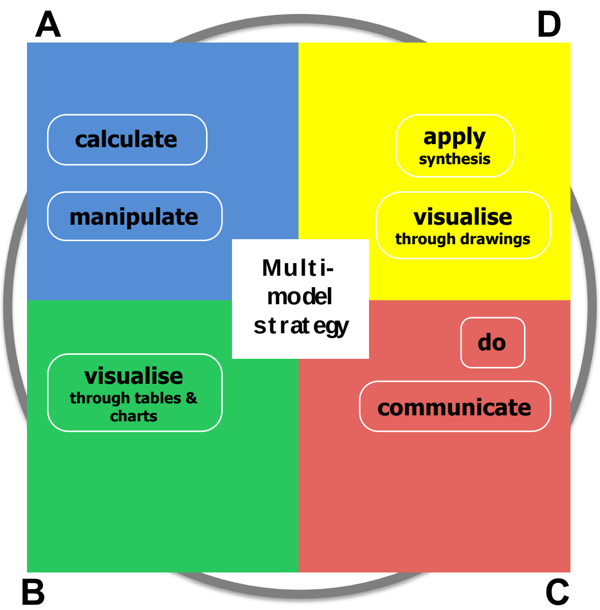
Factorise	***AlgeCards* Diagram**	**Rectangle Diagram**
$x^2 + 3x + 2$ $= (x+1)(x+2)$		

The fifth mode is that of *manipulation*. Ideally this stage would see learners factorise trinomials, but instead of positive coefficients as in the example above, learners would be able to factorise trinomials with negative values. In the context of the length and width of a rectangle, as used in the example above, negative values would not make sense, but at this stage of manipulation, the focus is solely on the abstract manipulation of the expression. Hoong, Kin and Pien (2015, p. 15) state that many Mathematics teachers tend to teach exclusively to this stage since they perceive a Multi-Modal strategy to take "up an unrealistic amount of classroom time; and/or not of direct benefit to students in terms of test scores for the topic" and propose that any attempt to promote a Multi-Modal strategy should take these perceptions into consideration. The ability to manipulate expressions and numbers is an important part of theorising and logical processing associated with Herrmann's A-quadrant.

The sixth mode is that of *apply* where problems are given in a specific context in order to determine whether learners can relate what they were able to calculate, manipulate and communicate to a real-life problem. But application does not only have to follow these modes, it can also precede these modes as means of introducing, and engaging learners into, a new topic. Application is a means of conceptualising and synthesising understanding and is therefore associated with Herrmann's D-quadrant.

The modes do not have to be followed in sequence. It is suggested by Wong (2015) that the same topic is covered by means of different modes over the extent of a number of learning opportunities, after which learners could be supported towards a holistic, or in terms of this study, a Whole Brain® understanding of the topic. In accordance with the research by Herrmann (1990), Wong (2015, p. 47) argues that learners "should be extended beyond their preferred mode or comfort zone in order to deepen their learning".

FIGURE 2.21: WONG'S MULTI-MODAL STRATEGY IN TERMS OF THE WHOLE BRAIN® MODEL

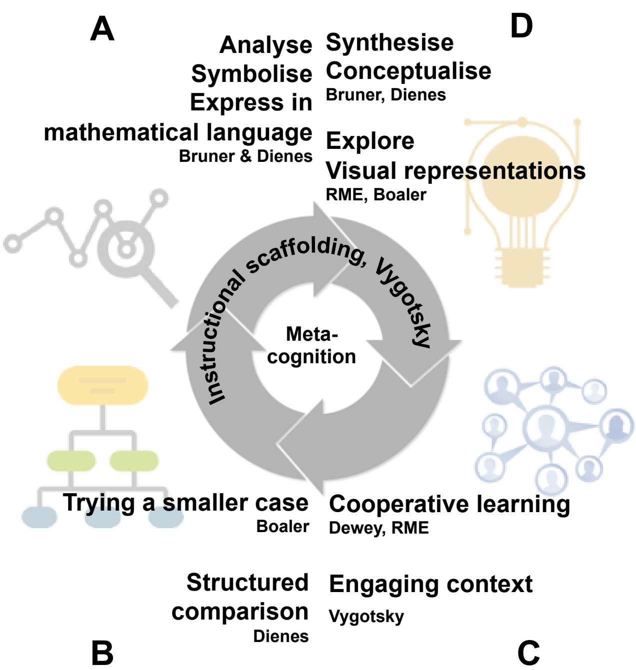


2.5 THE PROPOSED COMPREHENSIVE MATHEMATICS-SPECIFIC WHOLE BRAIN® MODEL FOR FACILITATING LEARNING IN MATHEMATICS

In considering the theories discussed and analysed according to Herrmann's Whole Brain® model in this chapter, the need for a Whole Brain® approach to facilitating and assessing learning in Mathematics is validated. It also validates the use Herrmann's Whole Brain® Theory as the foundation for an integrated theory of practice.

In order to create a structure similar to that of the Singaporean Pentagonal Model, I have synthesised the theories into the proposed comprehensive Mathematics-specific Whole Brain® model as indicated in Figure 2.22. This model is also proposed as the conceptual framework of this research innovation as indicated in Figure 1.2.

FIGURE 2.22: PROPOSED COMPREHENSIVE MATHEMATICS-SPECIFIC WHOLE BRAIN® MODEL FOR FACILITATING LEARNING IN MATHEMATICS



The comprehensive Mathematics-specific Whole Brain® model synthesises the Whole Brain® models discussed in this chapter and indicates meta-cognition as a Whole Brain® process at the centre of the diagrams. Instructional scaffolding is indicated as the process through which teachers can facilitate the Whole Brain® learning process.

My reflection on this conceptual framework as an integrated theory of practice was adapted through the course of the research innovation and the adapted post-innovation Mathematics-specific Whole Brain® model is indicated in Chapter 6. In the meta-reflective nature of action research, this integrated theory of practice is therefore my living (or growing) theory which is revisited and adapted through the course of the research innovation.

2.6 Professional Development as a process of informing practice

Dienes (1970, p. 269) argues that "the mathematics teacher… must be a little bit of a mathematician, a little bit of a psychologist and, of course first and foremost, a pedagogue". Not only is Dienes' plea in line with the seven roles of a teacher (Department of Education, 2011. p. 51), but it also suggests that teachers should aspire to be a Whole Brain® practitioners.

Unfortunately, by default "a teacher will teach as he was taught himself. He remembers how he was taught, and even without thinking he will carry on in the same way. If he was taught in school and even in teacher's college through lectures, he will tend to lecture to the children" (Dienes, 1970, p.265).

It is important to note that the way teachers would like their learners to learn is no different to the way teachers themselves learn. Active engagement is as applicable to learners when they engage in learning opportunities, as it is to teachers in their planning of these learning opportunities. The focus of this study is therefore not only on ways to facilitate active participation in the execution of tasks during learning opportunities for learners, but also on the active participation of teachers in their planning of these learning opportunities. The reflective practices in which teachers engaged during this study, does not only form part of the action research paradigm of this study, but also pertains to the professional development of teachers in the study.

The conceptual framework of this study therefore applies both to the learning opportunities and the professional development process in the planning of these learning opportunities. Exploring, scaffolding, creating and analysing, are all aspects which are equally important for learners in the process of understanding Mathematics, as it is for teachers engaging in professional development on their quest for developing more valuable learning opportunities.

With metacognition being central to both the learning process and the planning of the learning opportunity, the professional development proposed in this study is part and parcel of reflective practice.

Schön (1992, p. 123), who is synonymous with the term reflective practice, uses "'reflective practice' as (his) version of Dewey's 'reflective thought'". The notion of reflective practice builds on ideas expressed by Dewey "to integrate thought and action, theory and practice, the academy and the everyday world, but also in the spirit of a constructivist approach to the variety of ways in which we construct the reality of problematic situations".

Lieberman (1995, p. 52) explains that "(t)he focus is on development rather than training, because the belief is that teaching is an activity in which teachers make specific decisions about what action to take in response to a unique learning situation", rather than prescribed actions to specific learning situations. This study therefore used professional development, through the introduction of Herrmann's Whole Brain® theory, to initiate reflective practice. And since the Herrmann Brain Dominance Instrument® was developed for "services in personal, interpersonal, staff and organisational development" (Hall, 2004, p. 86) it is unquestionably suited.

Lieberman (1995, p. 53) further suggests four strategies for reflective practices in schools when engaging with professional development programmes, which include: "Reflection on learning", "Reflection on self", "Reflection on action" and "Reflection on program improvement". The reflective practice by the teachers involved in the professional development therefore supported the reflective practice teachers aim to impose on their learners when they engage in problem-solving. Metacognition therefore becomes an integral part of facilitation and assessment of learning – both for teachers and learners. Professional development in itself is therefore, according to Lieberman, a Whole Brain® endeavour.

Although metacognition is inherently an individual, internal and intrapersonal process, metacognition is born out of reflection, which is often initiated by a team of reflective practitioners. Garrison (2003, pp. 4,5) states that "true communities of inquiry are possible through collaborative and reflective communication. The goal is independent thinkers nurtured in an inter-dependent collaborative community of inquiry." The community of practice, which in turn supports the collaborative practice, consequently supports an individual's autonomous metacognition.

Rogan and Anderson (2011, p. 238) report that "the creation of such a community (of practice) might in the long run be of more benefit than the innovation itself as more extensive professional development usually results from such close interaction between faculty members". In the context of this study 'faculty members' refer to the teachers at the school in question who participated in the study. The professional development as the vehicle for innovation is therefore an overarching outcome in itself as the "implementation of the innovation provides an unparalleled vehicle for collaboration between [teachers]" (Rogan & Anderson, 2011, p. 238). The professional development therefore supports the implementation of the Whole Brain® theory, just as the Whole Brain® theory supports the professional development.

The specific type of professional development for this study was collective practice, also called a community of practice, within an array of processes of action research. Although it could be argued that this study involves peer mentoring, it should be noted that "the essential difference between the two (peer mentoring and community of practice) is that a community of practice generally involves more than two people" (Kennedy, 2014, p. 244). Where peer mentoring assumes that there is a difference in the level of knowledge between the mentor and the mentee, a community of practice draws on the sum total of "individual knowledge and the combinations of several individuals' knowledge through practice, as a powerful site for the creation of new knowledge" (Kennedy, 2014, p. 244). This is at the core of action research: a community of practitioners, collectively and individually reflecting on their practice in order to find answers to questions emerging from their reflective practice. This reflective nature of action research is not necessarily present in all communities of practice, but a community of practice is needed for reflective action research. Action research within a community of practice also moves the "balance of power towards teachers themselves through their identification and implementation of relevant research activities" (Kennedy, 2014, p. 244).

Kennedy (2014, p. 248) classifies the community of practice as a "transitional" professional development model, whereas action research (within a community of practice) is classified as a "transformative" professional development model. This implies that a community of practice could potentially inform practice, but that when the community of practice engage in action research, transformation is inevitable.

Wenger (2011, p. 5) states that effective communities of practice within educational institutions can impact the facilitation and assessment of learning along the following three extents:

> "Internally: How to organize educational experiences that ground school learning in practice through participation in communities around subject matters?
> Externally: How to connect the experience of students to actual practice through peripheral forms of participation in broader communities beyond the walls of the school?
> Over the lifetime of students: How to serve the lifelong learning needs of students by organizing communities of practice focused on topics of continuing interest to students beyond the initial schooling period"

What Wenger envisions for effective communities of practice, hence, those engaging in action research, is in line with the both the critical cross field outcomes as well as the seven roles of a teacher as stated in the National Curriculum Statement. In particular the critical outcome of learners having to "demonstrate an understanding of the world as a set of related systems by recognising that problem-solving contexts do not exist in isolation" (Department of Basic Education, 2011, p. 5) and a teacher being an "interpreter and designer of learning programmes and materials", a "leader, administrator and manager", a "scholar, researcher and lifelong learner", and a community citizen practicing pastoral care (Department of Education, 2011. p. 51).

2.7 CONCLUSION

In this chapter the necessity for a Whole Brain® approach to the facilitation and assessment of learning in Mathematics was validated through an analysis of pragmatic and cognitive psychology theories, cognitive domain knowledge as well as theories specific to facilitating learning opportunities in Mathematics. The need for a Whole Brain® approach was further validated by drawing comparisons between the acclaimed Singapore Mathematics Curriculum

Framework, which includes Wong's Multi-Modal, and the Mathematics-specific Whole Brain® model developed during this innovation. Lastly, professional development was introduced as means of introducing the theory underlying the Mathematics-specific Whole Brain® model as means of informing the teaching practice.

Action research as research design will consequently be discussed in Chapter 3 as well as action research as a Whole Brain® undertaking. The importance of Herrmann's Whole Brain® theory in terms of facilitating and assessing learning in Mathematics as well as the importance when engaging in action research within communities of practice, validates the use of the theory within an educational setting and therefore motivates the need for Whole Brain® research at school level in South Africa.

CHAPTER 3

"The great aim of education is not knowledge, but action."

Spencer (1896)

3.1 INTRODUCTION

As a teacher and researcher wanting my research not merely to produce knowledge, but knowledge transformed into action, it seems only fitting to use action research as the research design and living theory of this research innovation. McNiff (2013, p. 18) states that "(a)ction researchers see knowledge as something they do, a living process" and that once this happens "the boundaries between theory and practice dissolve and fade away, because theory is lived in practice and practice becomes a form of living theory" (McNiff, 2013, p. 35).

This chapter therefore positions the research design and methods in terms of my living theory approach to action research and concludes with matters of validity, reliability and trustworthiness. This approach implies that my understanding of the theory is *living* or organic, as it evolves throughout the course of the innovation through my engagement with reflection on the theory.

3.2 RESEARCH DESIGN

3.2.1 RESEARCH PARADIGM

Fitting with the action research design of knowledge, and very importantly the reflection on this knowledge being transformed into action, the paradigm of this study is that of praxis. This paradigm is also consonant with my own Herrmann Brain Dominance Instrument® profile of cerebral dominance.

Herrmann (1990, p. 3) describes an A- and D-quadrant dominant (cerebral) profile as “cognitive pragmatic”. Praxis as the paradigm of this innovation is therefore not only suited to action research, but also to my own strength as a researcher.

The connection between praxis and action research is captured in Cohen, Manion and Morrison’s (2007, p. 301) definition of praxis “as action informed through reflection, and with emancipation as its goal”. Emancipation in terms of the Herrmann Brain Dominance Instrument® is a rather significant notion, since, as stated earlier, the instrument should not be seen as a labelling tool, constricting the individual, but rather as an instrument designed to start a reflective process about differences and similarities between individuals engaging with the Herrmann Brain Dominance Instrument®. This reflective process could potentially lead to emancipation, when an individual starts exploring their non-dominant thinking preferences and as a result is no longer restricted to their dominant preference or preferences.

McTaggart (1994, p. 317) elaborates on the reflective nature of action research as “a form of self-reflective enquiry undertaken by participants in social situations in order to improve the rationality, justice, coherence and satisfactoriness of (a) their own social practices, (b) their understanding of these practices, and (c) the institutions, programmes and ultimately the society in which these practices are carried out”.

McTaggart’s definition of action research makes the different types of reflective processes that are involved in moving towards emancipation apparent. It also captures the essence of what this study intended to achieve: that teachers within the community of practice may have become more reflective of their own thinking preferences after the introduction of the Herrmann Brain Dominance Instrument®; that the participating teachers may have reflected and came to an informed understanding of how their thinking preferences inform their practice; that they may collectively plan and facilitate learning opportunities based on the proposed Mathematics-specific Whole Brain® model; and that the proposed learning opportunities may positively impact on their practice within their classroom and within the school community. Since action research and praxis are so closely related, action research could therefore in itself be considered a research paradigm.

Since I was an active participant in this study, the study was, more specifically participatory action research. Participatory action research recognises the dual role of the researcher as participant obtaining "knowledge enriched by diverse points of view in an educational process 'empowering' all those involved to change themselves, their relationships with each other and their world" (Ehrhart, 2012, p. 1). As with the definition of praxis, the idea of "empowering" (Ehrhart, 2012, p. 1) and "emancipating" (Cohen et al., 2007, p. 301) those involved in the research feeds into the role of the community of practice, as discussed in the previous chapter.

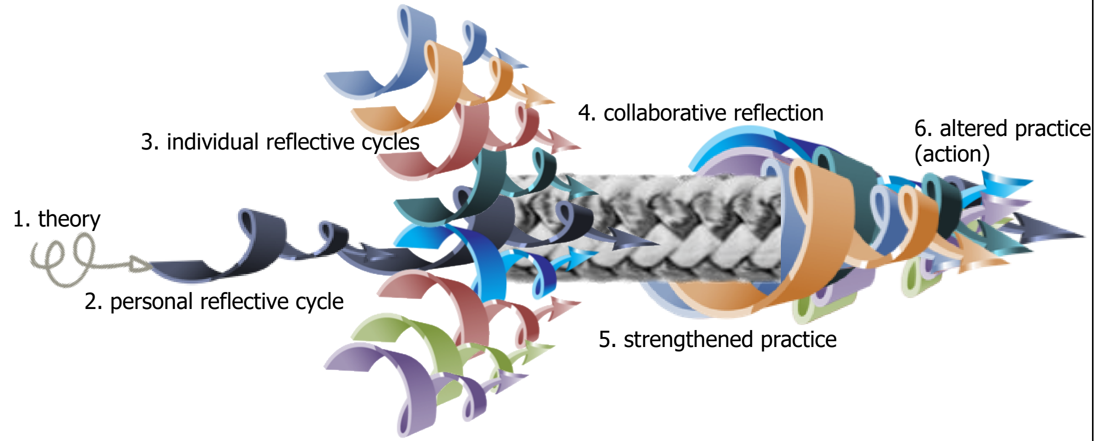
A fundamental element of the participatory action research process, as with action research, is the role of reflective practice: both the reflection of each individual, and the reflection between members within the community of practice. Somekh (1995, p. 347) states that "(a)t the deepest level, reflection in action research is a complex, holistic process, interdependent with decision-making", once again supporting the notion of knowledge and reflection informing action.

Phelps and Hase (2002, p. 514) expand on the notion of reflection by adding that action research is a "cyclical process in which action contributes to knowledge and knowledge alters action, and members of the context are central to the research process". But the cyclic process also "involves problem formulation, operationalization, hypothesis formulation, data gathering, data analysis, action design, action, evaluation of the action and redesign of the hypotheses, interpretations, and actions in an ongoing cycle" (Greenwood & Levin, 2013, p. 54). The cyclic process can therefore be seen as a creative problem-solving process (Lumsdaine & Lumsdaine, 1995), which leads to a relational understanding (Skemp, 1976) and conceptual knowledge (Rittle-Johnson & Alibali, 1999). Both the action research process and the process of learning Mathematics, is therefore a meta-cognitive Whole Brain® endeavour.

In order to illustrate the notion of reflective cycles grounded in theory and leading to altered practice or action, I designed the Randewijk Rope Model, seen in figure 3.1 below as well as in Figure 1.3. With theory as the core of the rope, around which my own, and the reflective cycles of my colleagues are woven, the theory is strengthened by the collective reflective practice of the group which strengthens the facilitation and assessing of learning in Mathematics.

Each individual's reflective cycle towards improved practices therefore not only strengthens the individual's personal professional development, here shown as a strand of rope, but also contributes towards the strengthening of the community of practice, indicated as the rope itself. My own reflective practice is grounded in Herrmann's Whole Brain® theory of facilitating and assessing learning, which forms the foundation of my conceptual framework. It is also the first strand of rope, or the core of the rope around which all reflection takes place. Since I engaged in professional development with my colleagues in order to inform their practice, and since my conceptual framework is the theory which aimed to inform our collective practice and will still be informing it in future, one can view the theory, or conceptual framework, as the strand of fibre at the core of the reflective process, which, in the nature of action research, informs practice or action. This participatory action research model therefore shows the close-knitted scholarly community of practice.

Figure 3.1: Randewijk Rope Model depicting the reflective nature of participatory action research



Du Toit (2012, p. 1221) states that "scholarly reflection is an essential principle of action research and when blended with the term whole brain learning, it gives rise to the construct whole brain scholarly reflection", which is both the paradigm and the objective of the study. "Whole brain scholarly reflection" (Du Toit, 2012, p. 1221) through the process of action research, is therefore vital in answering the research questions.

3.2.2 Mixed-methods research as research approach

McKernan (2016) advocates that the methods appropriate for action research should not be prescribed, but that they are dependent on what the action researcher deems to be valuable to the specific study. De Boer, Du Toit, Scheepers and Bothma (2013, p. 10) state that the Herrmann Brain Dominance Instrument®, which is used to determine the thinking preferences of participants in this research innovation, is a "visual representation… rich with quantitative data. The working, interpretation and visual representation on the other hand offers qualitative data that perfectly fits a mixed-method approach towards studying the application of Whole Brain® principles in the context of learning and facilitating learning". The research approach of this study is therefore a mixed-methods approach, supporting the nature of Herrmann's Whole Brain® theory and the Herrmann Brain Dominance Instrument® itself.

Since both action research (Greenwood & Levin, 2013) and mixed method research (Johnson & Onwuegbuzie, 2004) are born out of pragmatism, the method supports the paradigm.

Johnson and Onwuegbuzie (2004, p. 17) define mixed method research as "the class of research where the researcher mixes or combines quantitative and qualitative research techniques, methods, approaches, concepts or language into a single study. It explains that a mixed method approach is "an attempt to legitimate the use of multiple approaches in answering research questions, rather than restricting or constraining research choices". If we consider the field of Mathematics, which is quantitative in nature and the field of education, which is humanitarian and therefore largely qualitative in nature, it seems natural that a study that focuses on the reflective practice of Mathematics teachers should follow a mixed method approach. Furthermore, as the study focused on teachers not being restricted by their thinking preferences, so the research approach should also not be restricted to either a qualitative or quantitative approach.

3.2.3 Participatory action research as research strategy

The educational process involves the teachers, the learners and the content or curriculum to be covered. Initially, the idea was that the research methods used would focus on all three of these aspects in order to obtain the most comprehensive comparison between teachers' perspectives, learners' perspectives of their teachers' approach to learning and assessment as well as how teachers can potentially adapt content to accommodate more diverse thinking preferences. But through initial data collection, it became evident that the content teachers use does not necessarily produce data on their thinking preferences or their approaches to facilitation and assessment of learning. Similarly, the data gathered from learners, by giving them problem-solving questions in an attempt to analyse their methods, were also inefficient in gathering data on teachers' approaches to facilitating and assessing learning.

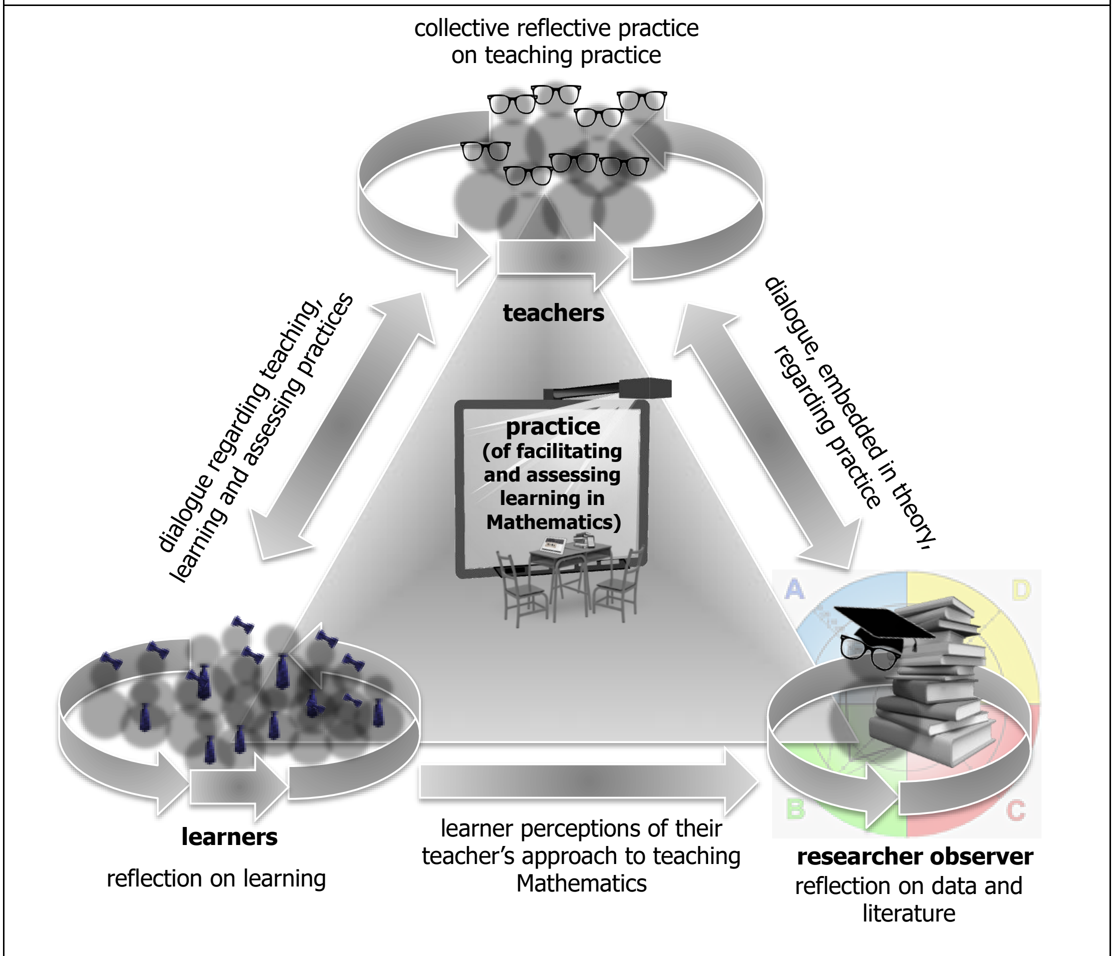
Due to the inefficient information from initial data collection, I amended the data gathering tools to focus less on what teachers and learners produce, but more on what they think – the Herrmann Brain Dominance Instrument® is, after all, a thinking preferences instrument. Similarly, as the focus of the study was that of collective reflective practice, within a community of practice, the methods focused on the dynamic process of reflections on facilitating and assessing learning, rather than on static products created as a result of these processes.

In order to aid the reflective practice of teacher participants, learners were asked to comment on what they perceive their teachers to value in their facilitation and assessment of learning as well as what they perceive to be the main strengths of their teachers' practice. Along with data gathered from teachers on their thinking preferences, their perception of Mathematics as well as their perception of how they facilitate and assess learning of Mathematics, I have observed teacher participants in order to triangulate information given both by the specific teacher and his or her learners. Within the context of the Whole Brain Theory® underpinning this investigation, it allowed me to give feedback to teachers, on how their own thinking preferences and perceptions are in line, or not in line, with that of their learners as well as my own observations. This feedback intended to activate teacher participants' scholarly reflection on their practice so that their professional development may be "transformative" (Kennedy, 2014).

The triangulation should be seen as the first cycle of the cyclic process of action research: where teachers reflect on feedback, possibly adapt their approach, and then reflect on their *adapted* approach, which creates a cyclic reflective-adaptive process. The facilitation and assessment of Mathematics therefore becomes a dynamic process where the responsibility of learning rests with both learners and teachers. Scharle and Szabó (2013, p. 7) state that "(w)hen we encourage students to focus on the *process* of their learning (rather than the *outcome*) we help them to consciously examine their own contributions to their learning. Such an awareness of the difference that their efforts can make is an essential first step to the development of a responsible attitude". This is what is meant by *facilitating* learning: activating thought patterns with learners rather than teaching skills and concepts. The process of gathering data for this study, by asking learners to reflect on how they are being taught and how they are learning, is therefore also part of the Whole Brain® metacognitive process teachers would like to activate with their learners in the Mathematics classroom.

The practice (of facilitating and assessing learning in Mathematics) is therefore not only informed through the conceptual framework, but also through the data collection process. In Figure 3.2 I show the interconnectivity between teachers, learners and myself as both researcher and participant.

FIGURE 3.2: REFLECTIVE NATURE OF PARTICIPATORY ACTION RESEARCH



I indicate myself, as researcher within this structure wearing proverbially two hats: that of scholar exploring the reflective practice in terms of the comprehensive Mathematics-specific Whole Brain® Model, the theory of this study, and that of teacher engaging in the participatory action research. With this dual role I endeavoured to bridge the divide between theory and practice by having an invested interest in both.

Figure 3.3 and 3.4 shows the triangulation that strengthens the practice. This triangulation specifically refers to the communication between learners and teachers, teachers and the researcher and the reflections the researcher gathered from the learners. This is both an individual reflective process for each teacher participant, including myself, as indicated in Figure 3.3, but also a collective reflective process as shown in Figure 3.4. Figure 3.1 indicated that each strand of rope is each teacher participant's personal reflective cycle. We can therefore imagine the reflective triangulation process of each teacher participant, within the Randewijk Rope Model.

FIGURE 3.3: EACH TEACHER'S INDIVIDUAL REFLECTIVE PRACTICE

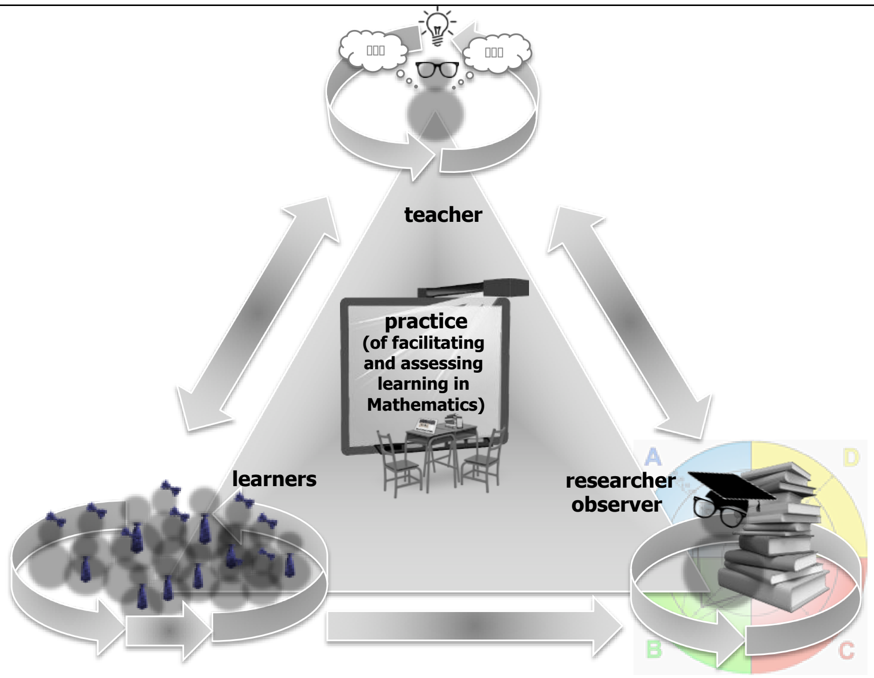
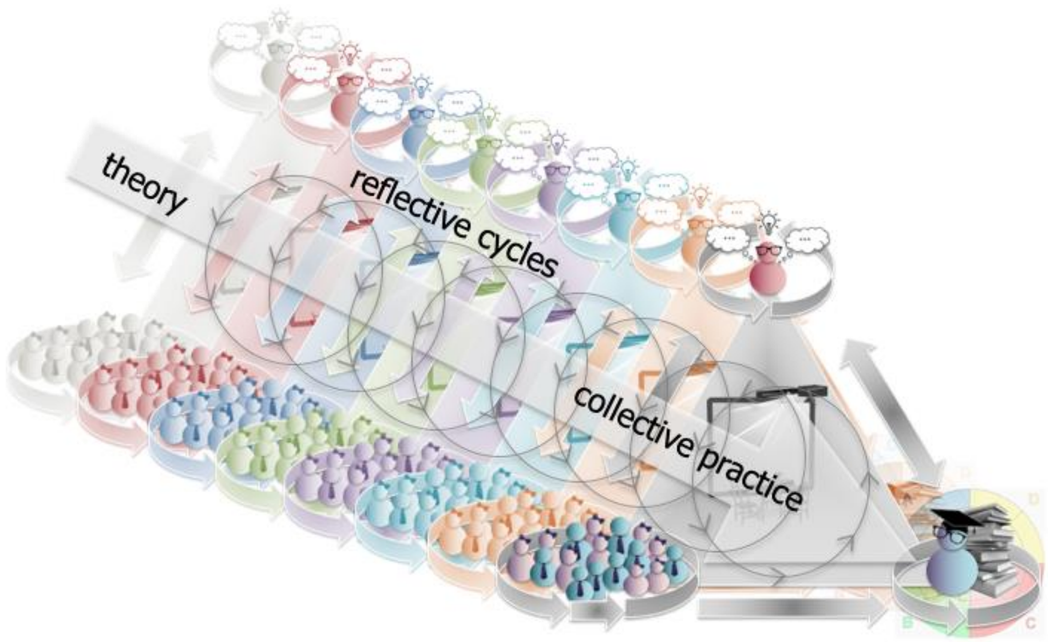


FIGURE 3.4: EACH TEACHER'S INDIVIDUAL REFLECTIVE PRACTICE WHICH FEEDS INTO THE COLLECTIVE REFLECTIVE PRACTICE



3.3 RESEARCH METHODS

The research methods used in this study can be divided into three stages: prior to innovation, innovation and during innovation. The term *during* innovation was used instead of post innovation to emphasise the importance that the reflective process activated through this study may continue well beyond the timeline of the study. This is different to the innovation itself, which refers to the introduction and administering of the Herrmann Brain Dominance Instrument®. The innovation, in this context, therefore refers to the introduction of Herrmann's Whole Brain® theory, whereas the during innovation process refers to the reflective process resulting from the introduction.

The course of the three-stage research process can be briefly summarised as follow.

1. Prior to the innovation, teacher participants were given a questionnaire

on what they perceived their practice to be. Learners were given a similar questionnaire on how they perceive their teacher's practice. Both questionnaires were predominantly quantitative in nature and designed according to Herrmann's four-quadrant Whole Brain® model. The results were categorised according to each of the four quadrants. Pie charts, constructed in Microsoft Excel, were used to represent the data since this representation is similar to that of Herrmann's Whole Brain® model.

2. The innovation itself consisted of participants completing the HBDI® questionnaire and taking part in the HBDI® Think Adventure. During the Think Adventure, Herrmann's Whole Brain® theory was introduced and explored in the context of team-building. The Think Adventure concluded with each participant receiving their unique HBDI® profile. The HBDI® profiles were administered by a certified HBDI® practitioner.

3. During the reflective innovation process, teacher participants were given feedback on their learners' questionnaire responses. Qualitative data was gathered through informal discussions, observations and interviews which also aided teacher participants in their reflective practice. Teacher participants were also encouraged to keep a reflective journal. The quantitative data from the pre-innovation questionnaire results together with the innovation HBDI® profiles, was used to initiate the reflective process. The qualitative data therefore aided a better understanding of the quantitative data, whilst the quantitative data provided a foundation and structure for the qualitative data methods.

Each of the three stages is consequently discussed, as is my reflective process in the design and use of the instruments. This reflective process formed part of my own Whole Brain® meta-reflection on the literature and how the theory transpired into practice – hence, my living theory.

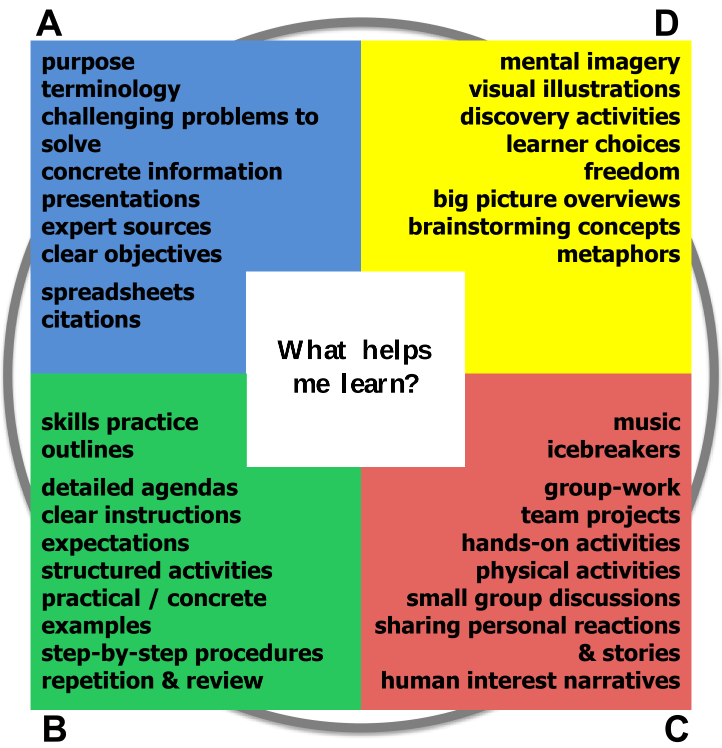
3.3.1 PRIOR TO THE INNOVATION

Prior to using the Herrmann Brain Dominance Instrument® as innovation tool, I wanted to establish the nature of teachers' current educational practices in facilitating and assessing learning in Mathematics. I did this through questionnaires with the teachers in my department as well as questionnaires to learners on their perspective of how their teachers facilitate and assess Mathematics in the senior phase. This was done both to activate the reflective process for teachers and learners, but also to gain insight into current practices before being introduced to Herrmann's Whole Brain® theory.

3.3.1.1 TEACHER QUESTIONNAIRE ON PERCEPTIONS AND PREFERENCES OF FACILITATING AND ASSESSING LEARNING IN MATHEMATICS

The questionnaire consisted of five questions, four of which were multiple-choice questions, and one that was open-ended. The options in each of the multiple-choice questions were equally distributed amongst Herrmann's four modes of thinking preferences and, with the help of Google Forms, the order of the questions was randomised for each participant. These questions were not aimed at establishing teachers' thinking preferences, but rather teachers' thinking regarding their teaching practice. Their perceptions regarding Mathematics, how it should be facilitated and assessed as well as the processes and thought patterns they value were not necessarily in line with their thinking preferences. Results were quantified according to each of the four quadrants. The correlation, or lack of correlation, between teachers' perception of Mathematics and their thinking preferences, according to the Herrmann Brain Dominance Instrument®, was used as point of discussion and reflection during the research process. All questions were adapted from Herrmann's Whole Brain® model on learning as discussed in Chapter 2 and can be seen in Figure 3.5.

FIGURE 3.5: THE WHOLE BRAIN® MODEL ON TASKS THAT AID LEARNING



The first question aimed to determine teachers' perception on the nature of Mathematics. Teachers were asked to choose three options in order to determine whether they have a mono- or a multi-quadrant view of Mathematics. Table 3.1 shows the questions categorised in each of the four quadrants. As mentioned earlier, the questions were not categorised according to quadrants when given to teachers, as can be seen in Appendix H.

TABLE 3.1: QUESTION 1 OF THE TEACHER QUESTIONNAIRE ON PREFERENCES

Question 1: I consider Mathematics to be a subject that … (choose three)

Perception on the nature of Mathematics			
A-QUADRANT	**B-QUADRANT**	**C-QUADRANT**	**D-QUADRANT**
seeks to validate statements and proof claims	is about practising and evaluating ideas	requires active participation during the learning experience	is a process of discovery and exploring new ideas
relies on subject matter expertise	is about being organised and consistent	is an opportunity to challenge and motivate learners	allows for intuition and educated guessing
places emphasis on accuracy and precision during problem-solving	is about practical application	is an opportunity to collaborate and share ideas	requires a conceptual (bigger picture) understanding

What teachers deem to be the nature of Mathematics and what thinking patterns and processes they promote and encourage in the classroom are not necessarily the same. Classroom practice could be influenced by certain constraints that force teachers to adopt a practice they deem to be better suited to the situation than the practice that they value. I therefore considered it necessary to determine what thinking patterns and processes teachers encourage in their classroom as shown in Table 3.2.

TABLE 3.2: QUESTION 2 OF THE TEACHER QUESTIONNAIRE ON PREFERENCES

Question 2: I like to encourage …. in solving problems in Mathematics (choose three)

Thinking patterns and processes encouraged			
A-QUADRANT	**B-QUADRANT**	**C-QUADRANT**	**D-QUADRANT**
critical thinking	step by step procedures	group discussions	brainstorming
logical reasoning	organisation of thoughts	sharing ideas	pattern-recognition
higher order reasoning	using examples	active participation (hands-on learning)	creativity

In order to force teachers to choose a thinking mode that they associate most with Mathematics, the third question, seen in Table 3.3, had only four options of which teachers had to choose only one option. Where the previous questions intended to determine whether teachers have a mono- or a multi-quadrant view, this question aimed to obtain the quadrant teachers *most* associated with their view of Mathematics, prior to the initiative. Once again it should be noted that a teacher’s view of Mathematics and their thinking preferences, as had been tested by the Herrmann Brain Dominance Instrument® are not necessarily in line.

Table 3.3: Question 3 of the Teacher Questionnaire on preferences			
Question 3: I consider Mathematics to be a(n) (choose only one)			
Key feature of Mathematics			
A-QUADRANT	**B-QUADRANT**	**C-QUADRANT**	**D-QUADRANT**
exact science	procedural problem-solving activity	human activity	continuous process of discovery

Dienes (1970) suggests that teachers teach as they themselves were taught, but since my teacher participants and I work in an environment where professional development is valued and as a result is scheduled into the teaching week, this notion does not necessarily hold true for my teacher participants. The following question was included as an indication of whether my colleagues value professional development, since professional development is used as the vehicle for my action research:

Table 3.4: Question 4 of the Teacher Questionnaire on preferences
Question 4: The way I teach Mathematics was mostly influenced by
• the way I was taught at school • pedagogy / didactics courses I took at tertiary level • professional development I received whilst teaching • a mixture of the above

The final question in the pre-innovation questionnaire was included in order to determine what each teacher participant valued and what motivated them in terms of their practice. Where the previous questions focus on teachers' thinking about their practice, the last question aims to tap into the sentiment behind their practice.

Table 3.5: Question 5 of the Teacher Questionnaire on preferences
Question 5: My teaching philosophy: please include an idea or quote that has been inspirational to your teaching career as Mathematics teacher.

3.3.1.2 LEARNER QUESTIONNAIRE ON THEIR PERCEPTION OF THEIR TEACHER'S APPROACH TO FACILITATING AND ASSESSING MATHEMATICS

Having conducted the teacher questionnaire prior to the learner questionnaire gave me an opportunity to refine the learner questionnaire. This refining process gave me an opportunity to change wording and remove any potential bias I might have included in the teacher questionnaire. Although the wording had to be made simpler for learners, aged 12 to 16, I wanted to keep the options for certain questions as similar as possible to those in the teacher questionnaire in order to determine whether what teachers perceived to be doing was indeed in line with what learners experienced in the classroom. I was also aware that my own limitations in terms of my low scoring C-quadrant could have caused me to not explore the full implications of this quadrant when it comes to facilitating and assessing learning in Mathematics.

The words used in Question 3 of the teacher questionnaire were not particularly explanatory of the key features of Mathematics and might not have been understood by the age group of learners who had to complete the questionnaire. For this reason, I reworded each key feature as follows:

- exact science as a logical and analytical approach
- procedural problem-solving as step-by-step instructions to follow
- human activity as an opportunity to share mathematical ideas and methods
- continuous process of discovery as a process of discovery and making connections

As with the teacher questionnaire the options in each of the multiple-choice questions were randomised for each participant and not categorised as in the table below.

TABLE 3.6: QUESTION 1 OF THE LEARNER QUESTIONNAIRE ON PREFERENCES			
Question 1: When my teacher talks about Mathematics, they explain it as… (choose only one)			
Key feature of Mathematics			
A-QUADRANT	**B-QUADRANT**	**C-QUADRANT**	**D-QUADRANT**
a logical and analytical approach	step-by-step instructions to follow	an opportunity to share mathematical ideas and methods	a process of discovery and making connections

When having to compile a list of mathematical thinking patterns and processes, A- and B-quadrant thinking patterns and processes specific to Mathematics can easily be extracted from Herrmann's Whole Brain® Model. This purely left-brain approach to Mathematics is however contrary to what this study promotes. Yet, I found it challenging to construct a list of right-brain thinking patterns and processes that does not portray C- and D-quadrant thinking patterns and processes as inferior to the left-brain. As discussed in Chapter 2, Boaler received a substantial amount of resistance regarding her emphasis on communicating answers, which were perceived as "just talk(ing) about math" (Boaler, 2008, p. 33). The wording used for C- and D-quadrant thinking patterns and processes should therefore be very carefully considered as to not create similar misinterpretations.

When considering my choice of thinking patterns and processes, the term *active participation* in the C-quadrant, did not make apparent the importance of communicating reasoning as emphasised by both Vytgotsky (O'Hara, 2007) and Boaler (2008).

Similarly, the word *creativity*, which I intended to use to explain Boaler's notion of "drawing the problem" (Boaler, 2008, p. 185) was not appropriate. Herrmann (1990, p. 5) states that the "creative process involves the whole brain" and confining it to the D-quadrant would be to limit the meaning of creativity. I had to consider that learners, who are not familiar with Boaler or Herrmann's research, would not interpret *drawing* (or creativity) as a means of visualising and interpreting a problem and therefore had to rephrase it in such a manner that the meaning would be made apparent.

The table below shows how each of these thinking patterns and processes were reworded in order to make the meaning more apparent to learners:

TABLE 3.7: QUESTION 2 OF THE LEARNER QUESTIONNAIRE ON PREFERENCES

Question 2: My teacher places a lot of emphasis on...

(Choose the THREE options that you think best describes your teacher.)

thinking patterns and processes emphasised by my teacher				
	A-QUADRANT	**B-QUADRANT**	**C-QUADRANT**	**D-QUADRANT**
Teacher questionnaire	*critical thinking*	*step-by-step procedures*	*group discussions*	*brainstorming*
Learner questionnaire	critical thinking	Step-by-step procedures	working with others	trial and error
Teacher questionnaire	*logical reasoning*	*organisation of thoughts*	*sharing ideas*	*pattern-recognition*
Learner questionnaire	logical reasoning	structuring my work	sharing ideas in class	looking for patterns (making connections)
Teacher questionnaire	*higher order reasoning*	*using examples*	*active participation (hands-on learning)*	*creativity*
Learner questionnaire	problem-solving	looking at examples	having to explain my methods and thinking	using drawings / diagrams to solve problems

The learner questionnaire's main focus was to establish how learners perceived their teacher's approach to Mathematics at the time of the completion of the questionnaire. However, I also wanted to activate their reflective process on how they learn. Before giving learners the same list of thinking patterns and processes to inquire what they would like their teachers to also focus on, I wanted them to reflect on how they prefer to learn, which is the intent of Question 3 as seen in Table 3.8. Since learners are not merely passive receivers of information, I wanted to focus their attention on their approach to the learning process before asking what their teachers could do to aid their learning. How learners prepare for a Mathematics assessment is also valuable feedback to teachers so that they can best support their learners – especially if we want learners to adopt a Whole Brain® approach to Mathematics rather than a single quadrant approach.

TABLE 3.8: QUESTION 3 OF THE LEARNER QUESTIONNAIRE ON PREFERENCES			
Question 3: When I prepare for a Mathematics test I like to... (There is no right or wrong answer here. We all study in a different way. Choose the option that you prefer the MOST.)			
Ways of preparing for a Mathematics assessment			
A-QUADRANT	**B-QUADRANT**	**C-QUADRANT**	**D-QUADRANT**
go through the homework questions I got wrong to understand where I went wrong and what to watch out for (I like to focus on the details)	study examples and step-by-step procedures to solve problems (practice!)	study with a friend (or friends) so that we can explain to each other	find connections (differences and similarities) between the different topics so that I can distinguish between them (I like to see the bigger picture)

Question 4 intended to address two areas of interest: Firstly, to activate a reflective process with learners on how they would like their teachers to assist their learning. Secondly, to give an indication of thinking patterns and processes that a specific teacher is not currently addressing in their classroom. The same options are given as in Question 2 as can be seen below:

TABLE 3.9: QUESTION 4 OF THE LEARNER QUESTIONNAIRE ON PREFERENCES			
Question 4: I think it would help my learning if my teacher could also focus on... (Choose a MAXIMUM OF THREE options that you would like your teacher to also focus on in order to help you learn.)			
thinking patterns and processes that would help my learning:			
A-QUADRANT	**B-QUADRANT**	**C-QUADRANT**	**D-QUADRANT**
critical thinking	step-by-step procedures	working with others	trial and error
logical reasoning	structuring my work	sharing ideas in class	looking for patterns (making connections)
problem-solving	looking at examples	having to explain my methods and thinking	using drawings / diagrams to solve problems

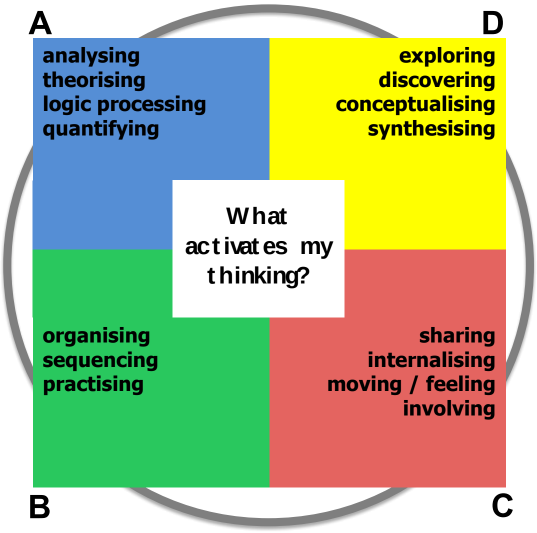
The following two questions on the learner questionnaire were included as a point of reflection, for both teachers and learners, on what learners perceived to be approaches that motivate (or activate) their learning as well as which approaches they perceived to cause them to become disengaged when doing Mathematics. This is not necessarily an indication of learners' thinking preferences, but their perception on approaches that they deemed beneficial to their learning of Mathematics. The listed options given for question 5, in Table 3.10, were adapted from Herrmann's Whole Brain® Model on what activates learning, as discussed in Chapter 2, and can be seen in Figure 3.6.

TABLE 3.10: QUESTION 5 OF THE LEARNER QUESTIONNAIRE ON PREFERENCES

Question 5: It really motivates me to learn when…
(Choose the TWO options that explain what motivates YOU when doing Mathematics)

Approaches that activate learners when doing Mathematics			
A-QUADRANT	**B-QUADRANT**	**C-QUADRANT**	**D-QUADRANT**
I can use logic to find solutions	I have clear guidelines that help me organise my work	I can share my ideas and work with a friend	I can explore new mathematical concepts without having to follow a specific method
I can break a difficult question down into smaller parts to be solved	I have examples to look at and lots of activities to practise what I have learnt	I can have an opportunity to build and draw mathematical shapes or play with Maths apps	I can see how different concepts are linked and can be used to solve a problem

FIGURE 3.6: THE WHOLE BRAIN MODEL® ON LEARNING TASKS THAT ACTIVATE THINKING



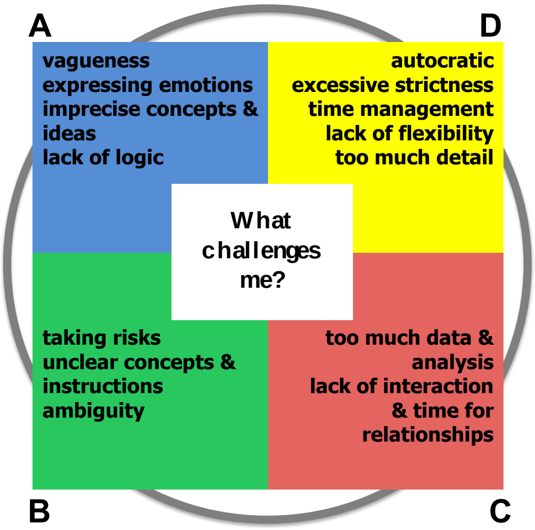
As with question 5, on which approaches learners perceive to motivate them, Question 6 in Table 3.11, focuses on what learners perceive disengages them, and is based on learner perceptions about learning Mathematics. The question was adopted from Herrmann's Whole Brain® Model on what challenges learners potentially face from each quadrant's perspective. These challenges were discussed in Chapter 2, and can be seen in Figure 3.7.

TABLE 3.11: QUESTION 6 OF THE LEARNER QUESTIONNAIRE ON PREFERENCES

Question 6: I really struggle when...
(Choose the TWO options that explain what makes it difficult for YOU to do Mathematics)

Approaches that disengage learners when doing Mathematics			
A-QUADRANT	**B-QUADRANT**	**C-QUADRANT**	**D-QUADRANT**
I have to do group work	I have to solve questions that look different to the ones I studied	I have to work in complete silence	I have to follow a specific method and can't use my own methods
time is wasted on long discussions or explanations	I have to use trial and error to find an answer because there is no set method	I have to read lots of instructions instead of someone explaining it	I have to do lots of practice on topics I already understand

FIGURE 3.7: THE WHOLE BRAIN MODEL® ON TASKS THAT CHALLENGE THINKING



As with the last question of the teacher questionnaire, the last question of the learner questionnaire was also open-ended. Question 7, indicated in Table 3.12, gave learners the opportunity to reflect on what they appreciate most about their teacher's approach to facilitating and assessing learning of Mathematics.

TABLE 3.12: QUESTION 7 OF THE LEARNER QUESTIONNAIRE ON PREFERENCES
Question 7: Write a short sentence (or sentences) on the one thing that your teacher does that really helps you to understand and learn Mathematics.

3.3.2 INNOVATION

3.3.2.1 THE HERRMANN BRAIN DOMINANCE INSTRUMENT®

The Herrmann Brain Dominance Instrument® (HBDI®), used to determine thinking and learning preferences, was used to determine each teacher's unique thinking preference profile. Each teacher participant's HBDI® profile formed the foundation of their professional development. The profile was used to start reflective conversations on their approach to facilitating and assessing learning and to reflect on their practice, the feedback from learners on their practice, and possible changes they might have made to their practice during the course of the professional development process.

The HBDI® was administered by a qualified HBDI® practitioner. The administration involved the issuing of the HBDI® to participants, the processing of individual profiles, and a group profile, as well as the debriefing of profiles to participants during a day-long team-building innovation.

The HBDI® questionnaire is included in Appendix F.

3.3.2.2. TEAM-BUILDING DAY

The HBDI® questionnaire was e-mailed to participants, by the qualified HBDI® practitioner, to complete prior to the team-building day. The team-building day itself was facilitated by the same practitioner and included activities to explain

Herrmann's Whole Brain® theory as well as the profile disclosure, which included each participant's profile as well as the team profile.

A team profile gives an indication of the strengths, as well as aversions, of the group. The collective profile can give an indication of shortcomings within a group that could potentially cause tension within the working group. A homogenous group of Mathematics teachers might work together very successfully and yet lack certain thinking patterns and processes needed for successful communication with other members of staff or even with learners.

Photographs of the activities were taken both by myself and the practitioner in order to capture teacher participants' engagement with each other as well as with Herrmann's Whole Brain® model. The implications of the HBDI® for facilitating and assessing learning in Mathematics were introduced by myself after the profile reveal. The team-building proposal can be found in Annexure D.

3.3.3 During innovation

The analysis and comparison of the pre-innovation teacher and learner questionnaires and the HBDI® profiles scores were used to construct individual interview questions for discussions with each teacher participant.

Conversations were started on the differences and similarities between a teacher's HBDI® profile and the data gathered from themselves and their learners prior to completing their profile, and these conversations were used to activate the reflective process for teachers.

The reflective collective practice during the course of the professional development process was documented through the use of a reflective journal. I mentored this process. The reflection was both a personal process of coming to understand one's HBDI® profile in relation to others, as well as reflection of the implication of Herrmann's Whole Brain® model on facilitating and assessing learning in Mathematics. My own reflective journal was used to document meetings and class visits. The aim was also that teachers visit each other's classrooms and share their reflections on the professional development initiative.

3.4 Validity, reliability and trustworthiness

Bunderson (1994, p. 1) found that the Herrmann Brain Dominance Instrument® "provides a valid, reliable measure of human mental preferences when applied in a professional way, interpreted in conformity with the four-quadrant model, and scored with the approved scoring method". Using a valid and reliable instrument in this study therefore contributes to the validity of the whole study. It also aided the creation of the other instruments designed for this study since they were designed according to the principles of Herrmann's Whole Brain® theory – which is considered trustworthy.

In terms of validity, Lather (1986) suggests the following self-corrective strategies to validate the research: construct validity, triangulation, member checking and catalytic validity. These strategies were used to assist me in validating the findings of this study and to aid my objectivity. Since participatory action research involves the researcher being both a scholar and a participant within the practice itself, the objectivity of the researcher could be questioned. However, the reflection on this duality brings richness to the research that would not be possible to obtain otherwise.

3.4.1 Construct validity

Lather (1986, p. 67) states that construct validity should give an "indication of how a priori theory has been changed by the logic of the data" in order to "construct validity in ways that will contribute to the growth of illuminating and change-enhancing social theory”. In this study, the literature review validated the use of Herrmann’s Whole Brain® theory in Mathematics education through analysing leading theories in Mathematics education research in terms of the Whole Brain® model. It also showed how the comprehensive Mathematics-specific Whole Brain® model informed both the conceptual framework for this study as well as the foundation for further reflection on the implications of the theory in practice. The theory therefore validated the practice, which in turn enhanced the construct development of the comprehensive Mathematics-specific Whole Brain® model. The theory therefore informed the practice, both in terms of facilitating and assessing learning in Mathematics and of data collection, which in turn informed the theory.

3.4.2 Triangulation

Cohen, Manion and Morrison (2007, p. 141) explain triangulation as an “attempt to map out, or explain more fully, the richness and complexity of human behaviour by studying it from more than one standpoint”, fitting with Herrmann’s Whole Brain® theory of viewing a situation from more than one perspective. For this study I use triangulation for two reasons: firstly, to determine each teachers’ *true practice* and secondly, to aid the Whole Brain® reflective action research.

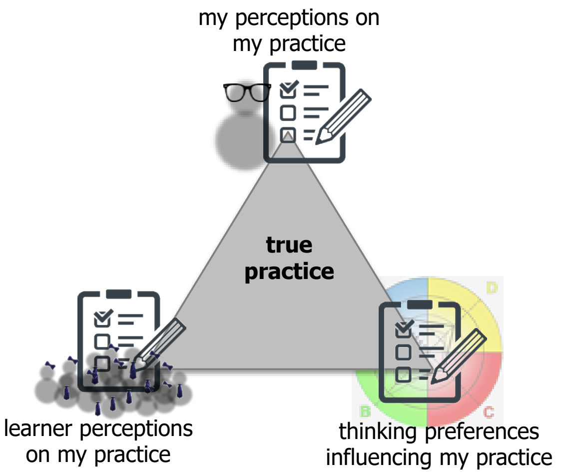


Figure 3.8:
Each teacher’s true practice triangulation

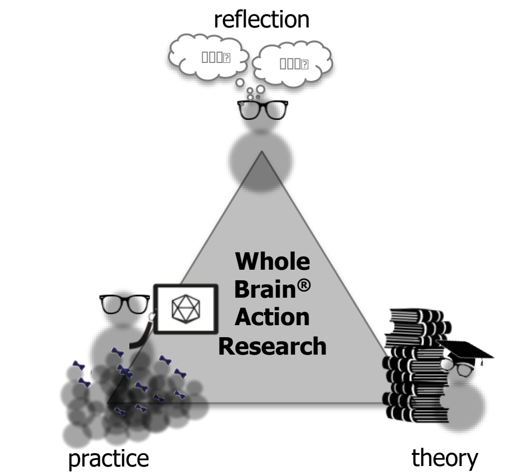


Figure 3.9:
Reflective action research triangulation

Teachers were given a short questionnaire on their perspective on how they facilitate and assess learning in Mathematics. Learners were also given a questionnaire on how they perceive their teachers to be facilitating and assessing learning in Mathematics and lastly teachers were given the Herrmann Brain Dominance Instrument® to determine their thinking preferences and aversions. Through the use and analysis of the three instruments, I was able to gain a better understanding of each teacher's true practice. This knowledge also aided my own interpretation of each teacher's practice upon observing them. This contributes to the inter-rater reliability of my observations, since my observations were informed through the perceptions of the teacher participant, the learners, as well as each participant's HBDI® profile. This informed observation guarded against my own subjectivity and meant that a different observer following the same approach would have yielded similar interpretations from the observations. This triangulation is shown in Figure 3.8.

The feedback to teachers on the triangulated data formed the foundation for their reflection on a Whole Brain® approach to facilitating and assessing learning in Mathematics. To further assist teacher participants' reflective practice, I structured the interview questions in such a manner that it included insight into teachers' reflections on the Whole Brain® theory, on their practice as well as their reflection on their reflection – in other words their meta-reflection. This is triangulation is shown in Figure 3.9. Through my observations when engaging with teachers one-on-one or when observing them in the classroom, I started conversations that aimed to aid each teacher's reflective practice. This cyclic process aims to be a continuous process where each teachers' reflective process, embedded in both theory and practice, becomes their reflective living theory.

Reflection on one's practice is a key element of action research. Although it is inherently an *intrapersonal* process, the external factors mentioned above were designed in such a manner that it will potentially aid a deeper level of reflection.

3.4.3 MEMBER CHECKING

"Member checking occurs throughout the inquiry, and is a process in which collected data is 'played back' to the informant to check for perceived accuracy and reactions" (Cho & Trent, 2006, p. 322). Member checking is also an integral part of participatory action research, since participants are required to reflect on the gathered data, learn from the reflection in order to inform their practice. Feedback that teacher participants received from the learner questionnaires also forms part of member checking as it forms part of "played back" information on their practice.

3.4.4 CATALYTIC VALIDITY

Cohen et al. (2007) state that catalytic validity "strives to ensure that research leads to action". For an action research study built on a paradigm of praxis, catalytic validity is therefore of utmost importance. Lather (1986) explains that "the reality-altering impact of the research process itself" should "consciously channel this impact so that respondents gain self-understanding and, ideally, self-determination through research participation". For this study the participants altered practice as a result of their Whole Brain® reflection, supports the notion of catalytic validity. As will be discussed Chapter 5, not all participants showed an equal amount of altered practice and teacher participants with less teaching experience indicated more changes in their practice than teacher participants with more teaching experience.

3.5 CONCLUSION

This chapter considered the research paradigm of praxis, the mixed-methods research approach and participatory action research as research strategy of this research innovation. It also highlighted the interconnectivity between praxis, mixed-methods and participatory action research.

The reflective process on the development of the research methods, as well as the research instruments themselves, were also discussed. This reflection on the development and use of the research instruments can in itself be seen as part of my personal reflection as well as my living theory.

Lastly, the literature review in Chapter 2 was proposed as the construct validity. Different triangulation processes within the research strategy, along with member checking, was proposed as a means of determining objectivity. Catalytic validity is considered an objective of this research innovation of theory informing practice.

CHAPTER 4

"Knowing yourself is the beginning of all wisdom."

Aristotle (n.d.)

4.1 INTRODUCTION

This chapter considers the data gathered during the participatory action research process. I start this chapter with my own Herrmann Brain Dominance Instrument® profile which has been the start of my personal reflective journey. My personal thinking preferences, and reflection on my preferences, are also considered to be the perspective from which I engaged with the data collection. My preferences are also compared to how my learners perceive my teaching to be.

Photos and an overview of the HBDI® Think Adventure are included along with the results of the Diversity Game.

Following this, I have included the pre-innovation questionnaire results on my colleagues' perceptions of Mathematics and the teaching of Mathematics. I organised these results according to Herrmann's Whole Brain® quadrants. The teacher participants' responses are also compared with learner feedback surveys. The data are organised according to quadrant, and learners and teacher perceptions are compared

Each teacher participant's Herrmann Brain Dominance Instrument® result is included, as well as the three key descriptors each participant chose during the Diversity Game during the HBDI® Think Adventure.

Lastly, I have compared the collective teacher data to those of the collective learner data in order to establish any possible trends.

4.2 INCEPTION

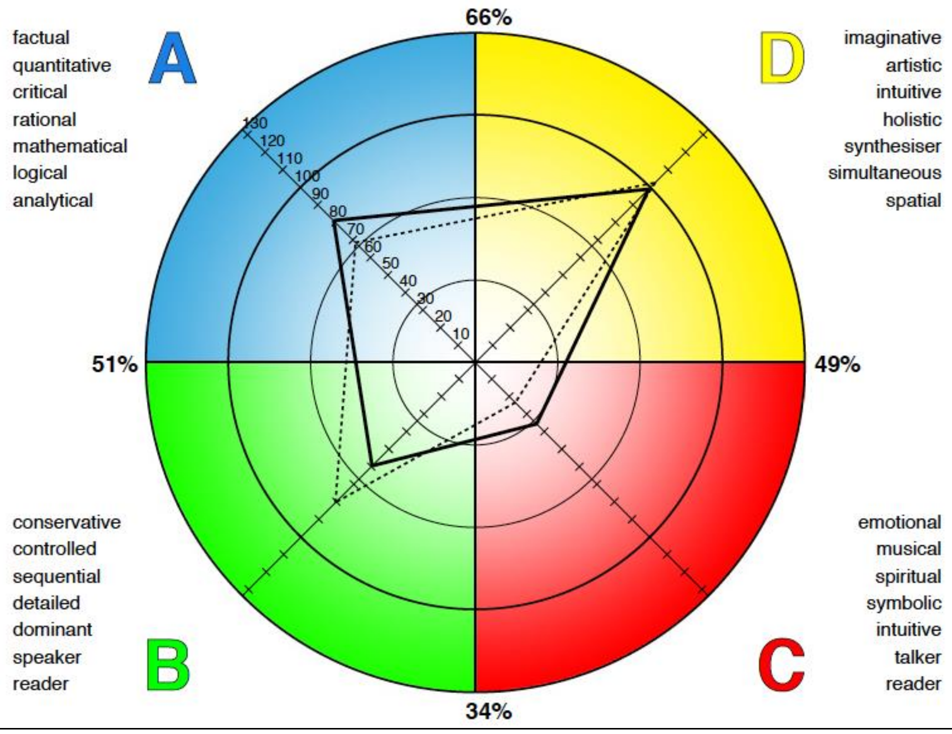
The inception of this study was my personal introduction to the Herrmann Brain Dominance Instrument® and can therefore be considered as the baseline for what has transpired into a formal research project. My HBDI® profile score, as can be seen in Table 4.1, prompted my own reflective process and also informed the way I viewed this research process. By including my own thinking preferences into this participatory action research process, I reflected on and used my own potential subjectivity and or limitations in a manner that has potentially contributed to this study rather than limited it.

<table>
<tr><th colspan="5">TABLE 4.1: QUESTION 7 OF THE LEARNER QUESTIONNAIRE ON PREFERENCES</th></tr>
<tr><td rowspan="12">
The Researcher:
Emmy Noether</td><td colspan="4">DIVERSITY GAME</td></tr>
<tr><td>A-QUADRANT</td><td>B-QUADRANT</td><td>C-QUADRANT</td><td>D-QUADRANT</td></tr>
<tr><td>2. problem-solver</td><td></td><td></td><td>1. synthesiser
3. imaginative</td></tr>
<tr><td colspan="4">Herrmann Brain Dominance Instrument® KEY DISCRIPTORS</td></tr>
<tr><td>A-QUADRANT</td><td>B-QUADRANT</td><td>C-QUADRANT</td><td>D-QUADRANT</td></tr>
<tr><td>analytical
critical
rational
mathematical
logical</td><td></td><td></td><td>*synthesizer
imaginative
holistic</td></tr>
<tr><td colspan="4">Herrmann Brain Dominance Instrument® PROFILE SCORE</td></tr>
<tr><td>A-QUADRANT</td><td>B-QUADRANT</td><td>C-QUADRANT</td><td>D-QUADRANT</td></tr>
<tr><td>81</td><td>59</td><td>35</td><td>99</td></tr>
<tr><td colspan="4">Herrmann Brain Dominance Instrument® ADJECTIVE PAIRS</td></tr>
<tr><td>A-QUADRANT</td><td>B-QUADRANT</td><td>C-QUADRANT</td><td>D-QUADRANT</td></tr>
<tr><td>6</td><td>7</td><td>2</td><td>9</td></tr>
</table>

My knowledge of Whole Brain® learning seem to complement what I have learnt during my Mathematics Didactics, Learner Support as well as Inclusive Education courses and sparked a curiosity that I needed to satisfy. I imagined how I would solve the problem of learners not being engaged in Mathematics classes through a research study looking at synthesising Mathematics Didactics, Learning Theories and Herrmann's Whole Brain Theory®. By looking at my HBDI® preferences, it was very clear why I felt the need to explore this idea. Being analytical and critical required of me to disseminate knowledge from all three fields of study so that I could rework it into a simplistic synthesised approach.

My greatest challenge has been to be reliant on the teacher participants for insight into their understanding of the HBDI® and how they see it influencing their teaching. As an individual focused on my own understanding, and with the C-quadrant being my least preferred quadrant, I had to shift my thinking from a theoretical focused approach to a relationship focused approach. This can be seen on my HBDI® profile in Figure 4.1, which shows higher scores for the A- and D-quadrants and lower scores for the C-quadrant. As explained in Figure 2.1 in Chapter 2, the solid line on the HBDI® profile indicates an individual's profile score, whereas the dotted lines, indicates the adjective pair score or stress profile. Figure 4.1 shows the slight shift in my preferences when I am under stress, with my C-quadrant preferences scoring particularly low.

FIGURE 4.1: MY HBDI® PROFILE



With these thinking preferences in mind, I started with an analysis of my own learner feedback surveys.

To investigate what learners perceive my emphasis to be, in comparison to what they would like my emphasis to be, I did a comparison between Question 2 and Question 4 from the learners' survey as seen in Table 4.2, Figure 4.2 and Figure 4.3. From this comparison, it became evident that there is not a definite congruence. Besides perception being subjective, there could also be other factors influencing these perceptions.

TABLE 4.2: QUESTION 2 AND QUESTION 4 COMPARISON

LEARNERS' FREQUENCIES: Question 2: MY TEACHER PLACES A LOT OF EMPHASIS ON....			
A-QUADRANT	**B-QUADRANT**	**C-QUADRANT**	**D-QUADRANT**
critical thinking = 1 logical reasoning = 2 problem-solving = 7	step by step = 16 examples = 16 structuring my work = 4	explaining = 9 working with other = 2 sharing ideas = 10	drawings / diagrams = 15 finding patterns = 13 trial and error = 6
10 (10%)	36 (36%)	21 (21%)	34 (34%)
LEARNERS' FREQUENCIES: Question 4: MY TEACHER COULD ALSO EMPHASISE...			
A-QUADRANT	**B-QUADRANT**	**C-QUADRANT**	**D-QUADRANT**
critical thinking = 4 logical reasoning = 10 problem-solving = 7	step by step = 6 examples = 3 structuring my work = 7	explaining = 4 working with other = 1 sharing ideas = 4	drawings / diagrams = 3 finding patterns = 4 trial and error = 4
21 (37%)	16 (28%)	9 (16%)	11 (19%)

Figure 4.2: Question 2 and Question 4 comparison

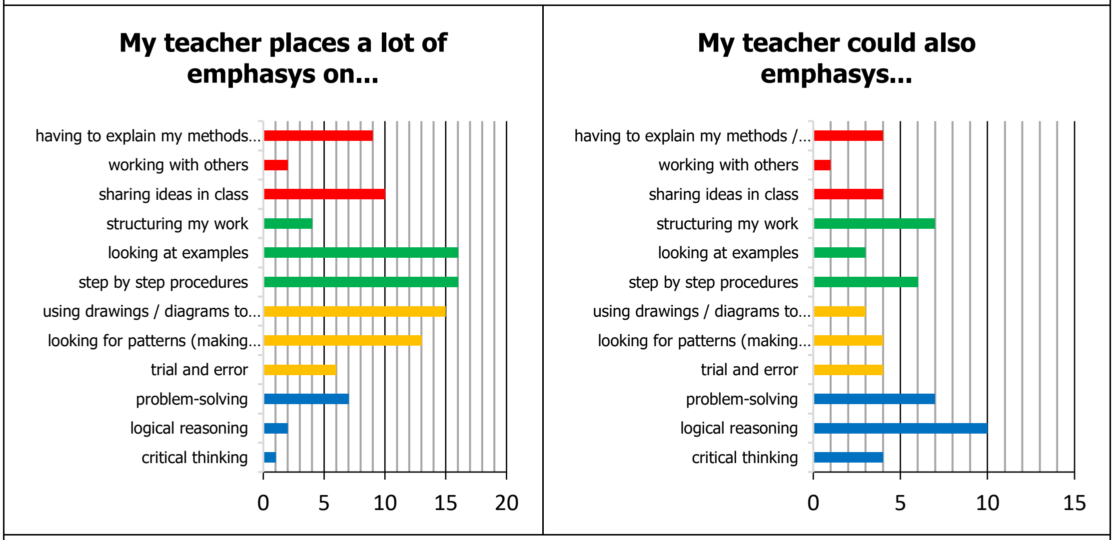
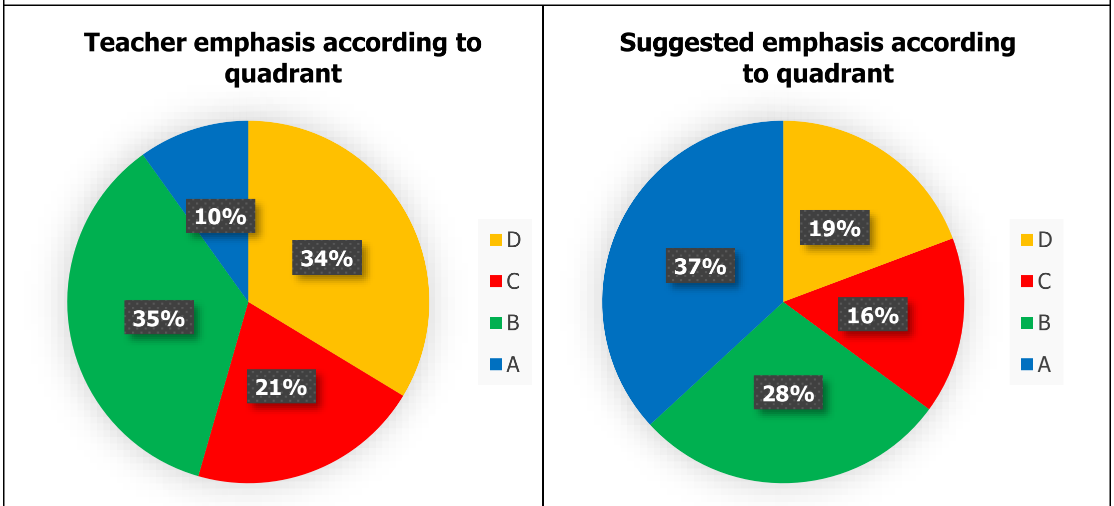


Figure 4.3: Question 2 and Question 4 comparison per quadrant



Left brain: 45% Right brain: 55%
Cerebral: 44% Limbic: 56%

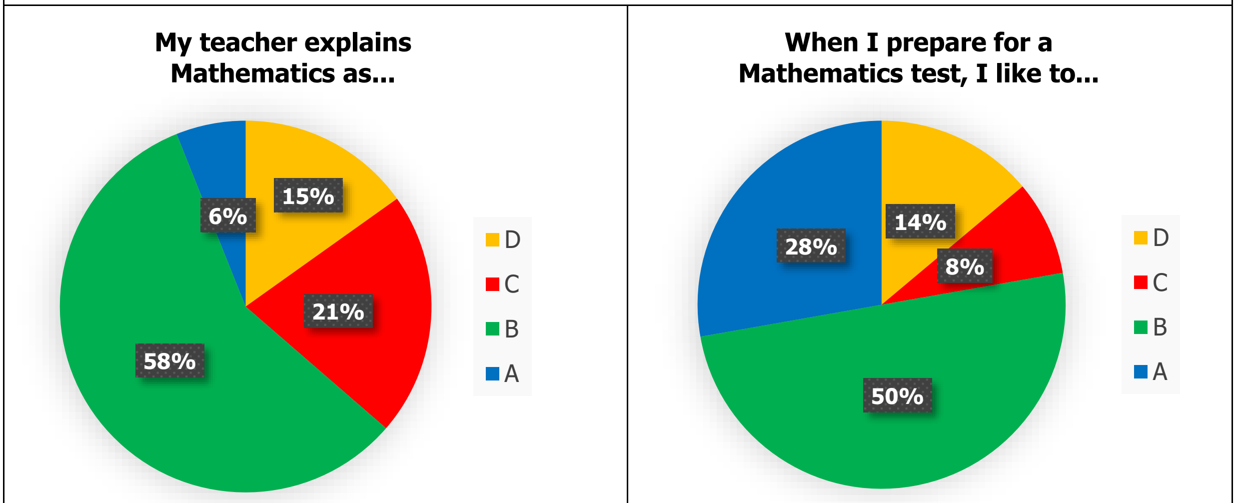
Left brain: 65% Right brain: 35%
Cerebral: 56% Limbic: 44%

I also wanted to see if my personal thinking preferences had any influences on how learners like to prepare for Mathematics assessments. I compared this to what learners perceive my focus in Mathematics to be as to ascertain if the methods they use in preparing for assessments are in line with what they deem my focus to be. This comparison between Question 1 and 3 of the learners' survey is shown in Table 4.3 and Figure 4.4. From the summarised data, it can be seen that there seems to be a correlation between what learners perceive my focus to be and how they prepare for assessments.

Table 4.3: Question 1 and Question 3 comparison

LEARNERS' FREQUENCIES **Question 1: WHEN MY TEACHER TALKS ABOUT MATHEMATICS, SHE EXPLAINS IT AS…**			
A-QUADRANT a logical and analytical process	**B-QUADRANT** step-by-step instructions to follow	**C-QUADRANT** an opportunity to share ideas and methods	**D-QUADRANT** a process of discovery and making connections
2 (6%)	19 (58%)	7 (21%)	5 (15%)
LEARNERS' FREQUENCIES **Question 3: WHEN I PREPARE FOR A MATHEMATICS TEST I LIKE TO…**			
A-QUADRANT go through the homework questions I got wrong to understand where I went wrong and what to watch out for (I like to focus on the details)	**B-QUADRANT** study examples and step-by-step procedures to solve problems (practice!)	**C-QUADRANT** study with a friend (or friends) so that we can explain to each other	**D-QUADRANT** find connections (differences and similarities) between the different topics so that I can distinguish between them (I like to see the bigger picture)
10 (28%)	18 (50%)	3 (8%)	5 (14%)

Figure 4.4: Question 1 and Question 3 comparison per quadrant



Left brain: 64% Right brain: 36%
Cerebral: 21% Limbic: 79%

Left brain: 78% Right brain: 22%
Cerebral: 42% Limbic: 58%

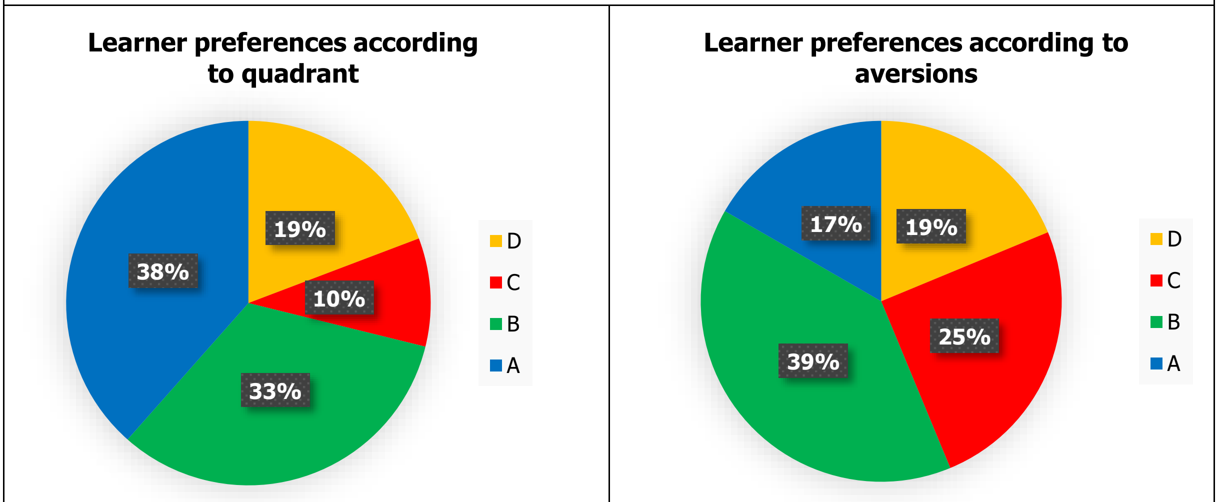
Herrmann (1996, p. 150) noted that when you have any group of a reasonable size, consisting of different people (or learners) with different preferences, the group will collectively have "a composite whole brain". To investigate this notion amongst the learners I teach, I compared my learners' preferences and aversions to see if they too would test with "a composite whole brain". Considering that learner aversions are another way of determining preferences, I have placed these questions together in order to establish any possible trends. This comparison can be seen in Table 4.4 and Figure 4.5.

It must however be noted that although these set of questions will give some indication of learners' preferences it is not nearly as comprehensive as the HBDI®. As can be seen in Figure 4.5, the spread is also not equal amongst the four quadrants. The aim of these questions is to see if any trends emerge that could be indicative of influences that might affect the way learners think about Mathematics. For example: Learners perceived my view of Mathematics to be predominantly B-quadrant focused, which could potentially influence both their preferences and aversions. Reflections on these trends are further discussed in Chapter 5.

TABLE 4.4: QUESTION 5 AND QUESTION 6 COMPARISON

Question 5: LEARNER PERSONAL PREFERENCE FREQUENCIES:			
A-QUADRANT	**B-QUADRANT**	**C-QUADRANT**	**D-QUADRANT**
logic = 9 breaking down = 11	clear guidelines = 7 examples = 10	share ideas = 5 play = 0	explore = 4 connections = 6
20 (38%)	17 (33%)	5 (10%)	10 (19%)
Question 6: LEARNER PERSONAL AVERSIONS FREQUENCIES:			
A-QUADRANT	**B-QUADRANT**	**C-QUADRANT**	**D-QUADRANT**
group work = 4 long discussions = 4	unfamiliar questions = 11 no set method = 8	working in silence = 5 lots of reading = 7	set method = 6 lots of practice = 3
8 (17%)	19 (39%)	12 (25%)	9 (19%)

FIGURE 4.5: QUESTION 5 AND QUESTION 6 COMPARISON PER QUADRANT



Left brain: 71% Right brain: 29%
Cerebral: 57% Limbic: 43%

Left brain: 54% Right brain: 46%
Cerebral: 48% Limbic: 52%

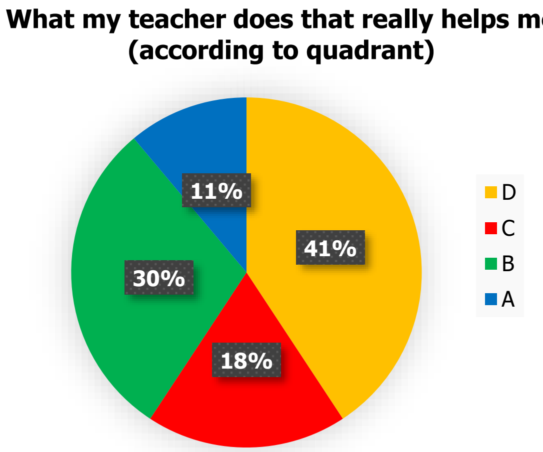
As discussed in Chapter 3, Question 7 was included to give learners a platform to express their perception of their teacher's approach to facilitating and assessing Mathematics in their own words without any possible bias by given descriptors as in the multiple-choice questions. Feedback received from my learners can be seen in Table 4.5 below and is summarised according to quadrant in Figure 4.6.

TABLE 4.5: QUESTION 7 RESULTS

LEARNERS' APRECIATION OF THEIR TEACHER'S APPROACH TO TEACHING MATHEMATICS	
A-QUADRANT (3)	**D-QUADRANT (11)**
Analysis and in depth explanations (3) • She helps me find my mistakes, so I can't make the same mistakes again. • My teacher understands my way of thinking and therefore ensures I understand everything and presents it in such a way that I understand. • if we get it wrong she will help us to understand where we made our mistake.	**Synthesis (1)** • She really helps me to understand the work and helps me make connection in my work. **Visual representation (7)** • She always explains through drawing and it really helps, as well as when she makes a lot of notes for us. • It really helps when she uses colour in her examples because I prefer that. • I understand better when my maths teacher uses COLOUR to solve problems • She encourages us to use a lot of colour in our book and that really helps figure things out. • Makes notes in colour • She uses colour and pictures as well as illustrations to explain certain mathematical concepts. By using these drawing, she makes what seems difficult and complicated, seem easier and more simple • My teacher makes Explain Everything[RT] videos that she shares with us; **Application (1)** • When she uses everyday examples to explain complicated problems. **Explore different strategies (2)** • My teacher know how to make everyone understand what she is talking about by explaining one thing using different methods • She provided multiple different methods so they we could use which ever one we understood.
B-QUADRANT (8)	**C-QUADRANT (5)**
Step by step procedures (2) • explains everything step by step • She puts all the sums we don't understand into step by step procedures that are colour coded	**Support and encouragement (5)** • She's just awesome and helps you in every way possible. • She always had a super bubbly personality and always focused on helping each and

Worked Examples (3) • It really helps when we write notes and examples of a topic, as I can then go back to the note if I get stuck • She gives us lots of questions and examples so the we can practice • My teacher does examples of what we must do with us, so that we understand and that helps me. **Repetition (1)** • When you don't understand she explains it to you again **Summaries (2)** • she makes booklets that gives summaries of topics • She makes the best notes for us to copy down	every individual on the specifics that each person struggled with. • She tolerates each and everyone of us even though we give her a bit of a challenge • She always is clear and calm when explaining concepts and ideas in mathematics. She never gets angry when someone in the class did not understand a concept and was always very caring and tried her very best to help us understand the various topics in the math year. • She will make sure the whole class understands the topic well before moving on.

FIGURE 4.6: QUESTION 7 RESULTS ACCORDING TO QUADRANT



As with my HBDI® score which shows my strongest preference to be for the D-quadrant, learners also express their appreciation for my D-quadrant approach to facilitating and assessing learning in Mathematics. This can be seen in Figure 4.6.

4.3 THE THINK ADVENTURE

The Whole Brain® Think Adventure was conducted by a registered Herrmann Brain Dominance Instrument® practitioner. It consisted of five parts:

1. The Diversity Game
2. Heterogenous group activity: buying a new car
3. Homogeneous group activity: designing your dream house

4. Communication activity: blindfolded paddling
5. Profile reveal
6. Application in the classroom: How do we teach to all four quadrants?

4.3.1 The Diversity Game

The Herrmann Brain Dominance Instrument® practitioner used the Diversity Game as both an ice breaker and a brief introduction to the Herrmann Brain Dominance Instrument®. The Diversity Game is an activity where participants have an opportunity to choose words, on key cards, they believed best describe themselves. They are also allowed to negotiate a trade with a colleague if they feel a descriptor that they require is being used by someone else. The idea behind the Diversity Game is to make participants reflect upon themselves and what they deem to be their preferred way of thinking. The practitioner asked participants to arrange their final three key cards in order of importance, with their primary descriptor at the top, their secondary descriptor in the middle and their tertiary descriptor at the bottom. After doing this, the participants were asked to place their primary descriptor, on a table according to the colour of the descriptor: blue cards being placed top left, green cards, bottom left, red cards, right bottom and yellow cards, top right. Secondary key cards, also had to be placed according to these colour allocations, but towards the middle of the table. And lastly tertiary cards, had to also be placed according to colour, but in the middle of the table. This layout can be seen in Figure 4.7 and is reworked into an electronic layout in Figure 4.8.

By placing key descriptors further away from the centre of the table, it indicates a strong preference for a specific quadrant, similar to how preferences are shown in the Herrmann Brain Dominance Instrument® as discussed in Figure 2.1 in Chapter 2.

FIGURE 4.7: PHOTOGRAPH OF THE KEY CARD DESCRIPTORS

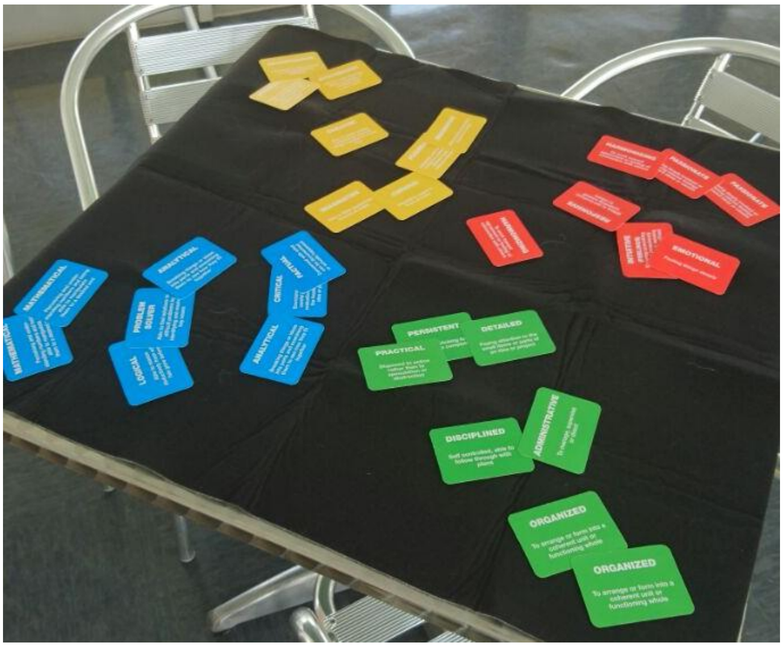
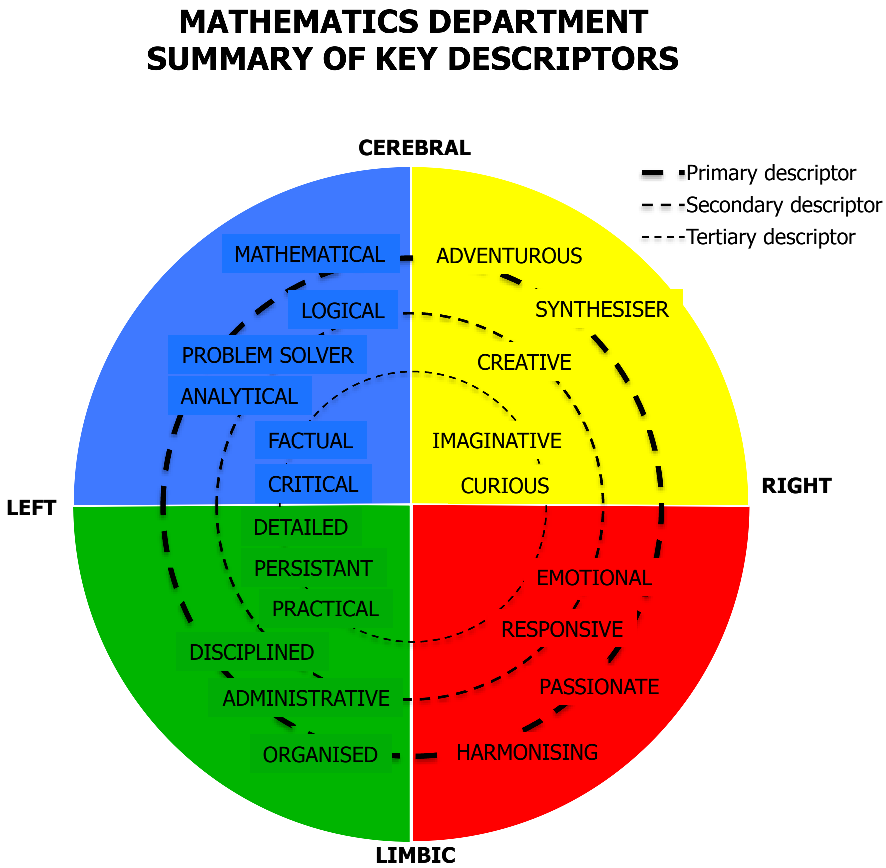


FIGURE 4.8: ELECTRONIC LAYOUT OF KEY CARD DESCRIPTORS

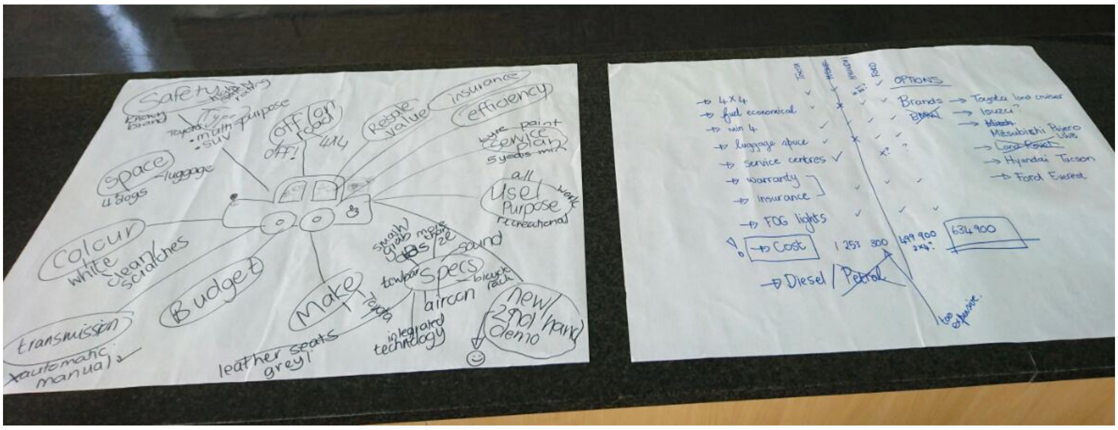


This activity allowed teacher participants to construct Herrmann Brain Dominance Model® unique to the Mathematics department. The practitioner left the model on the table for the duration of the Think Adventure as a reference for participants, whilst they engaged in the other activities.

4.3.2 The heterogenous group activity

The heterogenous group activity, seen in Figure 4.9, shows somewhat similar styles between the two groups in choosing the best vehicle for an off-road adventure. In the photograph indicated in Figure 4.9, the diagram on the left show more C- and D-quadrant influences whereas the diagram on the right shows more A- and B-quadrant influences. During this activity the person reporting on the group discussion seemed to have the most influence on the way the discussion was represented on paper.

Figure 4.9: Photograph of The heterogenous group activity



4.3.3 The homogenous group activity

The homogenous group activity pictures indicated in Figure 4.10 and Figure 2.11 show more distinct differences. Figure 4.10 shows a neat pencil drawing, done with a ruler with various details, including which side of the house faces north. From the photograph is can be seen that participants are somewhat withdrawn from the drawing (sitting with folded hands), and make careful considerations before contributing to the design. Rough drawings can be seen on a separate piece of paper where rough planning was done before committing to the design on the bigger piece of paper. All white board markers are neatly packed to one side of the table and only a pencil and ruler are used. Towards the right of the table an eraser can be seen which was used to correct any mistakes.

Figure 4.11 shows free-hand sketches, done with whiteboard markers. Participants in this photograph seemed to be more engaged with the design and it can be seen that more than one participant was making additions to the design.

FIGURE 4.10: PHOTOGRAPH OF THE HOMOGENEOUS GROUP CONSISTING OF PARTICIPANTS WITH A- AND B-QUADRANT PREFERENCES

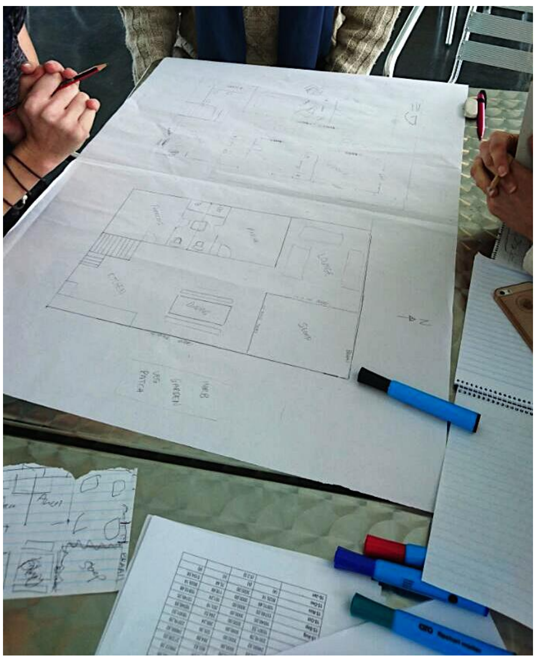
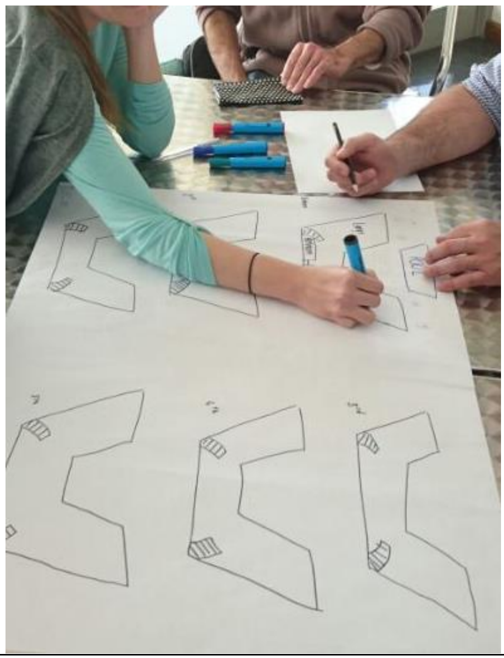


FIGURE 4.11: PHOTOGRAPH OF THE HETEROGENEOUS GROUP CONSISTING OF PARTICIPANTS WITH C- AND D-QUADRANT PREFERENCES



The aim of the heterogeneous and homogeneous group activities, were to show how teams operate when team members have different or similar thinking preferences. Differences regarding the outcomes each of the groups produced were discussed and possible explanations offered. Since the homogeneous groups consisted of members with preferences in the same hemisphere, left-brain and right-brain differences were used as the starting point for the discussions. The Diversity Game card arrangement was used to help aid understanding of the differences that emerged from the drawing activities.

4.3.4 The communication activity

The communication activity required participants to divide into two heterogenous (multi-quadrant) groups. Each group received a boat, a paddle and two blindfolds. Two teachers from each group had to be in a boat on the school swimming pool – both blindfolded. One had to paddle and navigate the boat, whilst the other teacher in the boat had to collect floating balls of a specific colour. Figure 4.12 shows the two blindfolded teachers from each group who had to collect the floating balls. The teacher on the left collected blue and green balls, whilst the teacher on the right collected red and yellow balls.

Figure 4.12: Photograph of Collecting floating ball during the communication activity

Instructions on where to paddle and which balls to collect were given by the remaining members of the group that could walk around the pool. Differences in communication styles became apparent as certain teacher participants were more task orientated, wanting to quickly collect all the floating balls, whilst others were more focused on the welfare of the team, watching out for any potential collisions. This can be seen in Figure 4.13 with one of the teacher participants on the side of the pool holding out her hand to protect the blindfolded teacher from hitting her head against the side of the pool.

The manner in which different team members with different quadrant strengths communicated also became apparent. Where some members preferred short clear instructions, such as left, right or straight ahead, others were happy to merely follow the voice of a team member moving around the pool.

FIGURE 4.13: PHOTOGRAPH OF BLINDFOLDED TEACHERS DURING THE COMMUNICATION ACTIVITY

4.3.5 PROFILE REVEAL

Before the profile reveal, the Herrmann Brain Dominance Instrument® practitioner debriefed each of the activities in terms of Herrmann's four quadrant Whole Brain® model whilst referring to the Diversity Game key card placements. Thinking patterns related to each of the four quadrants were discussed as well as the notion that certain thinking patterns should not be seen as superior or inferior to others. The Herrmann Brain Dominance Model®

was introduced and each participant was encouraged to make a prediction on what he or she expected their Herrmann Brain Dominance Instrument® profile to be before being given an opportunity to scrutinise their profile. All the activities building up to the profile reveal were used to start the reflection process regarding different thinking preferences. It also helped to build an anticipation with teacher participants about their own thinking preference scores as indicated by the Herrmann Brain Dominance Instrument®.

4.3.5 APPLICATION IN THE CLASSROOM

At this stage the Herrmann Brain Dominance Instrument® practitioner stepped back and gave an opportunity to participants to discuss the possible applications of Herrmann's Whole Brain Model® in the classroom. To guide the exploration, I introduced participants to literature supporting the facilitation and assessment of Whole Brain® learning in Mathematics. In order to explore the application of Whole Brain® learning, participants were asked to explore how they would facilitate the solving of the following two problems:

1. Determine how many squares of various sizes can be found on a chess board.
2. Determine how many combinations include at least one "4" on a three wheel lock containing the numbers 0 to 9.

In both instances, I used Boaler's approach of "drawing the problem, making a chart with the numbers (and) trying a smaller case" (Boaler, 2008, pp. 185-186) to guide teacher participants towards exploring an approach that would include thinking and learning approaches from all four quadrants. The value in giving Mathematics teachers a problem to explore themselves, opens an opportunity to discuss the thinking preferences they themselves use when faced with a problem they do not have the answer to straight away. It was also an opportunity to discuss the different ways different members within the department approached a problem. Although teachers may employ the strategy of discussing different problem-solving methods with their learners in their class, they may not always reflect on their own problem-solving strategies. Reflecting on their own strategies within the context of their thinking preferences, was used as a starting point from where to develop a sensitivity with teachers regarding their learners' thinking preferences.

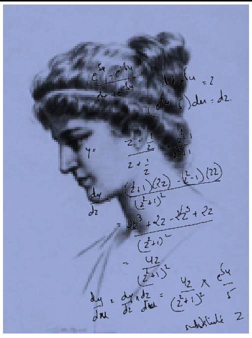
As with the remainder of the innovation and data collection process, these discussions formed part of the cyclic reflective action research process, since it opened discussions and challenged participants' views of their current teaching practice.

4.4 TEACHER PRE-INNOVATION SURVEY RESULTS IN COMPARISON TO LEARNER FEEDBACK

The pre-innovation teacher survey data is compared to the learner feedback data to determine if any trends are noticeable between the way learners perceive a teacher to teach and the way learners learn as well as to give feedback to teacher participants. As mentioned in Chapter 2, Hattie and Yates (2014, p. 14) state that "those teachers who are students of their own effects are the teachers who are the most influential in raising students' achievement".

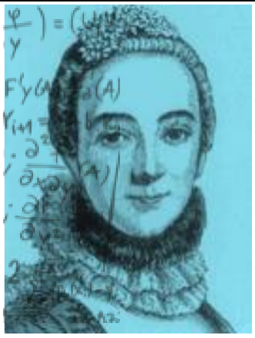
Each of the participants was assigned a pseudonym in order to conserve his or her anonymity (Figure 4.14). The names were assigned to each participant according to their gender, and in some instances, also according to their field of interest. By giving each participant a name, instead of a number (such as participant 1), I aimed to adopt a Whole Brain® approach to the data collection process. The research innovation, as presented to the teacher participants, was therefore not merely a quest for collecting data, but a way of initiating a relationship with each participant in order to gain insight into their thinking preferences and ultimately their meta-reflective process. Data collected from each participant in this study is therefore not merely static quantities of thinking preference scores, but rather an organic and reflective growth process. The reflections as a result of the quantities is what is of importance.

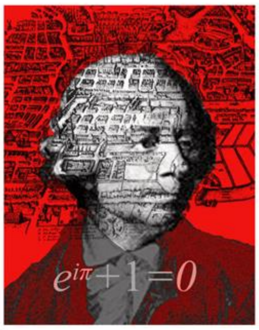
FIGURE 4.14: PARTICIPANT PSEUDONYMS


Hypatia

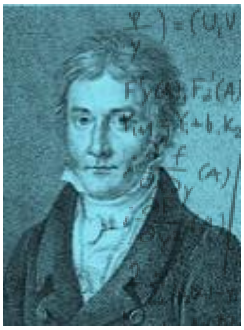

Sophie Germain

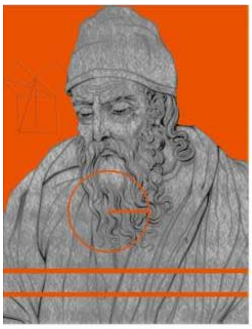
Ada Lovelace


Maria Agnesi



Leonhard Euler


Carl Friedrich Gauss


Euclid


Blaise Pascal

4.4.1 Sophie Germain's HBDI® and Pre-Innovation Questionnaire results

Sophie Germain's pre-innovation questionnaire results, as shown in Table 4.6, show a preference for the C-quadrant for both her perception on the nature of Mathematics as thinking patterns and processes emphasised. This is in line with her HBDI® profile score in Figure 4.17.

<table>
<tr><td colspan="4">TABLE 4.6: SOPHIE GERMAIN'S PRE-INNOVATION QUESTIONNAIRE RESULTS</td></tr>
<tr><td>
Sophie Germain</td><td colspan="3">SOPHIE GERMAIN

Teaching philosophy:
To get learners actively involved in the learning process
To get learners thinking critically and solving problems
I would like to take them to the place we are learning about to give them a 'real life experience' of the learning process</td></tr>
<tr><td colspan="4">SOPHIE GERMAINS'S PERCEPTION ON THE NATURE OF MATHEMATICS</td></tr>
<tr><td>A-QUADRANT</td><td>B-QUADRANT</td><td>C-QUADRANT</td><td>D-QUADRANT</td></tr>
<tr><td></td><td></td><td>requires active participation during the learning experience</td><td>is a process of discovery and exploring new ideas

requires a conceptual (bigger picture) understanding</td></tr>
<tr><td colspan="4">SOPHIE GERMAINS'S THINKING PATTERNS AND PROCESSES EMPHASISED</td></tr>
<tr><td>A-QUADRANT</td><td>B-QUADRANT</td><td>C-QUADRANT</td><td>D-QUADRANT</td></tr>
<tr><td></td><td>step by step procedures using examples</td><td>active participation (hands on learning)</td><td></td></tr>
</table>

Sophie's second most preferred quadrant, as indicated on her HBDI® profile in Figure 4.17, is the B-quadrant. Both her primary preferences for the C-quadrant and her secondary preference for the B-quadrant are also perceived by learners to be her emphasis. This is indicated in Table 4.7.

TABLE 4.7: SOPHIE GERMAIN'S LEARNER FREQUENCIES: QUESTION 2 AND QUESTION 4 COMPARISON			
LEARNERS' FREQUENCIES: Question 2: MY TEACHER PLACES A LOT OF EMPHASIS ON….			
A-QUADRANT	**B-QUADRANT**	**C-QUADRANT**	**D-QUADRANT**
critical thinking = 11 logical reasoning = 11 problem-solving = 17	step by step = 25 examples = 14 structuring my work = 6	explaining = 15 working with other = 11 sharing ideas = 15	drawings / diagrams = 9 finding patterns = 13 trial and error = 3
39 (26%)	45 (30%)	41 (27%)	25 (17%)
LEARNERS' FREQUENCIES: Question 4: MY TEACHER COULD ALSO EMPHASISE…			
A-QUADRANT	**B-QUADRANT**	**C-QUADRANT**	**D-QUADRANT**
critical thinking = 5 logical reasoning = 4 problem-solving = 7	step by step = 14 examples = 15 structuring my work = 14	explaining = 12 working with other = 10 sharing ideas = 12	drawings / diagrams = 13 finding patterns = 4 trial and error = 8
16 (14%)	43 (36%)	34 (29%)	25 (21%)

The information in Table 4.7 is illustrated in Figure 4.15 and indicates the learner frequencies for specific approaches as listed in the learner questionnaire. Figure 4.16 groups these approaches together per quadrant. In Figure 4.16 the slight emphasis on B- and C-quadrant approaches can be seen.

FIGURE 4.15: SOPHIE GERMAIN'S LEARNER FREQUENCIES: QUESTION 2 AND QUESTION 4 COMPARISON

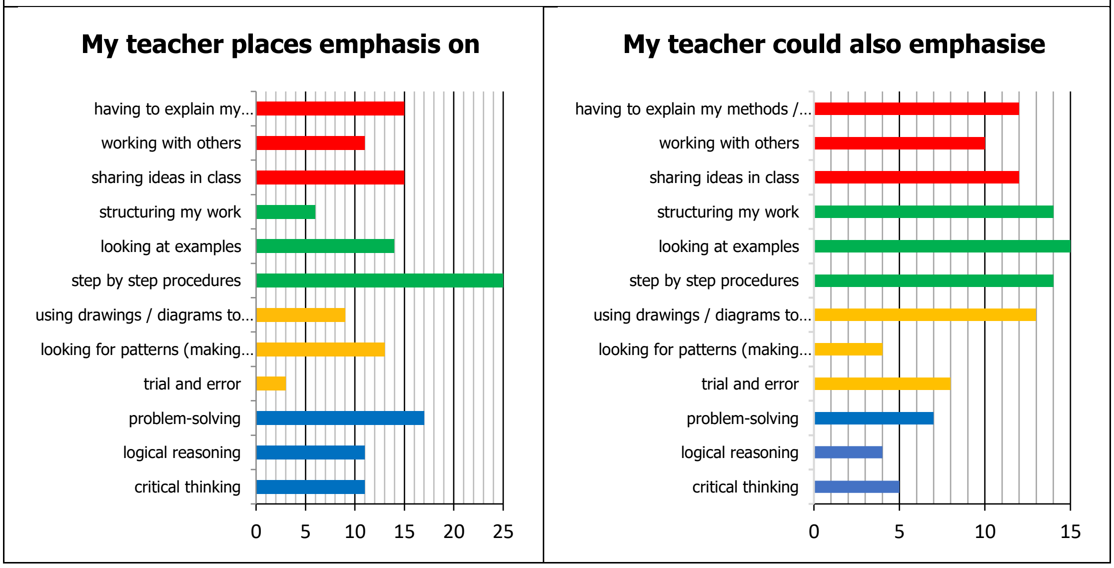
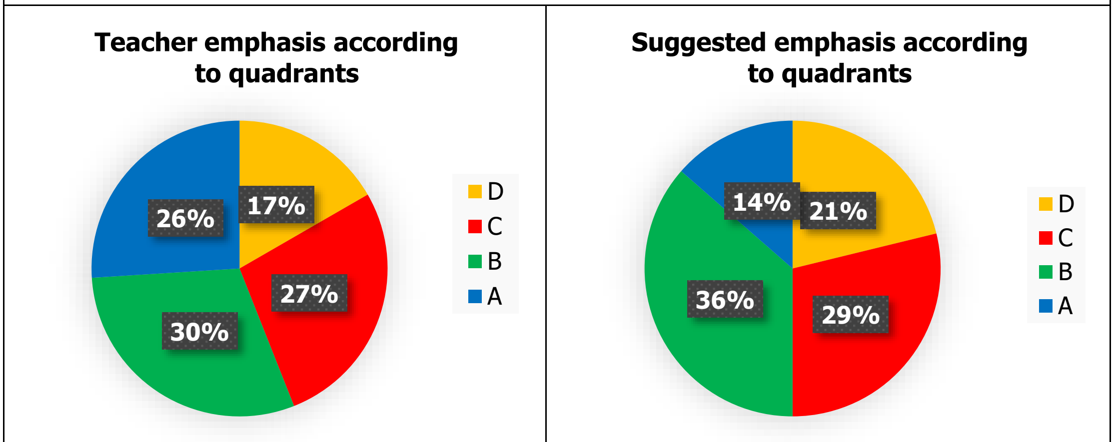


Figure 4.16: Sophie Germain's learner frequencies: Question 2 and Question 4 comparison per quadrant



Left brain: 56% Right brain: 44% Cerebral: 43% Limbic: 57%	Left brain: 50% Right brain: 50% Cerebral: 35% Limbic: 65%

Sophie Germain considers the key feature of facilitation and assessment of learning in Mathematics to be procedural problem-solving, as seen in Table 4.8.

Table 4.8: Sophie Germain's perception of the key features of Mathematics

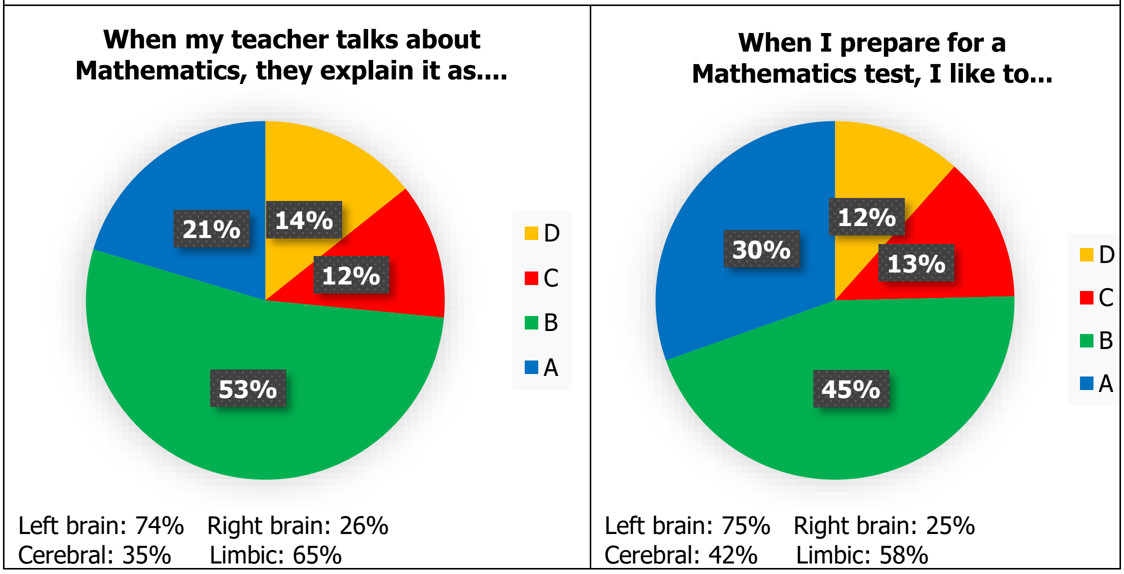
SOPHIE GERMAIN: KEY FEATURE OF MATHEMATICS			
A-QUADRANT	**B-QUADRANT**	**C-QUADRANT**	**D-QUADRANT**
	procedural problem-solving		

More than half of Sophie Germain's learners have also noted that they perceive her view of Mathematics to be procedural problem-solving. This is shown in Table 4.9 and Figure 4.17.

Table 4.9: Sophie Germain's learner frequencies: Question 1 and Question 3 comparison

LEARNERS' FREQUENCIES **Question 1: WHEN MY TEACHER TALKS ABOUT MATHEMATICS, SHE EXPLAINS IT AS…**			
A-QUADRANT a logical and analytical process	**B-QUADRANT** step-by-step instructions to follow	**C-QUADRANT** an opportunity to share ideas and methods	**D-QUADRANT** a process of discovery and making connections
10 (21%)	26 (53%)	6 (12%)	7 (14%)
LEARNERS' FREQUENCIES **Question 3: WHEN I PREPARE FOR A MATHEMATICS TEST I LIKE TO…**			
A-QUADRANT go through the homework questions I got wrong to understand where I went wrong and what to watch out for (I like to focus on the details)	**B-QUADRANT** study examples and step-by-step procedures to solve problems (practice!)	**C-QUADRANT** study with a friend (or friends) so that we can explain to each other	**D-QUADRANT** find connections (differences and similarities) between the different topics so that I can distinguish between them (I like to see the bigger picture)
21 (30%)	31 (45%)	9 (13%)	8 (12%)

Figure 4.17: Sophie Germain's learner frequencies: Question 1 and 3 comparison per quadrant

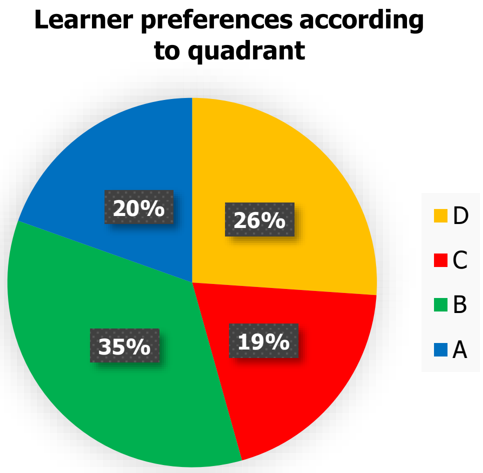


Sophie Germains' learners' preferences and aversions seem to be fairly evenly spread amongst the four quadrants as seen in Table 4.10 and Figure 4.18. The B-quadrant does show a slightly higher preference which could potentially be influenced by Sophie Germain's view of Mathematics as indicated in Table 4.8.

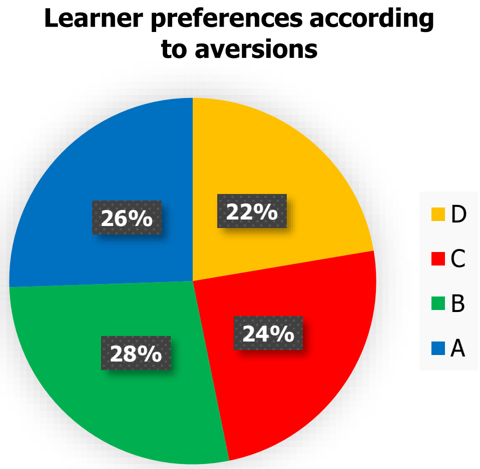
Table 4.10: Sophie Germain's learner frequencies: Question 5 and Question 6 comparison

Question 5: LEARNER PERSONAL PREFERENCE FREQUENCIES:			
A-QUADRANT	**B-QUADRANT**	**C-QUADRANT**	**D-QUADRANT**
logic = 8 breaking down = 10	clear guidelines = 15 examples = 17	share ideas = 16 play = 2	explore = 21 connections = 3
18 (20%)	32 (35%)	18 (19%)	24 (26%)
Question 6: LEARNER PERSONAL AVERSIONS FREQUENCIES:			
A-QUADRANT	**B-QUADRANT**	**C-QUADRANT**	**D-QUADRANT**
group work = 9 long discussions = 15	unfamiliar questions = 17 no set method = 9	working in silence = 8 lots of reading = 15	set method = 16 lots of practice = 5
24 (26%)	26 (28%)	23 (24%)	21 (22%)

FIGURE 4.18: SOPHIE GERMAIN'S LEARNER FREQUENCIES: QUESTION 5 AND QUESTION 6 COMPARISON PER QUADRANT



Left brain: 55% Right brain: 45%
Cerebral: 46% Limbic: 54%



Left brain: 54% Right brain: 46%
Cerebral: 48% Limbic: 52%

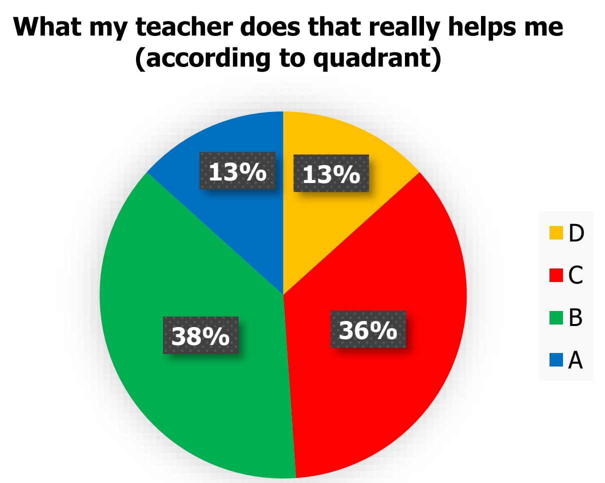
Sophie Germain's Question 7 results, as shown in Table 4.11 and Figure 4.19, show that learners appreciate her B- and C-quadrant approach to facilitating and assessing learning in Mathematics. This is in line with her HBDI® profile scores, as can be seen in Figure 4.20, that show that both these quadrants are her favoured thinking preference quadrants.

TABLE 4.11: SOPHIE GERMAIN'S QUESTION 7 RESULTS

LEARNERS' APPRECIATION OF THEIR TEACHER'S APPROACH TO TEACHING MATHEMATICS	
A-QUADRANT (6)	**D-QUADRANT (6)**
Analysis and in depth explanations (2) • To always read the question first before you answer • I really enjoyed how she taught as she went really in depth **Clear objective and purpose (4)** • Helps us understand the work • My teacher helps us to understand what we are learning • She is good at explaining things which makes it easier for me to learn • I understand everything she says	**Synthesis (1)** • making connections method really helped me **Explore different strategies (5)** • Homework is also based on trial and error • She lets us figure it out for ourselves. • She lets us figure it out, and this helps me learn because I figured it out myself • She prepares us to face unexpected problems and to solve them • Her explanation is varied
B-QUADRANT (17)	**C-QUADRANT (16)**
Step by step procedures (7) • Step by step explanation • The step by step procedure method • When my teacher gives step by step instructions for certain things • She does a lot of step by step explaining which helps me a lot on how to learn the topic	**Support and encouragement (8)** • She explains things well that helps me learn • Helps us when we are stuck with a question. • She always explains things really well, and is always willing to give extra help if you need it • She keeps explaining it until everybody know what to do

• She makes the really complicated things in math like algebra really easy by using different names for it and breaking it down into smaller and easier steps. • She tells me what study method she used and maybe I could use those to help me study • She gives methods to follow. **Practice to improve skills (3)** • She gives us more activities that we can work on in my own • She gives us activities that we can work on our own • My teacher gives me the right amount of homework and examples to work off of if I get stuck **Worked Examples (4)** • She gave us lots of examples and slides to study from • My teacher gives me the right amount of homework and examples to work off of if I get stuck • Does examples on the board with the class • I understand when my teacher goes through lots of examples **Repetition (3)** • My teacher explains the work over and over again until we understand it • Explains it every time I don't understand what is going on • What she did that really helped me learn, was she repeated her lessons. So if you don't understand or you cannot remember, you always know she would repeat it at least once, or until you understand.	• She gives extra tutorials if you struggle with a topic • She puts extra hours to ensure that we understand • my teacher helps us to understand what we are learning • She teaches us a method until she's 100% sure we understand the work **Engages and connects (4)** • She always explains things amazingly and she's funny and makes the lessons entertaining • She is a good teacher, great explanations • Really like my Maths teacher, she helps us when needed lets us ask questions. • Makes jokes **Collaboration (4)** • She put us in pairs and it was easier to understand where I went wrong by my partner explaining how he or she got the right answer • I liked that she let us have class discussion regarding the topic we were learning about • We can share our idea • We can share our thoughts and ideas

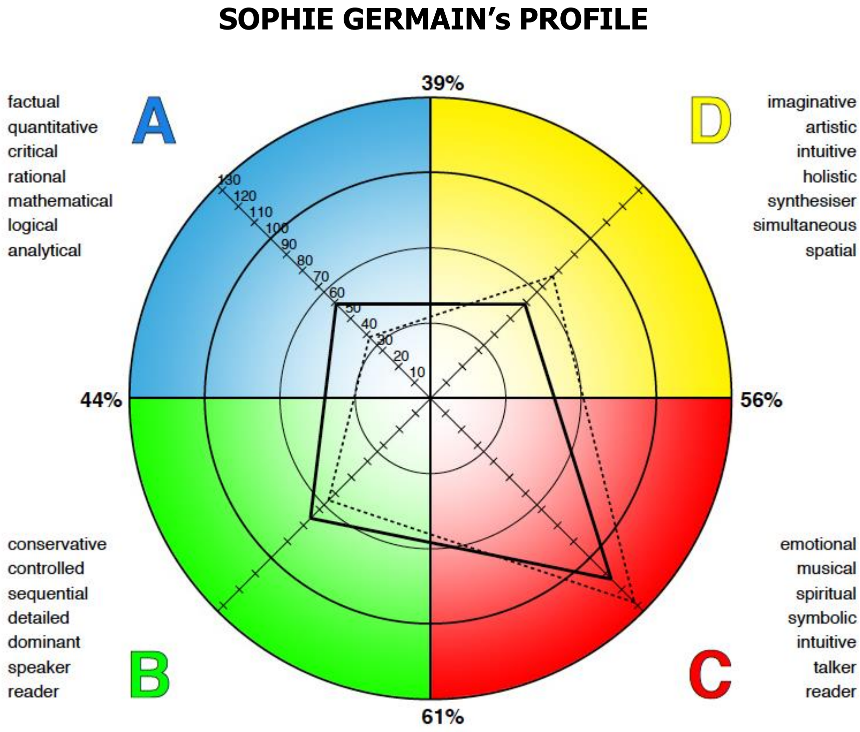
FIGURE 4.19: SOPHIE GERMAIN'S QUESTION 7 RESULTS ACCORDING TO QUADRANT



Left brain: 51%   Right brain: 49%
Cerebral: 26%   Limbic: 74%

Figure 4.20 shows Sophie Germain's HBDI® profile with a preference for the two limbic quadrants. This is indicated by the solid line on the four-quadrant model. Sophie's stress profile, indicated as the dotted line, indicates a shift towards the right-brain quadrants and away from the left-brain quadrants.

Figure 4.20: Sophie Germain's HBDI® profile



Sophie's Diversity Game key cards, show stronger correlation to her adjective pair score than to her profile score. This is indicated in Table 4.12.

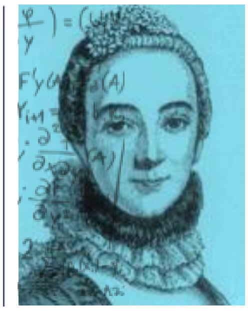
Table 4.12: Sophie Germain's HBDI® profile score in comparison to her Diversity Game descriptors

<table>
<tr><td rowspan="16">
Sophie Germain</td><td colspan="4">DIVERSITY GAME</td></tr>
<tr><td>A-QUADRANT</td><td>B-QUADRANT</td><td>C-QUADRANT</td><td>D-QUADRANT</td></tr>
<tr><td></td><td></td><td>1. passionate
2. emotional</td><td>3. imaginative</td></tr>
<tr><td colspan="4">Herrmann Brain Dominance Instrument® KEY DISCRIPTORS</td></tr>
<tr><td>A-QUADRANT</td><td>B-QUADRANT</td><td>C-QUADRANT</td><td>D-QUADRANT</td></tr>
<tr><td>critical
logical</td><td>* speaker
reader</td><td>* talker
emotional
musical
spiritual
reader</td><td>imaginative</td></tr>
<tr><td colspan="4">Herrmann Brain Dominance Instrument® PROFILE SCORE</td></tr>
<tr><td>A-QUADRANT</td><td>B-QUADRANT</td><td>C-QUADRANT</td><td>D-QUADRANT</td></tr>
<tr><td>59</td><td>75</td><td>113</td><td>59</td></tr>
<tr><td colspan="4">Herrmann Brain Dominance Instrument® ADJECTIVE PAIRS</td></tr>
<tr><td>A-QUADRANT</td><td>B-QUADRANT</td><td>C-QUADRANT</td><td>D-QUADRANT</td></tr>
<tr><td>3</td><td>5</td><td>10</td><td>6</td></tr>
</table>

4.4.2 Maria Agnesi's HBDI® and Pre-Innovation Questionnaire results

Maria Agensi's pre-innovation questionnaire results, shown in Table 4.13, shows an emphasis on the C-quadrant. This is contrary to her HBDI® profile scores in Figure 4.26 which shows a strong preference for the B-quadrant.

Table 4.13: Maria Agnesi's pre-innovation questionnaire results



Maria Agnesi

MARIA AGNESI

Teaching philosophy:
I aim to make my subject one my learners look forward to – even if it is simply the fact that they look forward to my lesson regardless of what I'm teaching.

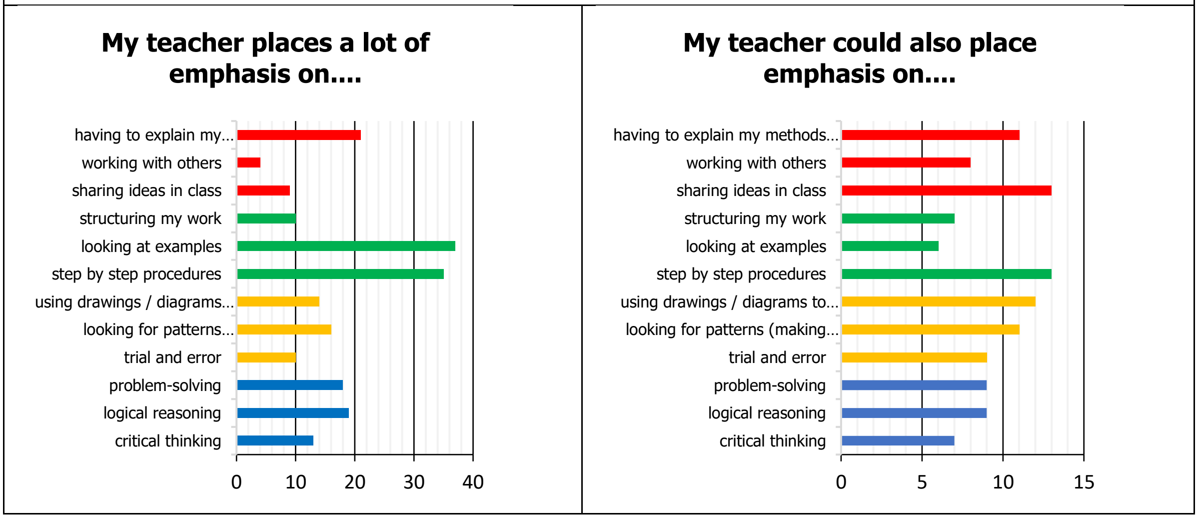
MARIA AGNESI'S PERCEPTION ON THE NATURE OF MATHEMATICS			
A-QUADRANT	**B-QUADRANT**	**C-QUADRANT**	**D-QUADRANT**
places emphasis on accuracy and precision during problem-solving		requires active participation during the learning experience is an opportunity to challenge and motivate learners	
MARIA AGNESI'S THINKING PATTERNS AND PROCESSES EMPHASISED			
A-QUADRANT	**B-QUADRANT**	**C-QUADRANT**	**D-QUADRANT**
	step by step procedures organisation of thoughts	Active participation (hands on learning)	

Maria Agnesi's learners perceive her emphasis to be predominantly B-quadrant focussed and from the feedback they would prefer her focus to be more evenly spread amongst the four quadrants. This can be seen in Table 4.14, Figure 4.21 and Figure 4.22 which indicates what learners perceive her emphasis to be in comparison to what they would like her to focus on.

Table 4.14: Maria Agnesi's Question 2 and Question 4 comparison

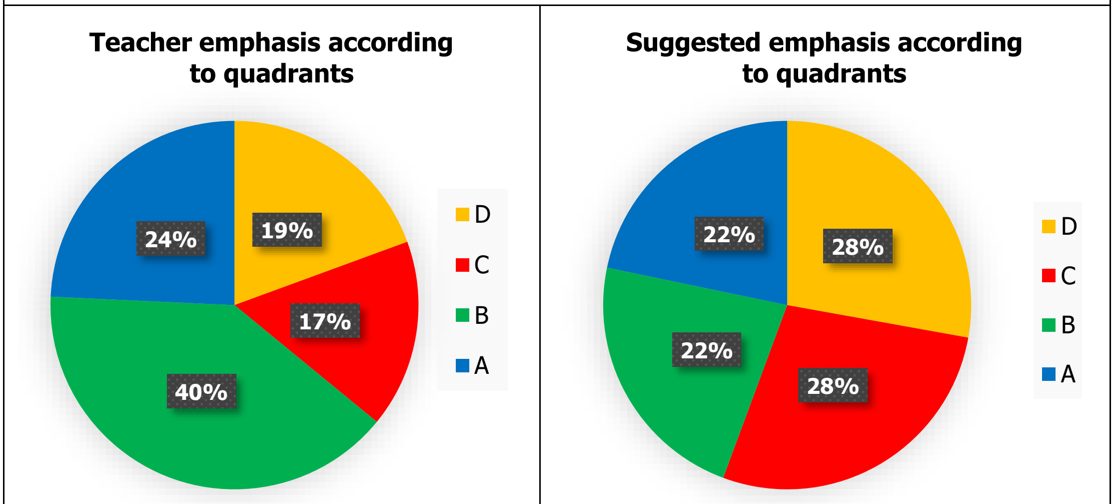
LEARNERS' FREQUENCIES Question 2: MY TEACHER PLACES A LOT OF EMPHASIS ON....			
A-QUADRANT	**B-QUADRANT**	**C-QUADRANT**	**D-QUADRANT**
critical thinking = 13 logical reasoning = 19 problem-solving = 18	step by step = 35 examples = 37 structuring my work = 10	explaining = 21 working with other = 4 sharing ideas = 9	drawings /diagrams = 14 finding patterns = 16 trial and error = 10
50 (24%)	82 (40%)	34 (17%)	40 (19%)
LEARNERS' FREQUENCIES Question 4: MY TEACHER COULD ALSO EMPHASISE...			
A-QUADRANT	**B-QUADRANT**	**C-QUADRANT**	**D-QUADRANT**
critical thinking = 7 logical reasoning = 9 problem-solving = 9	step by step = 13 examples = 6 structuring my work = 7	explaining = 11 working with other = 8 sharing ideas = 13	drawings /diagrams = 12 finding patterns = 11 trial and error = 9
25 (22%)	26 (22%)	32 (28%)	32 (28%)

Figure 4.21: Maria Agnesi's Question 2 and Question 4 comparison



The comparison per quadrant in Figure 4.22, shows that learners would prefer a somewhat bigger emphasis towards right-brain approaches. According to Figure 4.22, learners perceive Maria Agnesi's emphasis toward the left-brain quadrants to be 64% and would like the emphasis to be more evenly balanced.

FIGURE 4.22: MARIA AGNESI'S QUESTION 2 AND QUESTION 4 COMPARISON PER QUADRANT



Left brain: 64% Right brain: 36%
Cerebral: 43% Limbic: 57%

Left brain: 44% Right brain: 56%
Cerebral: 50% Limbic: 50%

Maria Agnesi's perception of the key features of Mathematics can be situated in the D-quadrant, as seen in Table 4.15. This is in contrast to the strong preference for the B-quadrant that learners perceive Maria Agnesi to have both in the approaches she emphasises (seen in Figure 4.22), as well as the manner which they perceive her to explain Mathematics (Figure 4.23).

TABLE 4.15: MARIA AGNESI'S PERCEPTION OF THE KEY FEATURES OF MATHEMATICS

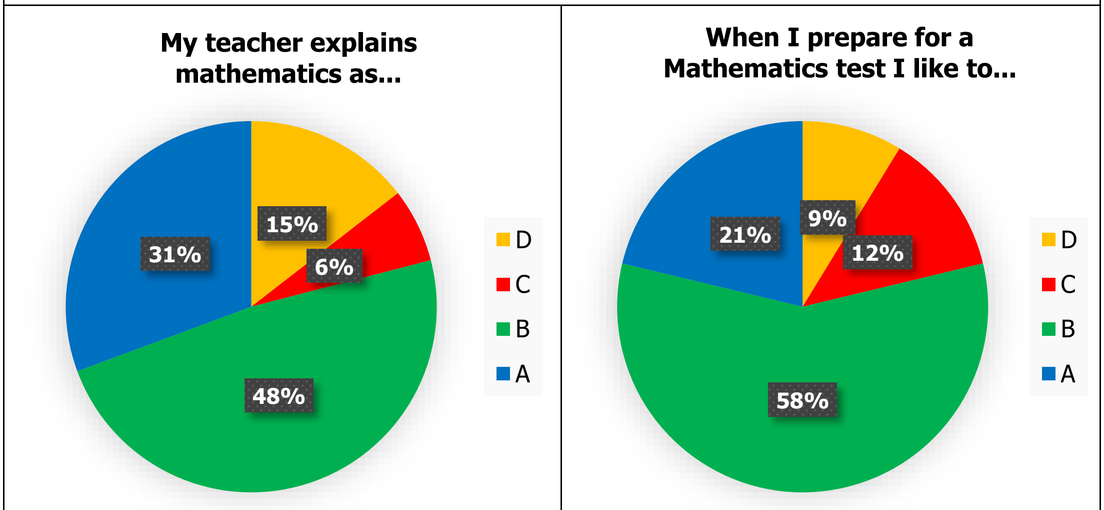
MARIA AGNESI: KEY FEATURE OF MATHEMATICS			
A-QUADRANT	**B-QUADRANT**	**C-QUADRANT**	**D-QUADRANT**
			continuous process of discovery

Maria Agnesi's learners seem to prepare for Mathematics assessments according to the same quadrant they perceive her to focus on. This particularly strong emphasis for the B-quadrant is shown in Table 4.16 as well as Figure 4.23.

Table 4.16: Maria Agnesi's Question 1 and Question 3 comparison

LEARNERS' FREQUENCIES **Question 1: WHEN MY TEACHER TALKS ABOUT MATHEMATICS, SHE EXPLAINS IT AS…**			
A-QUADRANT a logical and analytical process	**B-QUADRANT** step-by-step instructions to follow	**C-QUADRANT** an opportunity to share ideas and methods	**D-QUADRANT** a process of discovery and making connections
19 (31%)	30 (48%)	4 (6%)	9 (15%)
LEARNERS' FREQUENCIES **Question 3: WHEN I PREPARE FOR A MATHEMATICS TEST I LIKE TO…**			
A-QUADRANT go through the homework questions I got wrong to understand where I went wrong and what to watch out for (I like to focus on the details)	**B-QUADRANT** study examples and step-by-step procedures to solve problems (practice!)	**C-QUADRANT** study with a friend (or friends) so that we can explain to each other	**D-QUADRANT** find connections (differences and similarities) between the different topics so that I can distinguish between them (I like to see the bigger picture)
17 (21%)	46 (58%)	10 (12%)	7 (9%)

Figure 4.23: Maria Agnesi's Question 1 and Question 3 comparison per quadrant



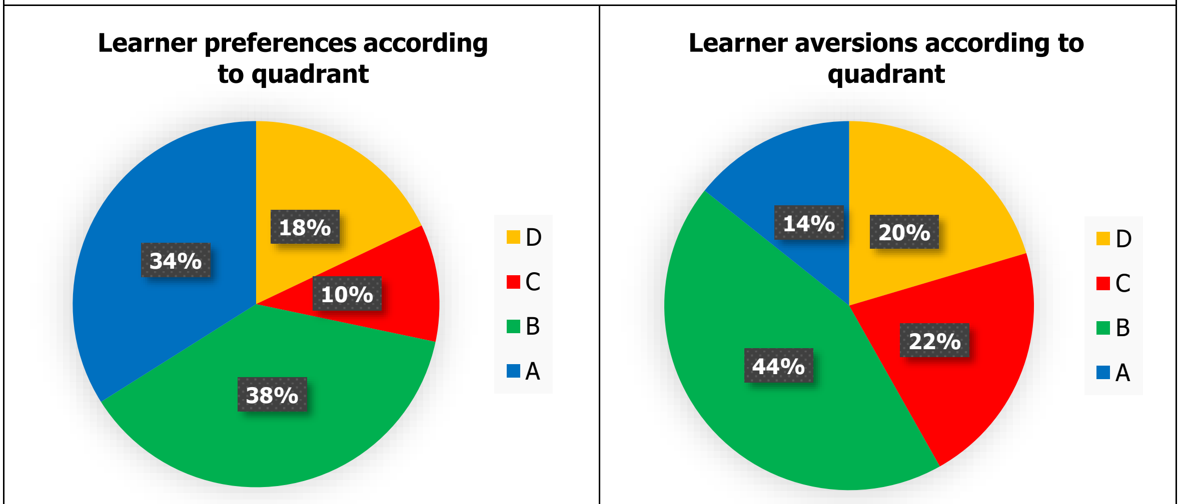
Left brain: 79% Right brain: 21%
Cerebral: 46% Limbic: 54%

Left brain: 79% Right brain: 21%
Cerebral: 30% Limbic: 70%

Question 5 and 6 should theoretically, according to Herrmann (1996), show an even spread amongst the four quadrants. Although Sophie Germain's learners showed a fairly even distribution amongst the quadrants (as shown in Figure 4.16), Maria Agnesi's learners, similar to my learner preferences and aversions (as shown in Figure 4.5), show a higher preference for the B-quadrant. This is indicated in Table 4.17 and Figure 4.24. This preference for the B-quadrant could possibly be associated with Maria Agnesi's learners' perception on how Maria Agnesi explains Mathematics as indicated in Figure 4.23.

Table 4.17: Maria Agnesi's Question 5 and Question 6 comparison			
Question 5: LEARNER PERSONAL PREFERENCE FREQUENCIES:			
A-QUADRANT	**B-QUADRANT**	**C-QUADRANT**	**D-QUADRANT**
logic = 14 breaking down = 22	clear guidelines = 18 examples = 22	share ideas = 8 play = 3	explore = 5 connections = 14
36 (34%)	40 (38%)	11 (10%)	19 (18%)
Question 6: LEARNER PERSONAL AVERSIONS FREQUENCIES:			
A-QUADRANT	**B-QUADRANT**	**C-QUADRANT**	**D-QUADRANT**
group work = 6 long discussions = 8	unfamiliar questions = 26 no set method = 17	working in silence = 2 lots of reading = 19	set method = 7 lots of practice = 13
14 (14%)	43 (44%)	21 (22%)	20 (20%)

Figure 4.24: Maria Agnesi's Question 5 and Question 6 comparison per quadrant



Left brain: 72% Right brain: 28%
Cerebral: 52% Limbic: 48%

Left brain: 58% Right brain: 42%
Cerebral: 34% Limbic: 66%

Most of the data received from Maria Agnesi's learners indicate a preference for B-quadrant thinking approaches. This trend is also visible on analysing her learner appreciation feedback results as seen in Table 4.18 and Figure 4.25.

Table 4.18: Maria Agnesi's Question 7 results according to quadrant

LEARNERS' APPRECIATION OF THEIR TEACHER'S APPROACH TO TEACHING MATHEMATICS	
A-QUADRANT (8)	**D-QUADRANT (4)**
Analysis and in depth explanations (8) • She places allot of emphasis on really understanding a problem and using both a set of general mathematical instructions as general problem solving and reasoning in order to find solutions to questions. • She explains thoroughly • She explains really clearly and logically. • Explain in depth • She goes through things thoroughly • She is really good at providing a thorough and understandable explanation of any topic she teaches • She explains the work clearly and extremely well. • Really explains it well	**Explore different strategies (3)** • If I do not understand the work, she will explain it in multiple and different ways until I get it • She made us figure it out by ourselves. • Writing down mindmaps and examples on the new topics that we are doing. **Synthesis (1)** • What I personally (secretly) do is try to use maths to define and help me understand what I enjoy (or find exploits in games that I'm not allowed to play)
B-QUADRANT (27)	**C-QUADRANT (13)**
Step by step procedures (2) • She wrote down a list of steps to follow when approaching certain sums. • Goes through the whole process step by step and doesn't leave you in the dark for you to find out **Practice to improve skills (3)** • LOTS AND LOTS OF PRACTICE!! • …lets us practice as a class in order to see where we are • …practice at school and at home which we always go through in class once we are finished. I find this useful and excellent practice for the long run. **Worked Examples (10)** • … doing examples on the board • … doing many examples and past tests • We go through many examples. • She does lots of examples to make sure we know how to do all kinds of sums • She shows a lot of examples • She goes through many examples. • She goes through examples. • My teacher provides us with many examples • gives us written examples of the topic. • She also gives lot's of examples and lets us practice in class first then gives us homework and she never just throws us into the deep end. She explains things slowly and in an easy way to understand and doesn't rush through the work **Organised notes (12)** • She recorded each lesson and put it on classroom. This helps me as I can go look back at what we did in class if I get stuck with my homework. • She made use of the Smart Board in the classroom in a way that would help if I did not understand. She would make all of the notes she made on the board available on Google classroom every day and therefore if I really struggled with a concept, had a day where I was just too tired in class or anything else I could go home and review the notes which helped so much.	**Support and encouragement (13)** • She is very helpful in understanding • She makes sure everyone understands what she is talking about and doesn't rush. • Always explains things completely and never just assumes that we know what's happening. • Consistently ensures that I am on top of the work. • The paces of the lessons allowed me to grasp the topics easier than this year. • She went over it with me when I was confused and she didn't get very angry • She was my favourite maths teacher ever! • She is always patient. • She will always help me and explain everything to me so that I can understand it • She helps me understand by her interacting with the class • She is really patient and easy-going which is why I believe I did better than I had ever done in maths when I was in her class. She also teaches at a moderate pace which I really appreciate, as some teachers tend to rush through topics, thus not giving students enough time to practise or get to grips with the concepts being taught. I always felt comfortable with the work before moving on • She's also open to questions which helps us understand the work better. • She was always very open to giving us extra tutorials.

• She makes us notes through smart board and she sends us the notes through • She makes lots of notes that really helps me. • Her notes on (Google) classroom were always so neat and easily accessible, meaning I was able to study from them when I was absent from class. • She gave very organised and neat notes that made it easy to understand and learn from. • She makes us write down notes on the topic we are currently doing as well as gives us written examples of the topic. • She makes a huge effort to post notes and examples done in class onto (Google) classroom. I find this very helpful as it gives me step by step examples to go through at home. This helps me understand the concepts. • She explains things really well in class on explain everything (App) and then posts the notes she makes on (Google) classroom for us to study from • She uses her Apple pencil and the projector to explain and it really helps because you can see the process more easily than a picture or a diagram • She gives us our notes from during our the class • She provides us with quality notes.	

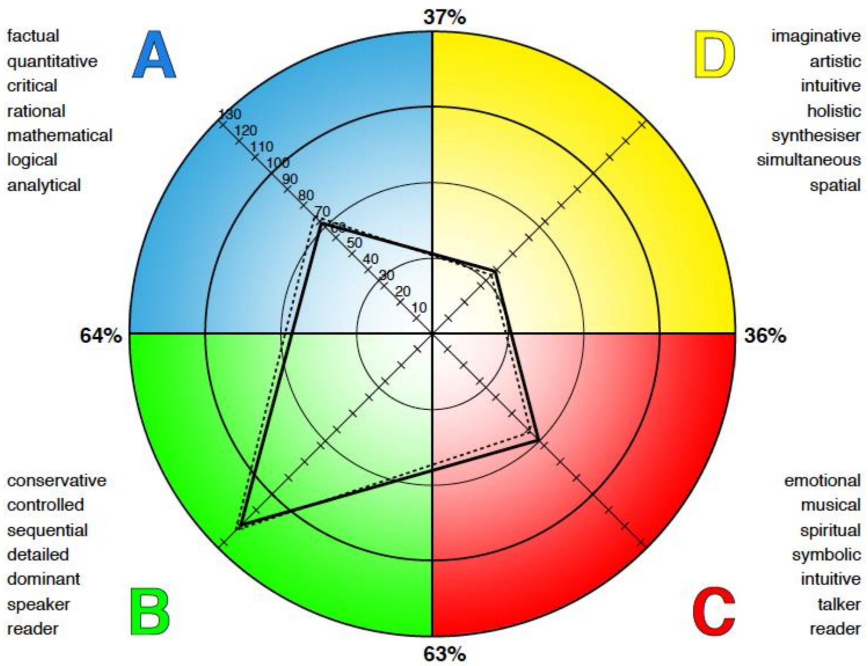
FIGURE 4.25: MARIA AGNESI'S QUESTION 7 RESULTS ACCORDING TO QUADRANT

Left brain: 67% Right brain: 33%
Cerebral: 23% Limbic: 77%

Both Maria Agnesi's HBDI® profile score and adjective pair score show a strong preference for B-quadrant thinking skills. There is also hardly any difference between her profile score and adjective pair score (or stress profile).

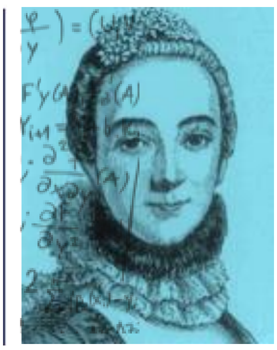
FIGURE 4.26: MARIA AGNESI'S HBDI® PROFILE

MARIA AGNESI's PROFILE



Maria Agnesi's Diversity Game descriptor key cards are aligned with her HBDI® profile scores, once again indicating a strong preference for the B-quadrant.

TABLE 4.19: MARIA AGNESI'S HBDI® PROFILE SCORES IN COMPARISON TO HER DIVERSITY GAME DESCRIPTORS



Maria Agnesi

DIVERSITY GAME			
A-QUADRANT	**B-QUADRANT**	**C-QUADRANT**	**D-QUADRANT**
	1. organised 2. administrative 3. practical		
Herrmann Brain Dominance Instrument® KEY DISCRIPTORS			
A-QUADRANT	**B-QUADRANT**	**C-QUADRANT**	**D-QUADRANT**
quantitative logical mathematical	*sequential dominant speaker reader	emotional talker reader	
Herrmann Brain Dominance Instrument® PROFILE SCORE			
A-QUADRANT	**B-QUADRANT**	**C-QUADRANT**	**D-QUADRANT**
69	119	66	39
Herrmann Brain Dominance Instrument® ADJECTIVE PAIRS			
A-QUADRANT	**B-QUADRANT**	**C-QUADRANT**	**D-QUADRANT**
6	10	5	3

4.4.3 Ada Lovelace's HBDI® and Pre-Innovation Questionnaire results

Ada Lovelace's pre-innovation questionnaire results, in Table 4.20, show a fairly even spread amongst the four quadrants.

Table 4.20: Ada Lovelace's pre-innovation questionnaire results			
 Ada Lovelace	**ADA LOVELACE** **Teaching philosophy:** The mediocre teacher tells. The good teacher explains. The superior teacher demonstrates. The great teacher inspires. *William Arthur Ward*		
ADA LOVELACE's PERCEPTION ON THE NATURE OF MATHEMATICS			
A-QUADRANT	**B-QUADRANT**	**C-QUADRANT**	**D-QUADRANT**
	is about being organized and consistent	is an opportunity to challenge and motivate learners	is a process of discovery and exploring new ideas
ADA LOVELACE's THINKING PATTERNS AND PROCESSES EMPHASISED			
A-QUADRANT	**B-QUADRANT**	**C-QUADRANT**	**D-QUADRANT**
critical thinking logical reasoning			brainstorming

Similar to the question 2 results from Sophie Germain's, Maria Agnesi's and my own learners, Ada Lovelace's learners also perceived her emphasis to be more B-quadrant focussed. This can be seen in Table 4.21 and Figure 4.27 which compare Ada Lovelace's learner questionnaire results for Question 2 and Question 4.

When analysing Maria Agnesi's learner questionnaire results, this focus could be ascribed to her personal strong preference for the B-quadrant, but since neither Sophie Germain, Ada Lovelace or myself test with a particularly strong B-quadrant preference, this perception of a B-quadrant focus is noteworthy and will be further discussed in Chapter 5.

Table 4.21: Ada Lovelace's learner frequencies: Question 2 and Question 4 comparison			
LEARNERS' FREQUENCIES MY TEACHER PLACES A LOT OF EMPHASIS ON....			
A-QUADRANT	**B-QUADRANT**	**C-QUADRANT**	**D-QUADRANT**
critical thinking = 9 logical reasoning = 9 problem-solving = 12	step by step = 27 examples = 25 structuring my work = 6	explaining = 16 working with other = 1 sharing ideas = 8	drawings / diagrams = 5 finding patterns = 13 trial and error = 11
30 (21%)	58 (41%)	25 (18%)	29 (20%)
LEARNERS' FREQUENCIES MY TEACHER COULD ALSO EMPHASISE....			
A-QUADRANT	**B-QUADRANT**	**C-QUADRANT**	**D-QUADRANT**
critical thinking = 15 logical reasoning = 9 problem-solving = 9	step by step = 10 examples = 13 structuring my work = 14	explaining = 9 working with other = 12 sharing ideas = 12	drawings/ diagrams = 10 finding patterns = 7 trial and error = 7
33 (26%)	37 (29%)	33 (26%)	24 (19%)

Figure 4.27: Ada Lovelace's learner frequencies: Question 2 and Question 4 comparison

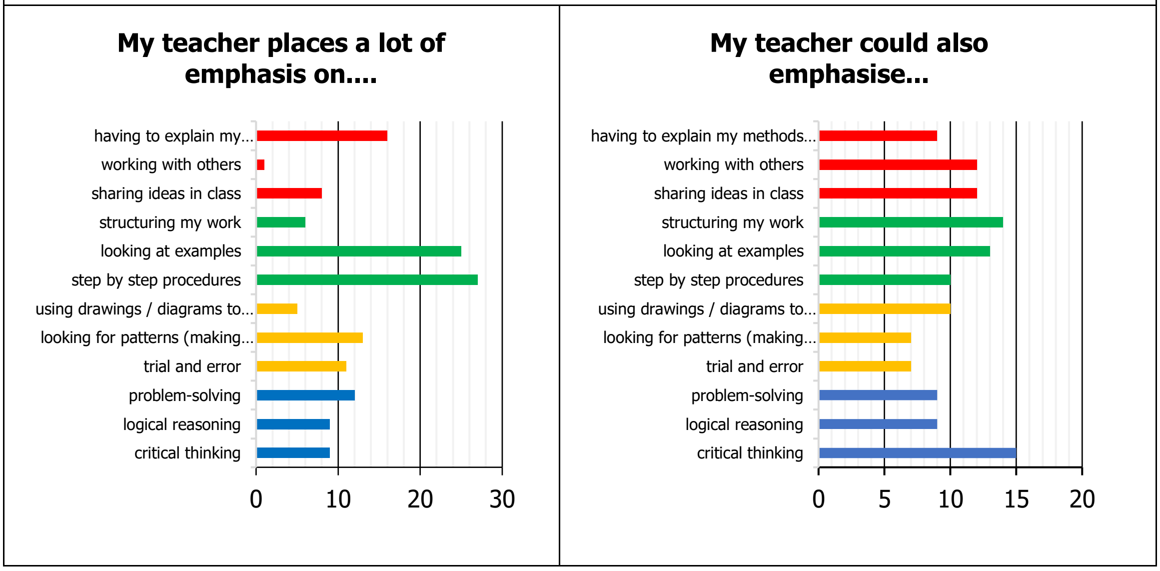
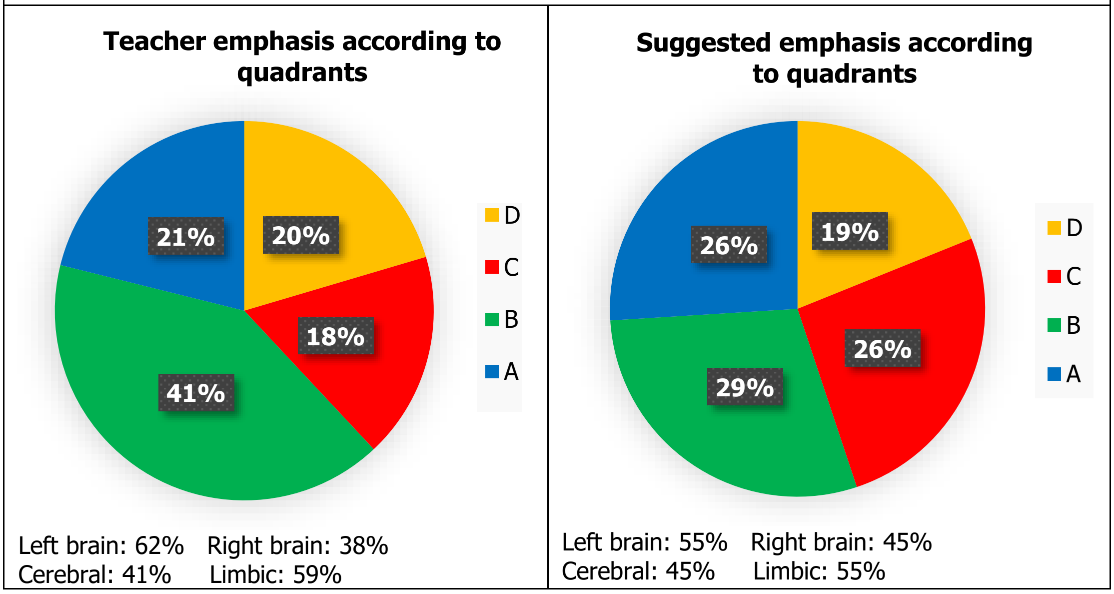


Figure 4.28 indicates that learners would prefer their teacher to have a more Whole Brain orientated approach whereas they perceive her current approach to be more B-quadrant focussed.

FIGURE 4.2: ADA LOVELACE'S LEARNER FREQUENCIES: QUESTION 2 AND QUESTION 4 COMPARISON PER QUADRANT



In Ada Lovelace's pre-questionnaire results, a somewhat higher preference for the D-quadrant can be seen as indicated in Table 4.20 and 4.22. Both Maria Agnesi and Ada Lovelace chose the key feature of Mathematics to be a "continuous process of discovery" despite it not being congruent to their HBDI® profile descriptors or their learner questionnaire results. Rather than giving an indication of their view of Mathematics prior to the research innovation as a process of discovery, it could be indicative of their view of the innovation itself as a process of discovery. This could be motivated by the high value placed on professional development within this particular community of practice.

TABLE 4.22: ADA LOVELACE'S PERCEPTION OF THE KEY FEATURES OF MATHEMATICS

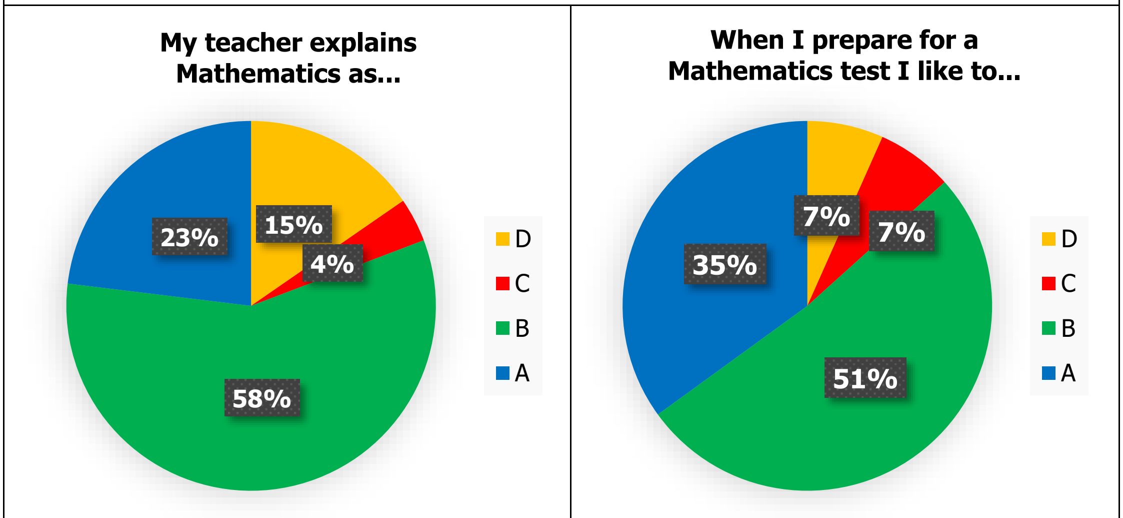
ADA LOVELACE: KEY FEATURE OF MATHEMATICS			
A-QUADRANT	**B-QUADRANT**	**C-QUADRANT**	**D-QUADRANT**
			continuous process of discovery

Similar to the B-quadrant emphasis shown in Ada Lovelace's learners' Question 2 results, both Question 1 and Question 3 show a similar focus towards B-quadrant thinking processes. This is indicated in Table 4.23 and Figure 4.29.

Table 4.23: Ada Lovelace's learner frequencies: Question 1 and Question 3 comparison

LEARNERS' FREQUENCIES Question 1: WHEN MY TEACHER TALKS ABOUT MATHEMATICS, SHE EXPLAINS IT AS…			
A-QUADRANT a logical and analytical process	**B-QUADRANT** step-by-step instructions to follow	**C-QUADRANT** an opportunity to share ideas and methods	**D-QUADRANT** a process of discovery and making connections
12 (23%)	30 (58%)	2 (4%)	8 (15%)
LEARNERS' FREQUENCIES Question 3: WHEN I PREPARE FOR A MATHEMATICS TEST I LIKE TO…			
A-QUADRANT go through the homework questions I got wrong to understand where I went wrong and what to watch out for (I like to focus on the details)	**B-QUADRANT** study examples and step-by-step procedures to solve problems (practice!)	**C-QUADRANT** study with a friend (or friends) so that we can explain to each other	**D-QUADRANT** find connections (differences and similarities) between the different topics so that I can distinguish between them (I like to see the bigger picture)
21 (35%)	31 (51%)	4 (7%)	4 (7%)

Figure 4.29: Ada Lovelace's learner frequencies: Question 1 and Question 3 comparison per quadrant



Left brain: 81% Right brain: 19%
Cerebral: 38% Limbic: 62%

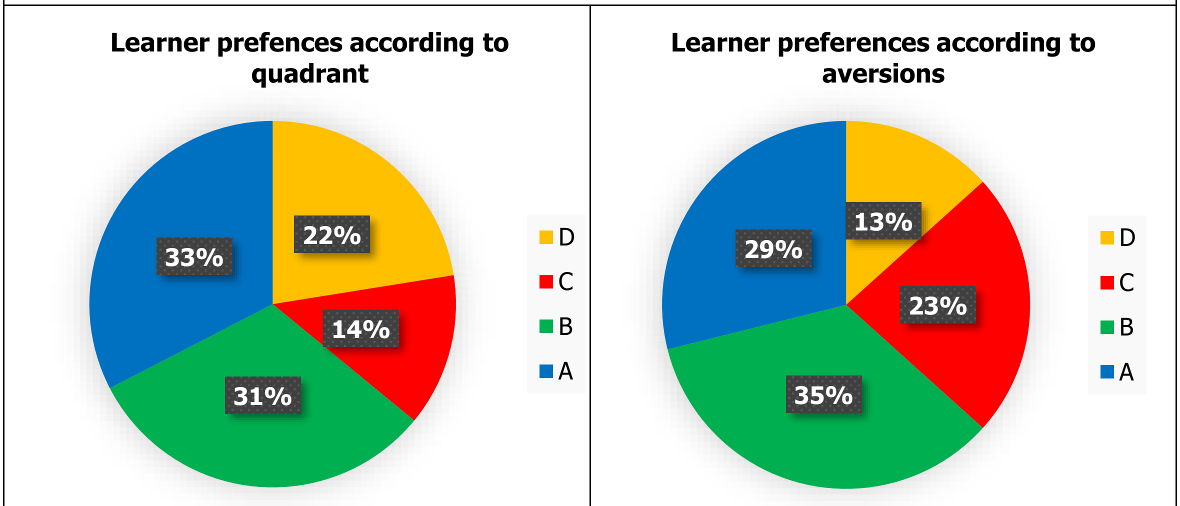
Left brain: 86% Right brain: 14%
Cerebral: 42% Limbic: 58%

When compared to Question 1, 2 and 3, the results of Ada Lovelace's learners' Question 5 and 6 results are more evenly distributed amongst the four quadrants. In Table 4.24 and Figure 4.30, a higher preference is shown for the left-brain thinking preferences.

Table 4.24: Ada Lovelace's learner frequencies: Question 5 and Question 6 comparison

Question 5: LEARNER PERSONAL PREFERENCE FREQUENCIES:			
A-QUADRANT	**B-QUADRANT**	**C-QUADRANT**	**D-QUADRANT**
logic = 15 breaking down = 14	clear guidelines = 13 examples = 15	share ideas = 0 play = 12	explore = 11 connections = 9
29 (33%)	28 (31%)	12 (14%)	20 (22%)
Question 6: LEARNER PERSONAL AVERSIONS FREQUENCIES:			
A-QUADRANT	**B-QUADRANT**	**C-QUADRANT**	**D-QUADRANT**
group work = 9 long discussions = 17	unfamiliar questions = 15 no set method = 16	working in silence = 10 lots of reading = 11	set method = 5 lots of practice = 7
26 (29%)	31 (35%)	21 (23%)	12 (13%)

Figure 4.30: Ada Lovelace's learner frequencies: Question 5 and Question 6 comparison per quadrant



Left brain: 64% Right brain: 36%
Cerebral: 55% Limbic: 45%

Left brain: 64% Right brain: 36%
Cerebral: 42% Limbic: 58%

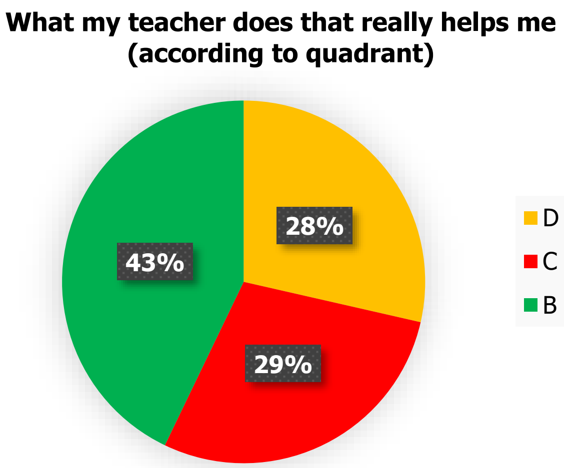
From the data that was received, a focus towards the B-quadrant is evident as can be seen in Table 4.25 and Figure 4.31.

Table 4.25: Ada Lovelace's Question 7 results

LEARNERS' APRECIATION OF THEIR TEACHER'S APPROACH TO TEACHING MATHEMATICS	
A-QUADRANT (0)	**D-QUADRANT (2)**
	Explore different strategies (2) • Explains why we use specific methods/equations for maths in depth and doesn't just give us a method. (explore) She lets us figure it out for ourselves. • My teacher always gives us full explanations and she always gives us different ways to solve one problem (explore) She prepares us to face unexpected problems and to solve them

B-QUADRANT (3)	C-QUADRANT (2)
Practice to improve skills (3) • She gave us a lot of homework which helped improve my marks greatly • She gave us past year papers She teaches mainly from the textbook and gave us lots of homework which we were given sometime in class to complete. A lot of the class was spent on practical use.	**Support and encouragement (1)** • She explains concepts in such a way that everyone can understand. (support and encouragement) **Collaboration (1)** • She also allowed as to work in pairs and help each other.

FIGURE 4.31: ADA LOVELACE'S QUESTION 7 RESULTS ACCORDING TO QUADRANT

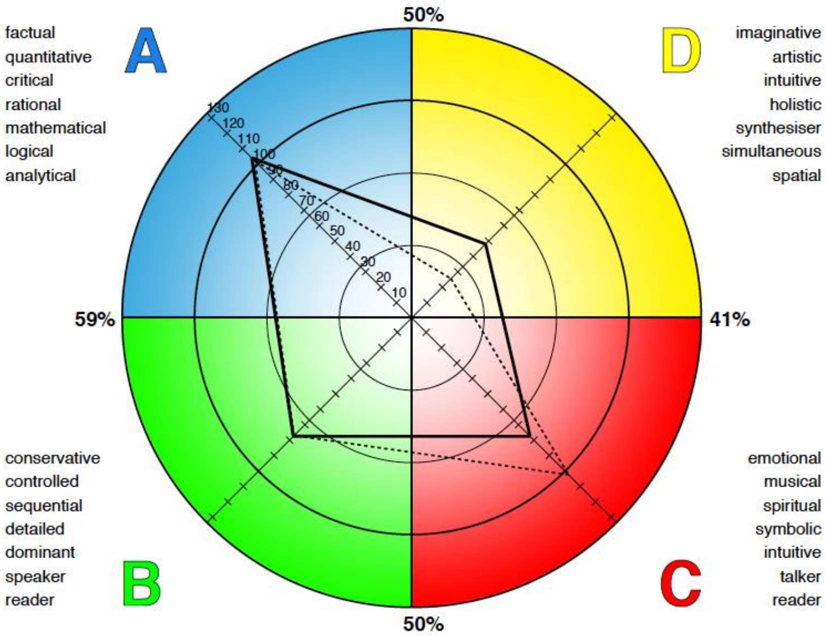


Left brain: 43% Right brain: 57%
Cerebral: 28% Limbic: 72%

Ada Lovelace show a preference for the A-, B- and C-quadrant with a somewhat higher preference for the A-quadrant as can be seen in Figure 4.32. Her profile changes towards an A- and C-quadrant focus under stress, as indicated with the dotted line on her HBDI® profile.

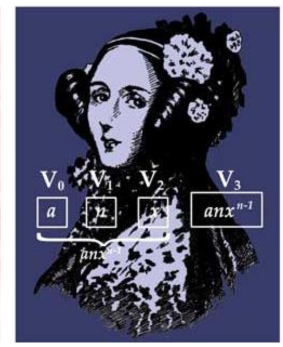
Figure 4.32: Ada Lovelace's HBDI® profile

ADA LOVELACE's PROFILE



Contrary to Ada Lovelace's triple-dominant HBDI® profile, her primary descriptor in the Diversity Game was a D-quadrant descriptor. Ada Lovelace's D-quadrant, according to the HBDI® is her least preferred quadrant. This contradiction between Ada Lovelace's pre-questionnaire results and her HBDI® profile is discussed in Chapter 5.

Table 4.26: Ada Lovelace's HBDI® profile score in comparison to her Diversity Game descriptors

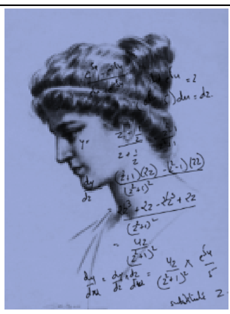
	DIVERSITY GAME			
	A-QUADRANT	**B-QUADRANT**	**C-QUADRANT**	**D-QUADRANT**
	2. problem-solver 3. critical			1. adventurous
	Herrmann Brain Dominance Instrument® KEY DISCRIPTORS			
	A-QUADRANT	**B-QUADRANT**	**C-QUADRANT**	**D-QUADRANT**
 Ada Lovelace	* logical rational mathematical analytical	sequential reader	emotional intuitive reader	intuitive
	Herrmann Brain Dominance Instrument® PROFILE SCORE			
	A-QUADRANT	**B-QUADRANT**	**C-QUADRANT**	**D-QUADRANT**
	104	77	77	48
	Herrmann Brain Dominance Instrument® ADJECTIVE PAIRS			
	A-QUADRANT	**B-QUADRANT**	**C-QUADRANT**	**D-QUADRANT**
	8	6	8	2

4.4.4 Hypatia's HBDI® and Pre-Innovation Questionnaire results

Hypatia's pre-innovation questionnaire, her Herrmann Brain Dominance Instrument® profile and the learner feedback surveys is compared in the following section. It should be noted that Hypatia has less learner feedback data, since she teaches fewer classes due to her managerial and administrative responsibilities within the school. Since Hypatia's learner questionnaire results consist of a particularly small data set of top-achieving girls, interpretations should be made with caution.

Hypatia's pre-innovation results fall into all four quadrants as shown in Table 4.27. When considering the left-brain thinking patterns and processes she emphasises according to her pre-innovation questionnaire results, the congruency between these processes and her HBDI® profile scores, shown in Figure 4.38, can be drawn.

Table 4.27: Hypatia's pre-innovation questionnaire results



Hypatia

HYPATIA

Teaching philosophy: simplicity and common sense brings understanding

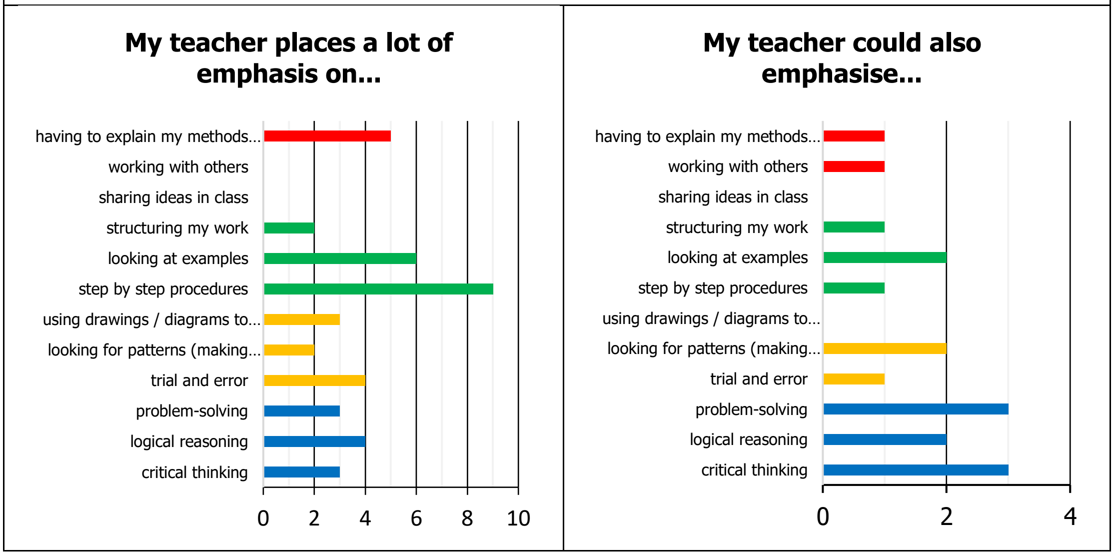
HYPATIA'S PERCEPTION ON THE NATURE OF MATHEMATICS			
A-QUADRANT	**B-QUADRANT**	**C-QUADRANT**	**D-QUADRANT**
	is about practical application	is an opportunity to challenge and motivate learners	requires a conceptual (bigger picture) understanding
HYPATIA'S THINKING PATTERNS AND PROCESSES EMPHASISED			
A-QUADRANT	**B-QUADRANT**	**C-QUADRANT**	**D-QUADRANT**
critical thinking logical reasoning	organisation of thoughts		

As with prior learner questionnaire results, an emphasis towards the B-quadrant can also be seen in Hypatia's Question 2 results as shown in Table 4.28, Figure 4.30 and Figure 4.34.

TABLE 4.28: HYPATIA'S LEARNER FREQUENCIES: QUESTION 2 AND QUESTION 4 COMPARISON

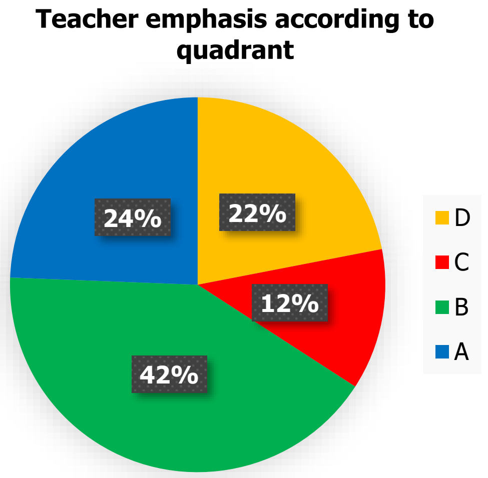
LEARNERS' FREQUENCIES **Question 2: MY TEACHER PLACES A LOT OF EMPHASIS ON....**			
A-QUADRANT	**B-QUADRANT**	**C-QUADRANT**	**D-QUADRANT**
critical thinking = 3 logical reasoning = 4 problem-solving = 3	step by step = 9 examples = 6 structuring my work = 2	explaining = 5 working with other = 0 sharing ideas = 0	drawings /diagrams = 3 finding patterns = 2 trial and error = 4
10 (24%)	17 (42%)	5 (12%)	9 (22%)
LEARNERS' FREQUENCIES **Question 4: MY TEACHER COULD ALSO EMPHASISE**			
A-QUADRANT	**B-QUADRANT**	**C-QUADRANT**	**D-QUADRANT**
critical thinking = 3 logical reasoning = 2 problem-solving = 3	step by step = 1 examples = 2 structuring my work = 1	explaining = 1 working with other = 1 sharing ideas = 0	drawings /diagrams = 0 finding patterns = 2 trial and error = 1
8	4	2	3

FIGURE 4.33: HYPATIA'S LEARNER FREQUENCIES: QUESTION 2 AND QUESTION 4 COMPARISON

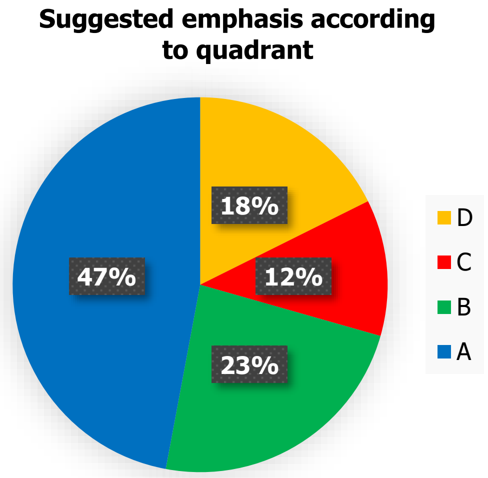


Contrary to what has been seen in previous pre-questionnaire results, Hypatia's learners suggest that she should place a higher emphasis on the A-quadrant as indicated in Figure 4.34. This emphasis towards the A-quadrant is congruent with Hypatia's preferred quadrant on her HBDI® profile.

FIGURE 4.34: HYPATIA'S LEARNER FREQUENCIES: QUESTION 2 AND QUESTION 4 COMPARISON PER QUADRANT



Left brain: 66% Right brain: 34%
Cerebral: 46% Limbic: 54%



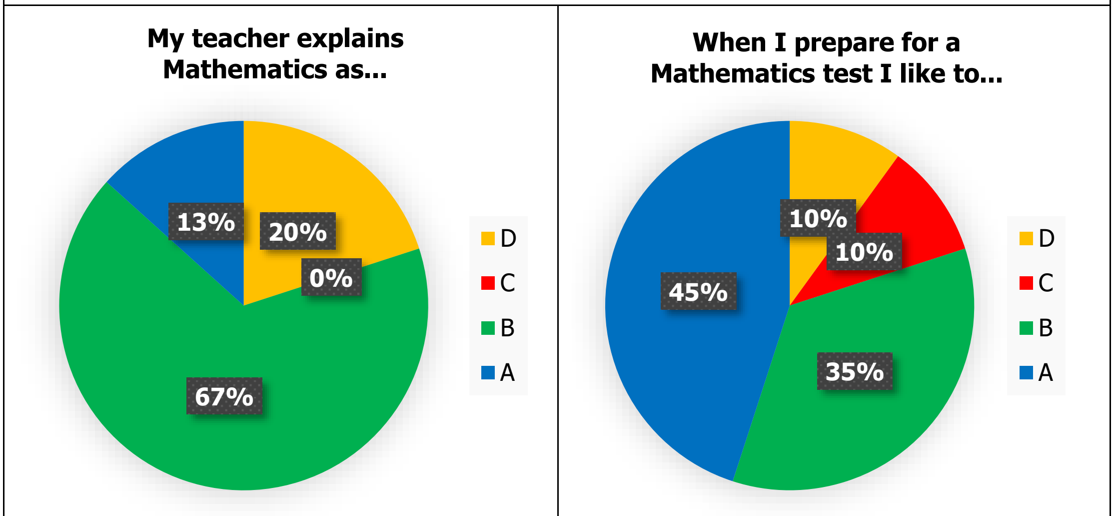
Left brain: 70% Right brain: 30%
Cerebral: 65% Limbic: 35%

TABLE 4.29: HYPATIA'S PERCEPTION ON THE KEY FEATURES OF MATHEMATICS			
HYPATIA: KEY FEATURE OF MATHEMATICS			
A-QUADRANT	**B-QUADRANT**	**C-QUADRANT**	**D-QUADRANT**
	procedural problem-solving		

When comparing the results of Question 1 and Question 3, there seem to be a discrepancy between the way Hypatia's learners perceive her to explain Mathematics and how they like to prepare for Mathematics assessments. This is indicated in Table 4.30 and Figure 4.35.

TABLE 4.30: HYPATIA'S LEARNER FREQUENCIES: QUESTION 1 AND QUESTION 3 COMPARISON			
LEARNERS' FREQUENCIES **Question 1: WHEN MY TEACHER TALKS ABOUT MATHEMATICS, THEY EXPLAIN IT AS…**			
A-QUADRANT a logical and analytical process	**B-QUADRANT** step-by-step instructions to follow	**C-QUADRANT** an opportunity to share ideas and methods	**D-QUADRANT** a process of discovery and making connections
2 (13%)	10 (67%)	0 (0%)	3 (20%)
LEARNERS' FREQUENCIES **Question 3: WHEN I PREPARE FOR A MATHEMATICS TEST, I LIKE TO…**			
A-QUADRANT go through the homework questions I got wrong to understand where I went wrong and what to watch out for (I like to focus on the details)	**B-QUADRANT** study examples and step-by-step procedures to solve problems (practice!)	**C-QUADRANT** study with a friend (or friends) so that we can explain to each other	**D-QUADRANT** find connections (differences and similarities) between the different topics so that I can distinguish between them (I like to see the bigger picture)
9 (45%)	7 (35%)	2 (10%)	2 (10%)

FIGURE 4.35: HYPATIA'S LEARNER FREQUENCIES: QUESTION 1 AND QUESTION 3 COMPARISON PER QUADRANT



Left brain: 80% Right brain: 20%
Cerebral: 33% Limbic: 67%

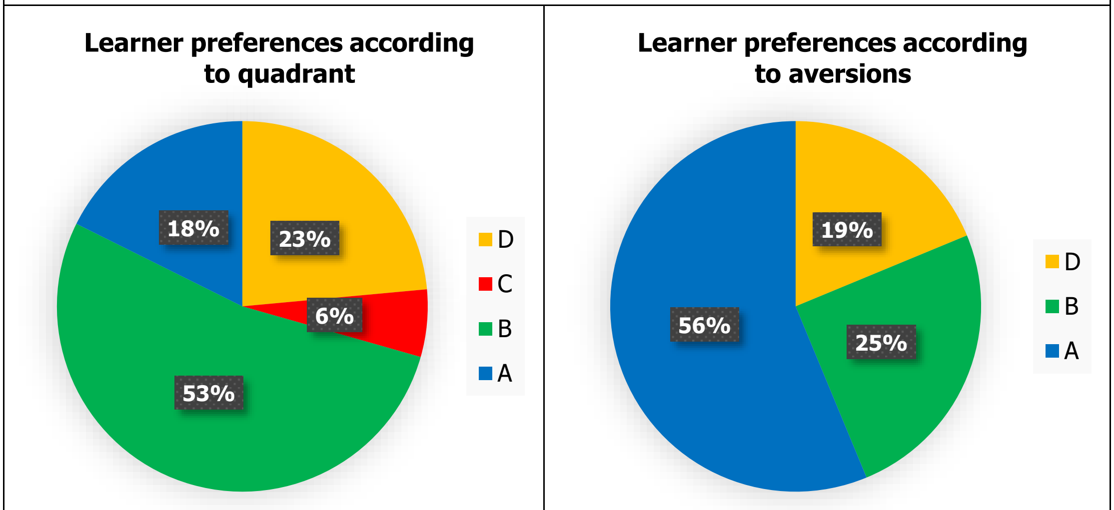
Left brain: 80% Right brain: 20%
Cerebral: 55% Limbic: 45%

Similar to the trend that emerged from Hypatia's Question 1 and Question 3 results, the results of Question 5 and Question 6 indicated in Table 4.31 and Figure 4.36 also indicate a predominant preference for left-brain thinking preferences with almost no preference for the C-quadrant.

TABLE 4.31: HYPATIA'S LEARNER FREQUENCIES: QUESTION 5 AND QUESTION 6 COMPARISON

Question 5: LEARNER PERSONAL PREFERENCE FREQUENCIES:			
A-QUADRANT	**B-QUADRANT**	**C-QUADRANT**	**D-QUADRANT**
logic = 1 breaking down = 2	clear guidelines = 2 examples = 7	share ideas = 0 play = 1	explore = 2 connections = 2
3 (18%)	9 (53%)	1 (6%)	4 (23%)
Question 6: LEARNER PERSONAL AVERSIONS FREQUENCIES:			
A-QUADRANT	**B-QUADRANT**	**C-QUADRANT**	**D-QUADRANT**
group work = 1 long discussions = 8	unfamiliar questions = 2 no set method = 2	working in silence = 0 lots of reading = 0	set method = 0 lots of practice = 3
9 (80%)	4 (25%)	0	3 (19%)

Figure 4.36: Hypatia's learner frequencies: Question 5 and Question 6 comparison per quadrant



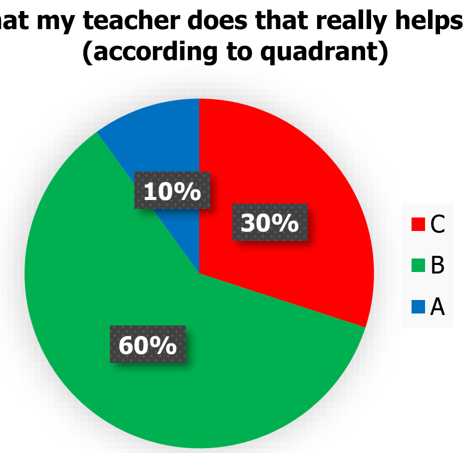
Left brain: 80% Right brain: 20% Cerebral: 33% Limbic: 67%	Left brain: 80% Right brain: 20% Cerebral: 55% Limbic: 45%

The B-quadrant focus that was evident in Questions 1, 2 and 5 is also evident in Hypatia's Question 7 results as indicated in Table 4.32 and Figure 4.37.

Table 4.32: Hypatia's Question 7 results

LEARNERS' APRECIATION OF THEIR TEACHER'S APPROACH TO TEACHING MATHEMATICS	
A-QUADRANT (1)	**D-QUADRANT (0)**
Analysis and in depth explanations (1) • She helps you understand something you struggle with and doesn't just give you the answer.	
B-QUADRANT (6)	**C-QUADRANT (3)**
Step by step procedures (1) • If you don't understand the method, she will go through it step by step. **Repetition (2)** • She really help us understand what we are doing and makes sure all of us understand and she will explain it many times until we all understand it • She goes over the things we don't know until we know it before moving on. **Worked Examples (2)** • She uses examples and we can ask her questions on what we don't understand. • She writes examples and uses the iPad to show us how to do most of the work. **Organised notes (1)** • She puts all the notes on Classroom	**Support and encouragement (3)** • She will help you no matter what, and will explain it in a way you will understand with kindness • She motivates me to look at harder problems. • I enjoy her method of teaching and the way she teaches the methods to us in class.

FIGURE 4.37: HYPATIA'S QUESTION 7 RESULTS ACCORDING TO QUADRANT



Left brain: 70% Right brain: 30%
Cerebral: 40% Limbic: 60%

Hypatia's HBDI® profile in Figure 4.38 indicates a left-brain dominant profile with a stress profile that is predominantly limbic. Her left-brain dominance is a possible explanation for the left-brain preferences that can be seen in her learner questionnaire results. Her left-brain preferences can also be seen in Table 4.33 which compares her Diversity Game key card descriptors to her HBDI® profile scores.

FIGURE 4.38: HYPATIA'S HDBI® PROFILE

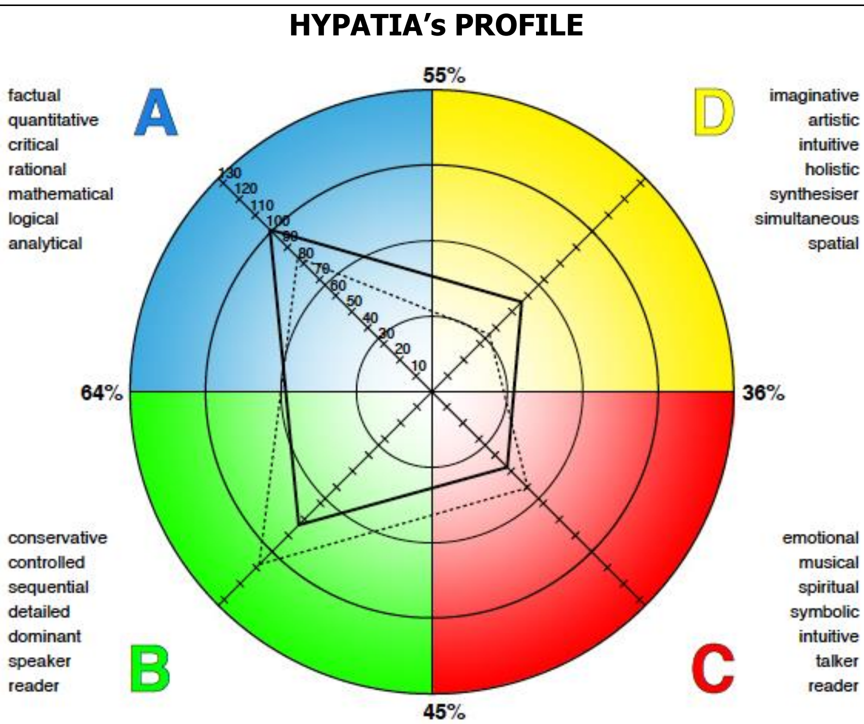
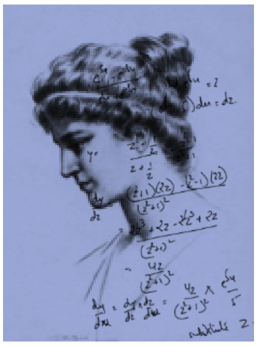
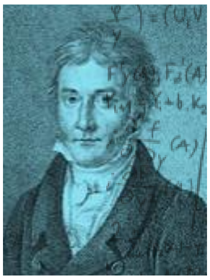


TABLE 4.33: HYPATIA'S HDBI® PROFILE SCORE IN COMPARISON TO HER DIVERSITY GAME DESCRIPTORS

	DIVERSITY GAME			
	A-QUADRANT	**B-QUADRANT**	**C-QUADRANT**	**D-QUADRANT**
	1. logical 2. rational	2. detailed		
	Herrmann Brain Dominance Instrument® KEY DISCRIPTORS			
	A-QUADRANT	**B-QUADRANT**	**C-QUADRANT**	**D-QUADRANT**
 Hypatia	*analytical factual rational mathematical logical	controlled detailed	intuitive	intuitive
	Herrmann Brain Dominance Instrument® PROFILE SCORE			
	A-QUADRANT	**B-QUADRANT**	**C-QUADRANT**	**D-QUADRANT**
	101	83	47	56
	Herrmann Brain Dominance Instrument® ADJECTIVE PAIRS			
	A-QUADRANT	**B-QUADRANT**	**C-QUADRANT**	**D-QUADRANT**
	7	9	5	3

4.4.5 Carl Gauss's HBDI® and Pre-Innovation Questionnaire results

Despite Carl Gauss's HBDI® profile, seen in Figure 4.44, indicating a particularly strong preference for the A- and B-quadrants, his pre-innovation questionnaire results show a view of Mathematics that also include C- and D-quadrant thinking processes. These perceptions are indicated in Table 4.34.

Table 4.34: Carl Gauss's pre-innovation questionnaire results			
 Carl Friedrich Gauss	**CARL GAUSS** **Teaching philosophy:** Maths provides a creative platform for thinking with self-discipline		
CARL GAUSS'S PERCEPTION ON THE NATURE OF MATHEMATICS			
A-QUADRANT	**B-QUADRANT**	**C-QUADRANT**	**D-QUADRANT**
seeks to validate statements and proof claims		requires active participation during the learning experience	is a process of discovery and exploring new ideas
CARL GAUSS'S THINKING PATTERNS AND PROCESSES EMPHASISED			
A-QUADRANT	**B-QUADRANT**	**C-QUADRANT**	**D-QUADRANT**
logical reasoning			brainstorming pattern-recognition

Similar to Carl Gauss's HBDI® profile, learners perceive his emphasis to be predominantly left-brain focussed. Most likely due to this left-brain focus, learners suggest that Carl Gauss place more emphasis on right-brain processes. Table 4.35, Figure 4.39 and Figure 4.40 indicate this comparison between Question 2 and Question 4. Whereas the Question 2 results indicated a left-brain emphasis of 70%, Question 4 results indicated that learners would like Carl Gauss to also emphasise right-brain processes.

TABLE 4.35: CARL GAUSS'S LEARNER FREQUENCIES: QUESTION 2 AND QUESTION 4 COMPARISON

LEARNERS' FREQUENCIES: Question 2: MY TEACHER PLACES A LOT OF EMPHASIS ON....			
A-QUADRANT	**B-QUADRANT**	**C-QUADRANT**	**D-QUADRANT**
critical thinking = 19 logical reasoning = 21 problem-solving = 19	step by step = 33 examples = 13 structuring my work = 8	explaining = 16 working with other = 4 sharing ideas = 8	drawings /diagrams = 2 finding patterns = 11 trial and error = 8
59 (37%)	54 (33%)	28 (17%)	21 (13%)
LEARNERS' FREQUENCIES: Question 4: MY TEACHER COULD ALSO EMPHASISE...			
A-QUADRANT	**B-QUADRANT**	**C-QUADRANT**	**D-QUADRANT**
critical thinking = 7 logical reasoning = 5 problem-solving = 14	step by step = 11 examples = 11 structuring my work = 7	explaining = 7 working with other = 18 sharing ideas = 13	drawings/diagrams = 15 finding patterns = 8 trial and error = 8
26 (21%)	29 (23%)	38 (31%)	31 (25%)

FIGURE 4.39: CARL GAUSS'S LEARNER FREQUENCIES: QUESTION 2 AND QUESTION 4 COMPARISON

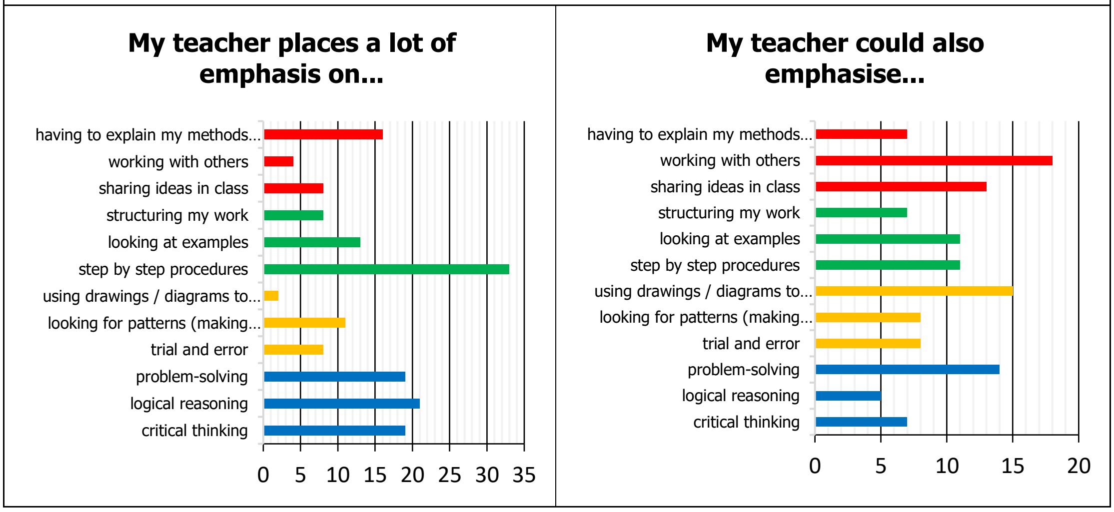
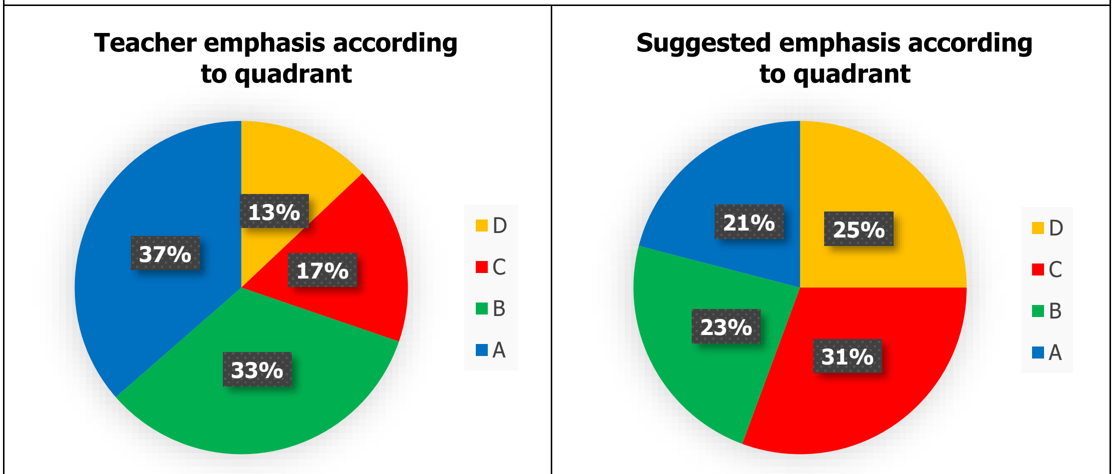


FIGURE 4.40: CARL GAUSS'S LEARNER FREQUENCIES: QUESTION 2 AND QUESTION 4 COMPARISON PER QUADRANT



Left brain: 70% Right brain: 30%
Cerebral: 50% Limbic: 50%

Left brain: 44% Right brain: 56%
Cerebral: 46% Limbic: 54%

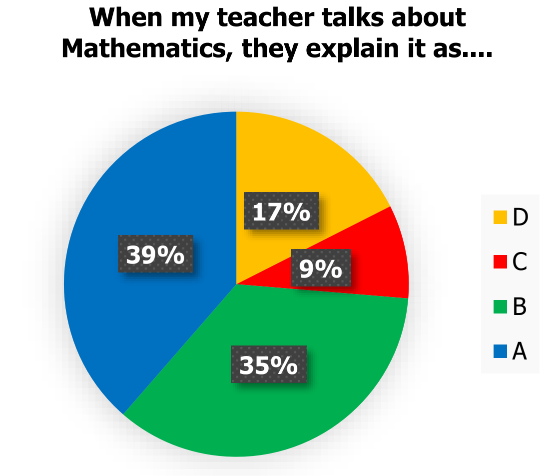
As seen in data from other teacher participants, Carl Gauss also indicated that they key feature of Mathematics is that of a "continuous process of discovery" as indicated in Table 4.36.

TABLE 4.36: CARL GAUSS'S PERCEPTION OF THE KEY FEATURES OF MATHEMATICS			
CARL GAUSS: KEY FEATURE OF MATHEMATICS			
A-QUADRANT	**B-QUADRANT**	**C-QUADRANT**	**D-QUADRANT**
			continuous process of discovery

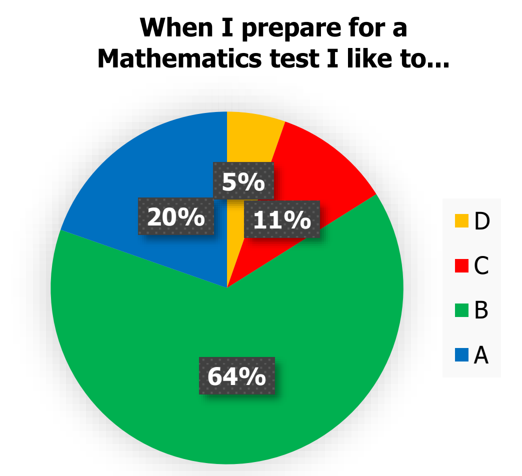
Results from Question 1 as indicated in Table 4.37 and Figure 4.41, indicate that learners perceive Carl Gauss to explain Mathematics in a manner that is congruent with his left-brain dominant HBDI® profile. When considering the results from Question 3 also indicated in Table 4.37 and Figure 4.41, there is a particularly strong emphasis on a B-quadrant approach to preparing for Mathematics assessments. Although learners don't perceive Carl Gauss's emphasis to be overly B-quadrant focussed, the majority of learners prefer to prepare for Mathematics assessments in a B-quadrant manner.

TABLE 4.37: CARL GAUSS'S LEARNER FREQUENCIES: QUESTION 1 AND QUESTION 3 COMPARISON			
LEARNERS' FREQUENCIES **Question 1: WHEN MY TEACHER TALKS ABOUT MATHEMATICS, THEY EXPLAIN IT AS...**			
A-QUADRANT a logical and analytical process	**B-QUADRANT** step-by-step instructions to follow	**C-QUADRANT** an opportunity to share ideas and methods	**D-QUADRANT** a process of discovery and making connections
22 (39%)	20 (35%)	5 (9%)	10 (17%)
LEARNERS' FREQUENCIES **Question 3: WHEN I PREPARE FOR A MATHEMATICS TEST, I LIKE TO...**			
A-QUADRANT go through the homework questions I got wrong to understand where I went wrong and what to watch out for (I like to focus on the details)	**B-QUADRANT** study examples and step-by-step procedures to solve problems (practice!)	**C-QUADRANT** study with a friend (or friends) so that we can explain to each other	**D-QUADRANT** find connections (differences and similarities) between the different topics so that I can distinguish between them (I like to see the bigger picture)
11 (20%)	36 (64%)	6 (11%)	3 (5%)

FIGURE 4.41: CARL GAUSS'S LEARNER FREQUENCIES: QUESTION 1 AND QUESTION 3 COMPARISON PER QUADRANT



Left brain: 74% Right brain: 26%
Cerebral: 56% Limbic: 44%



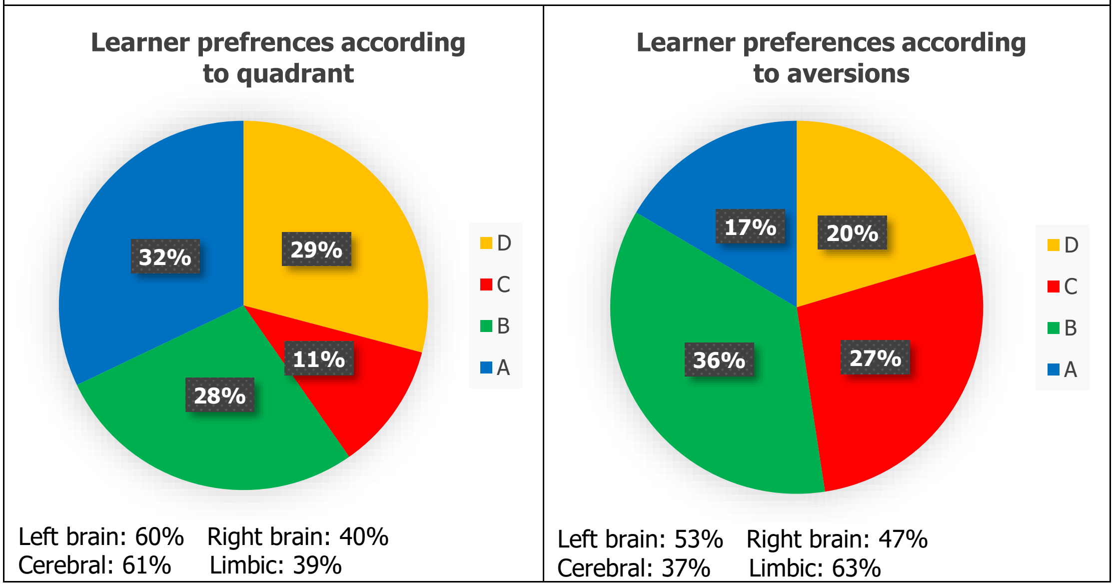
Left brain: 84% Right brain: 16%
Cerebral: 25% Limbic: 75%

Contrary to other questions in the learner questionnaire, Question 5 and Question 6 normally indicate more evenly spread preferences amongst the four quadrants. What is interesting to note is that as indicated in Table 4.38 and Figure 4.42, Carl Gauss's learners indicated a 61% preference for the cerebral quadrants for Question 5 and only a 37% preference for the cerebral quadrants in Question 6.

TABLE 4.38: CARL GAUSS'S LEARNER FREQUENCIES: QUESTION 5 AND QUESTION 6 COMPARISON

Question 5: LEARNER PERSONAL PREFERENCE FREQUENCIES:			
A-QUADRANT	**B-QUADRANT**	**C-QUADRANT**	**D-QUADRANT**
logic = 24 breaking down = 19	clear guidelines = 21 examples = 16	share ideas = 12 play = 3	explore = 18 connections = 21
43 (32%)	37 (28%)	15 (11%)	39 (29%)
Question 6: LEARNER PERSONAL AVERSIONS FREQUENCIES:			
A-QUADRANT	**B-QUADRANT**	**C-QUADRANT**	**D-QUADRANT**
group work = 4 long discussions = 13	unfamiliar questions = 23 no set method = 14	working in silence = 14 lots of reading = 14	set method = 15 lots of practice = 6
17 (17%)	37 (36%)	28 (27%)	21 (20%)

FIGURE 4.42: CARL GAUSS'S LEARNER FREQUENCIES: QUESTION 5 AND QUESTION 6 COMPARISON PER QUADRANT



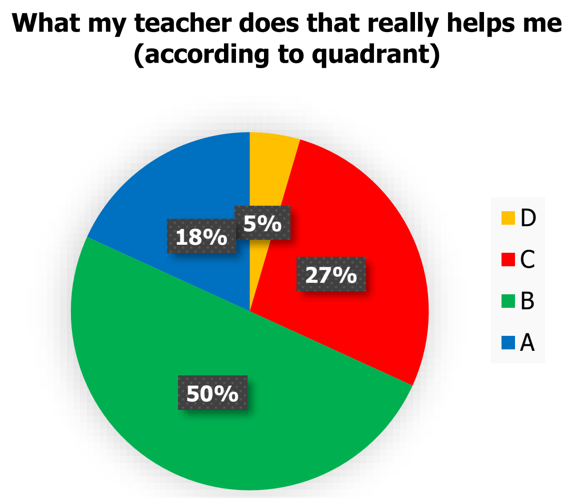
The predominant preference for the B-quadrant in Question 3 is also seen in Question 7 as indicated in Table 4.39 and Figure 4.43. How learners like to prepare for Mathematics assessments and what they appreciate about his approach is therefore closely related. Similar to Carl Gauss's HBDI® profile scores indicated in Figure 4.44 which indicate a particularly low D-quadrant preference, learners also indicate this quadrant as an approach they are least likely to recognise.

TABLE 4.39: CARL GAUSS'S QUESTION 7 RESULTS

LEARNERS' APRECIATION OF THEIR TEACHER'S APPROACH TO TEACHING MATHEMATICS	
A-QUADRANT (4)	**D-QUADRANT (1)**
Purpose (3) • My teacher is very straightforward with his explanation and he keeps the class quiet to everyone can work in silence. • Doesn't write in a lot of colour and writes exactly how it should be done • He explains quickly and uses tech **Analysis (1)** • He breaks down the question and helps us understand where we went wrong	**Explore different strategies (1)** • He looks at different methods
B-QUADRANT (11)	**C-QUADRANT (6)**
Classroom procedures (2) • Gives homework and checks it. • I like the way he teaches, he also checks my homework which gives me discipline **Step by step procedures (1)** • Go through it in step by step description	**Support and encouragement (6)** • When/if you need help Sir will take the time to explain in a method you understand best • He is the first teacher that helped me to do working out • He uses stories • He mails our parents and gives more information so they know what is happening

Repetition (2) • Explaining a method for a sum and recapping later on. • I really like the way my teacher will keep on explaining until everyone in the class understands **Practice (2)** • He practises the work with us before a test • Gives us lots of sums to practise with which helps when it comes to test. **Worked examples (4)** • Does a lot of examples to make sure we understand • I like how he gives us different examples so that we are ready for anything for the tests • My teacher gives different examples, which helps me preparing for tests because of the different possibilities. • LOTS of examples	• He helps make sure that we all understand and are ok with what we do • I like how he is always calm when he explains.

FIGURE 4.43: CARL GAUSS'S QUESTION 7 RESULTS PER QUADRANT



Left brain: 68% Right brain: 32%
Cerebral: 23% Limbic: 77%

Carl Gauss tests with a double dominant HBDI® profile with scores of over 100 for both the A- and B-quadrants as can be seen in Figure 4.44. This is somewhat different to the descriptors he chose in the Diversity Game as indicated in Table 4.40. Carl Gauss's curiosity is discussed in Chapter 5 alongside his reflection on both his profile and his teaching practice.

FIGURE 4.44: CARL GAUSS'S HBDI® PROFILE

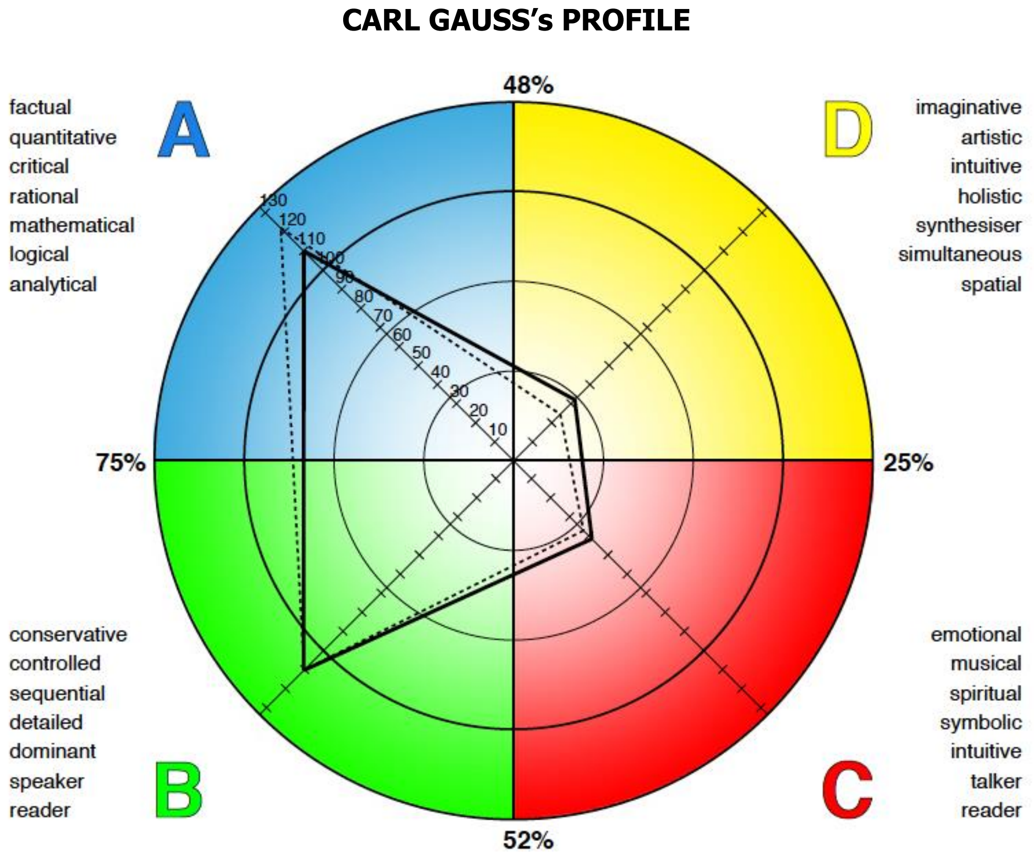
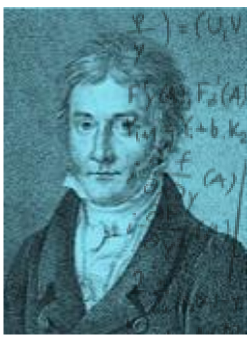


TABLE 4.40: CARL GAUSS'S HBDI® PROFILE SCORE IN COMPARISON TO HIS DIVERSITY GAME RESULTS



Carl Friedrich Gauss

DIVERSITY GAME			
A-QUADRANT	**B-QUADRANT**	**C-QUADRANT**	**D-QUADRANT**
1. mathematical	2. disciplined		3. curious
Herrmann Brain Dominance Instrument® KEY DISCRIPTORS			
A-QUADRANT	**B-QUADRANT**	**C-QUADRANT**	**D-QUADRANT**
critical mathematical rational logical	* controlled conservative sequential	reader	
Herrmann Brain Dominance Instrument® PROFILE SCORE			
A-QUADRANT	**B-QUADRANT**	**C-QUADRANT**	**D-QUADRANT**
110	110	41	32
Herrmann Brain Dominance Instrument® ADJECTIVE PAIRS			
A-QUADRANT	**B-QUADRANT**	**C-QUADRANT**	**D-QUADRANT**
10	9	3	2

4.4.6 Blaise Pascal's HBDI® and Pre-Innovation Questionnaire results

Blaise Pascal's pre-innovation questionnaire results as can be seen in Table 4.41, is similar to his HBDI® profile scores seen in Figure 4.50, and indicate a strong preference for the A-quadrant.

<table>
<tr><td colspan="4">TABLE 4.41: BLAISE PASCAL'S PRE-INNOVATION QUESTIONNAIRE RESULTS</td></tr>
<tr><td>
Blaise Pascal</td><td colspan="3">PASCAL
Teaching philosophy: Deep, relevant understanding of conceptual and procedural knowledge</td></tr>
<tr><td colspan="4">BLAISE PASCAL'S PERCEPTION ON THE NATURE OF MATHEMATICS</td></tr>
<tr><td>A-QUADRANT</td><td>B-QUADRANT</td><td>C-QUADRANT</td><td>D-QUADRANT</td></tr>
<tr><td>seeks to validate statements and proof claims

places emphasis on accuracy and precision during problem-solving</td><td></td><td>is an opportunity to collaborate and share ideas</td><td></td></tr>
<tr><td colspan="4">BLAISE PASCAL'S THINKING PATTERNS AND PROCESSES EMPHASISED</td></tr>
<tr><td>A-QUADRANT</td><td>B-QUADRANT</td><td>C-QUADRANT</td><td>D-QUADRANT</td></tr>
<tr><td>critical thinking
logical reasoning</td><td>organisation of thoughts</td><td></td><td></td></tr>
</table>

Once again, an emphasis towards the B-quadrant is evident when looking at Question 2 of the learner questionnaire results. In Table 4.42, Figure 4.45 and Figure 4.46 it can be seen that there is not a noteworthy difference between what learners perceive Blaise Pascal to emphasise and what they would like him to emphasise.

TABLE 4.42: BLAISE PASCAL'S LEARNER FREQUENCIES: QUESTION 2 AND QUESTION 4 COMPARISON

LEARNERS' FREQUENCIES Question 2: MY TEACHER PLACES A LOT OF EMPHASIS ON....			
A-QUADRANT	**B-QUADRANT**	**C-QUADRANT**	**D-QUADRANT**
critical thinking = 2 logical reasoning = 6 problem-solving = 4	step by step = 13 examples = 3 structuring my work = 5	explaining = 7 working with other = 3 sharing ideas = 7	drawings /diagrams = 2 finding patterns = 2 trial and error = 5
12 (23%)	21 (39%)	11 (21%)	9 (17%)
LEARNERS' FREQUENCIES Question 4: MY TEACHER COULD ALSO EMPHASISE....			
A-QUADRANT	**B-QUADRANT**	**C-QUADRANT**	**D-QUADRANT**
critical thinking = 2 logical reasoning = 6 problem-solving = 3	step by step = 15 examples = 3 structuring my work = 4	explaining = 7 working with other = 3 sharing ideas = 2	drawings /diagrams = 1 finding patterns = 1 trial and error = 3
12 (22%)	21 (44%)	11 (24%)	9 (10%)

FIGURE 4.45: BLAISE PASCAL'S LEARNER FREQUENCIES: QUESTION 2 AND QUESTION 4 COMPARISON

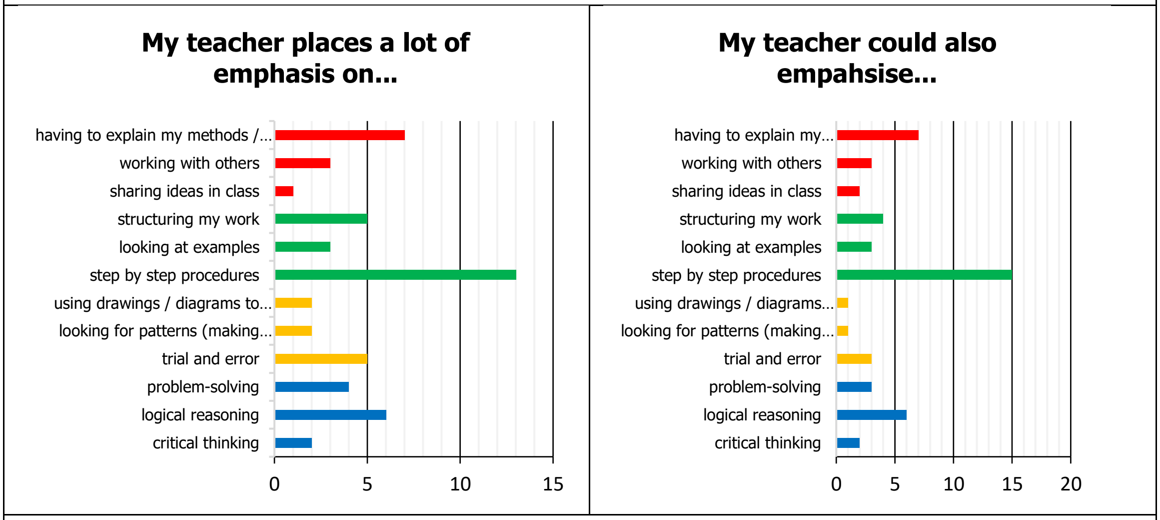
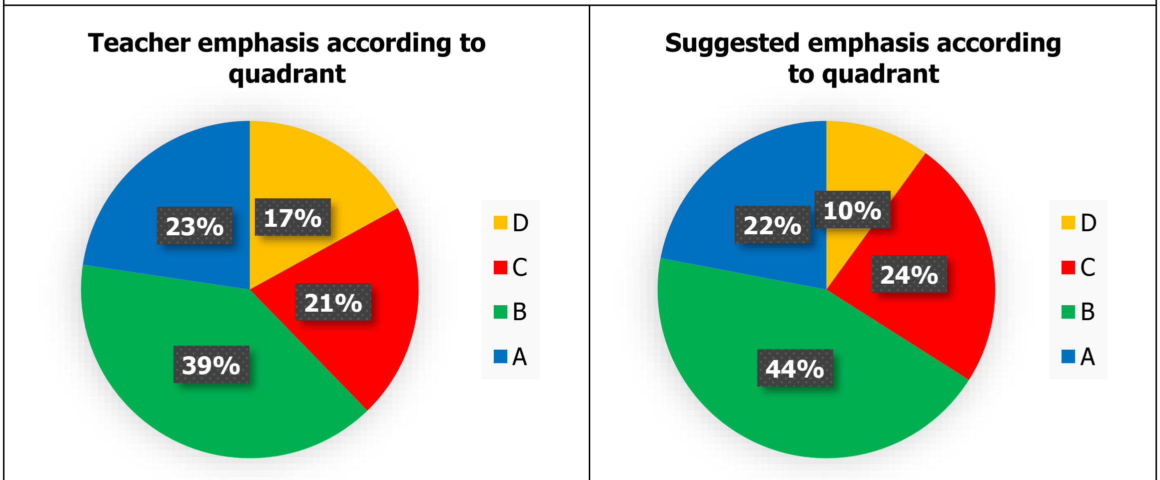


FIGURE 4.46: BLAISE PASCAL'S LEARNER FREQUENCIES: QUESTION 2 AND QUESTION 4 COMPARISON PER QUADRANT



Left brain: 62% Right brain: 38%
Cerebral: 40% Limbic: 60%

Left brain: 66% Right brain: 34%
Cerebral: 32% Limbic: 68%

What Blaise Pascal's learners deem his emphasis to be, as seen in Figure 4.46, is in line with what Blaise Pascal himself deems to be the key feature of Mathematics. In Table 4.43 Blaise Pascal indicated "procedural problem-solving" as the key feature in Mathematics. In Figure 4.45, learners also noted an emphasis on step by step procedures.

TABLE 4.43: BLAISE PASCAL'S PERCEPTION OF THE KEY FEATURES OF MATHEMATICS

BLAISE PASCAL: KEY FEATURE OF MATHEMATICS			
A-QUADRANT	**B-QUADRANT**	**C-QUADRANT**	**D-QUADRANT**
	procedural problem-solving		

Blaise Pascal's learner questionnaire results for Question 1 is of particular interest, since it indicates that 52% of learners perceive him to explain Mathematics as a process of discovery and making connections. This can be seen in Table 4.44 and Figure 4.47. This strong D-quadrant preference is not in line with his HBDI® profile score or any other feedback from his learners. Blaise Pascal's reflection on this question, along with my own, is discussed in Chapter 5.

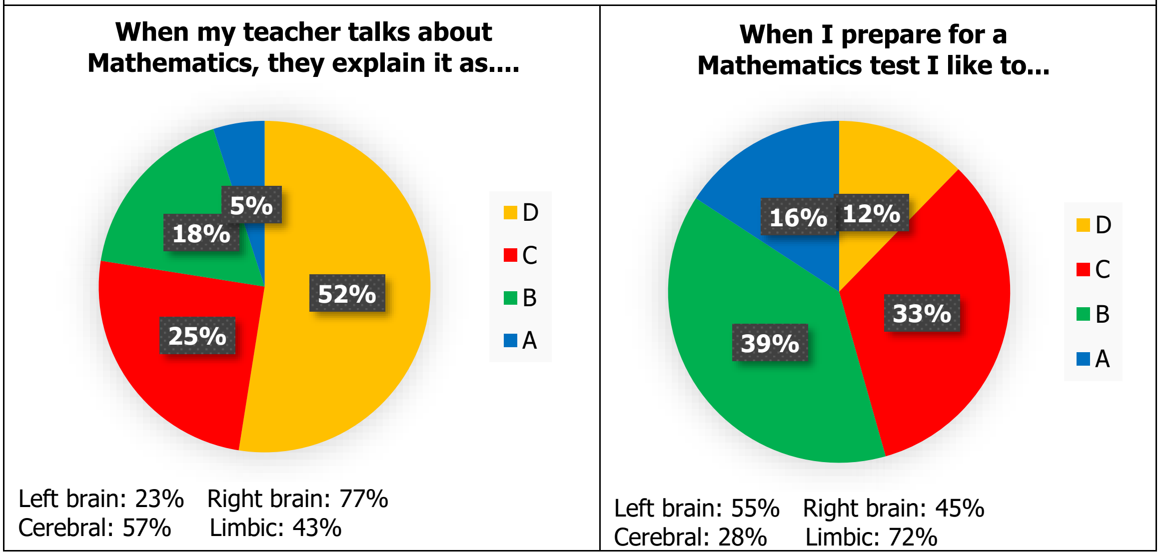
TABLE 4.44: BLAISE PASCAL'S LEARNER FREQUENCIES: QUESTION 1 AND QUESTION 3 COMPARISON

LEARNERS' FREQUENCIES **Question 1: WHEN MY TEACHER TALKS ABOUT MATHEMATICS, HE EXPLAINS IT AS…**			
A-QUADRANT a logical and analytical process	**B-QUADRANT** step-by-step instructions to follow	**C-QUADRANT** an opportunity to share ideas and methods	**D-QUADRANT** a process of discovery and making connections
2 (5%)	7 (18%)	10 (25%)	21 (52%)
LEARNERS' FREQUENCIES **Question 3: WHEN I PREPARE FOR A MATHEMATICS TEST, I LIKE TO…**			
A-QUADRANT go through the homework questions I got wrong to understand where I went wrong and what to watch out for (I like to focus on the details)	**B-QUADRANT** study examples and step-by-step procedures to solve problems (practice!)	**C-QUADRANT** study with a friend (or friends) so that we can explain to each other	**D-QUADRANT** find connections (differences and similarities) between the different topics so that I can distinguish between them (I like to see the bigger picture)
9 (16%)	22 (39%)	19 (33%)	7 (12%)

Blaise Pascal's learner questionnaire results for Question 3 show similarities to his Question 6 learner questionnaire results indicated in Table 4.45 and Figure

4.48. How Blaise Pascal's learners prefer to prepare for Mathematics assessments, is therefore independent of how they perceive him to explain it.

FIGURE 4.47: BLAISE PASCAL'S LEARNER FREQUENCIES: QUESTION 1 AND QUESTION 3 COMPARISON PER QUADRANT

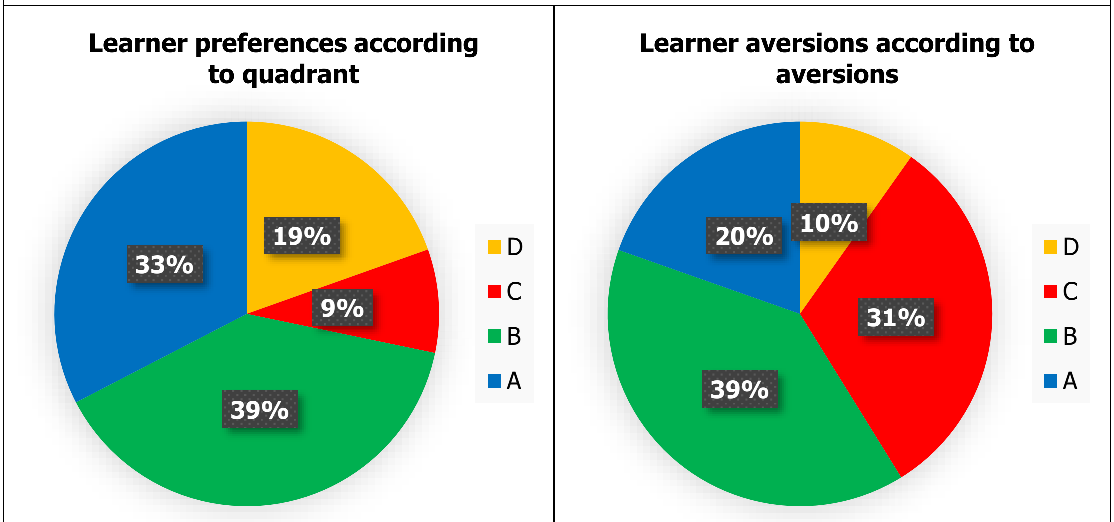


From both the Question 5 and Question 6 results, indicated in Table 4.45 and Figure 4.48, it can be seen that learners prefer left-brain approaches when it comes to Mathematics.

TABLE 4.45: BLAISE PASCAL'S LEARNER FREQUENCIES: QUESTION 5 AND QUESTION 6 COMPARISON

Question 5: LEARNER PERSONAL PREFERENCE FREQUENCIES:			
A-QUADRANT	**B-QUADRANT**	**C-QUADRANT**	**D-QUADRANT**
logic = 6 breaking down = 9	clear guidelines = 10 examples = 8	share ideas = 4 play = 0	explore = 4 connections = 5
15 (33%)	18 (39%)	4 (9%)	9 (19%)
Question 6: LEARNER PERSONAL AVERSIONS FREQUENCIES:			
A-QUADRANT	**B-QUADRANT**	**C-QUADRANT**	**D-QUADRANT**
group work = 2 long discussions = 8	unfamiliar questions = 11 no set method = 9	working in silence = 6 lots of reading = 10	set method = 3 lots of practice = 2
12 (20%)	36 (39%)	20 (31%)	18 (10%)

FIGURE 4.48: BLAISE PASCAL'S LEARNER FREQUENCIES: QUESTION 5 AND QUESTION 6 COMPARISON PER QUADRANT



Left brain: 72% Right brain: 28%
Cerebral: 52% Limbic: 48%

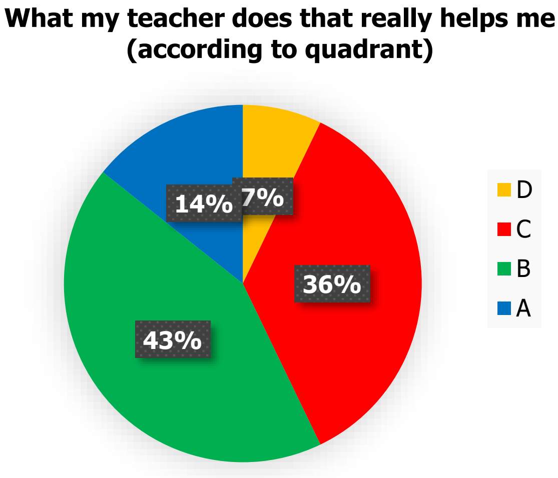
Left brain: 59% Right brain: 41%
Cerebral: 30% Limbic: 70%

Unlike all the preceding questions in the learner questionnaire, Question 7 was not a compulsory question in the Google Form. This means that although it was not possible for learners to submit the form without answering Question 1 to 6, it was possible for them to submit the form without completing Question 7. As with Ada Lovelace, very few learners completed Question 7. The results gathered, show an appreciation for Blaise Pascal's B- and C-quadrant approaches as indicated in Table 4.46 and Figure 4.49.

TABLE 4.46: BLAISE PASCAL'S QUESTION 7 RESULTS

LEARNERS' APRECIATION OF THEIR TEACHER'S APPROACH TO TEACHING MATHEMATICS	
A-QUADRANT (2)	**D-QUADRANT (1)**
Problem-solving (1) • focus on other work outside the syllabus which was perfect for me. **Logical (1)** • Explain things in a logical way	**Conceptualise (1)** • He was very focused on the bigger picture
B-QUADRANT (6)	**C-QUADRANT (5)**
Step by step procedures (2) • He gave instructions and steps to help solve math problems and learn the work **Repetition (4)** • He explained the work until we properly understood it • Going back to show me again and again even when he had explained it a million times • Going back again and again until I understood everything • Tutorials	**Support and encouragement (5)** • The fact that he let us listen to our own music whilst working created a nice comfort-zone to learn new concepts. • He was enthusiastic about maths and enjoyed it. • Motivating me to practise. • Fun classes • Allows freedom to listen to music whilst working

FIGURE 4.49: BLAISE PASCAL'S QUESTION 7 RESULTS ACCORDING TO QUADRANT



Left brain: 57% Right brain: 43%
Cerebral: 21% Limbic: 79%

Blaise Pascal's HBDI® profile score, in Figure 4.50, show a double dominant profile which becomes a triple dominant profile under stress. Blaise Pascal's C-quadrant preference, which increases under stress, also seems to be in line with his Diversity Game key descriptors indicated in Table 4.47. This C-quadrant focus is discussed Chapter 5.

FIGURE 4.50: BLAISE PASCAL'S HBDI® PROFILE

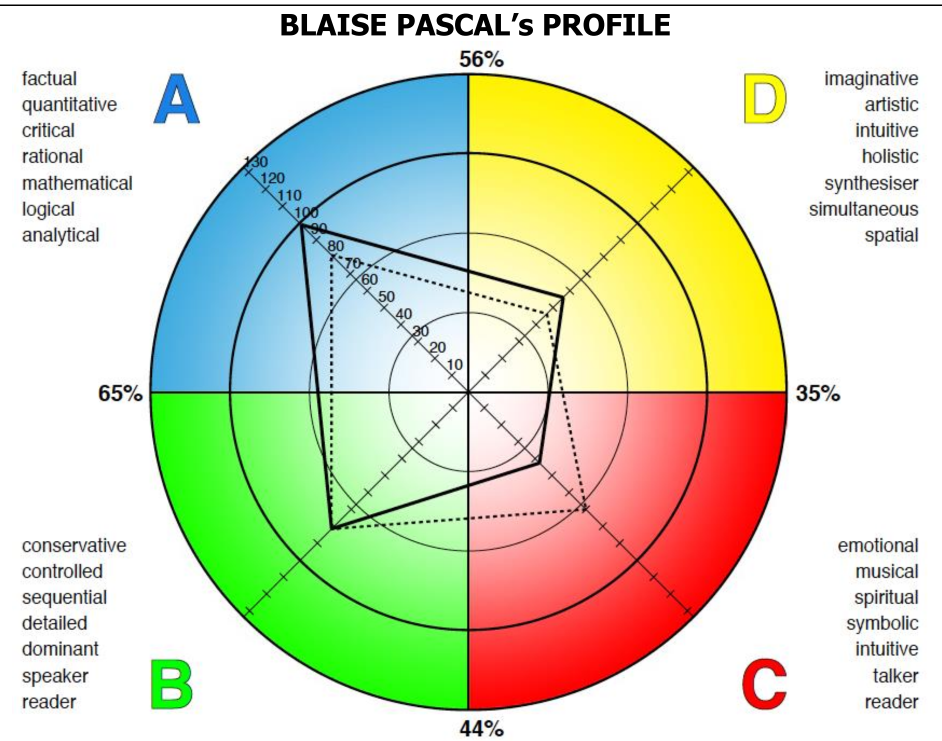


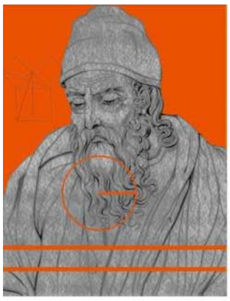
TABLE 4.47: BLAISE PASCAL'S HBDI® PROFILE SCORE IN COMPARISON TO HIS DIVERSITY GAME DESCRIPTORS

Blaise Pascal

DIVERSITY GAME			
A-QUADRANT	**B-QUADRANT**	**C-QUADRANT**	**D-QUADRANT**
	2. persistent	1. passionate 2. harmonising	
Herrmann Brain Dominance Instrument® KEY DISCRIPTORS			
A-QUADRANT	**B-QUADRANT**	**C-QUADRANT**	**D-QUADRANT**
mathematical analytical critical rational logical	* dominant detailed		imaginative
Herrmann Brain Dominance Instrument® PROFILE SCORE			
A-QUADRANT	**B-QUADRANT**	**C-QUADRANT**	**D-QUADRANT**
99	81	42	56
Herrmann Brain Dominance Instrument® ADJECTIVE PAIRS			
A-QUADRANT	**B-QUADRANT**	**C-QUADRANT**	**D-QUADRANT**
7	7	6	4

4.4.7 EUCLID'S HBDI® AND PRE-INNOVATION QUESTIONNAIRE RESULTS

Contrary to Euclid's HBDI® profile, in Figure 4.55, which indicates a triple dominance in the A-, C- and D-quadrants, Euclid's pre-innovation questionnaire results indicate a stronger preference for the A-quadrant as seen in Table 4.48.

TABLE 4.48: EUCLID'S PRE-INNOVATION QUESTIONNAIRE RESULTS			
 Euclid	**EUCLID** **Teaching philosophy:** Disce aut discede – learn or leave		
EUCLID'S PERCEPTION ON THE NATURE OF MATHEMATICS			
A-QUADRANT	**B-QUADRANT**	**C-QUADRANT**	**D-QUADRANT**
seeks to validate statements and proof claims places emphasis on accuracy and precision during problem-solving		is an opportunity to collaborate and share ideas	
EUCLID: THINKING PATTERNS AND PROCESSES EMPHASISED			
A-QUADRANT	**B-QUADRANT**	**C-QUADRANT**	**D-QUADRANT**
logical reasoning higher order reasoning	step by step procedures		

Despite Euclid HBDI® profile indicating that his least preferred quadrant is the B-quadrant, his learners preferences indicate that he places more emphasis on the B-quadrant although it shows a fairly even spread across the four quadrants. In the Question 2 and 4 comparison in Table 4.49, Figure 4.51 and Figure 4.52, learners indicated that Euclid could place even more emphasis on the B-quadrant.

Table 4.49: Euclid's learner frequencies: Question 2 and Question 4 comparison

LEARNERS' FREQUENCIES MY TEACHER PLACES A LOT OF EMPHASIS ON....			
A-QUADRANT	**B-QUADRANT**	**C-QUADRANT**	**D-QUADRANT**
critical thinking = 15 logical reasoning = 13 problem-solving = 12	step by step = 12 examples = 18 structuring my work = 18	explaining = 10 working with other = 15 sharing ideas = 16	drawings /diagrams = 6 finding patterns = 10 trial and error = 15
40 (25%)	48 (30%)	41 (26%)	31 (19%)
LEARNERS' FREQUENCIES MY TEACHER COULD ALSO EMPHASIS ON....			
A-QUADRANT	**B-QUADRANT**	**C-QUADRANT**	**D-QUADRANT**
critical thinking = 5 logical reasoning = 5 problem-solving = 6	step by step = 20 examples = 9 structuring my work = 8	explaining = 19 working with other = 6 sharing ideas = 10	drawings /diagrams = 3 finding patterns = 3 trial and error = 7
16 (16%)	37 (36%)	35 (35%)	13 (13%)

Figure 4.51: Euclid's learner frequencies: Question 2 and Question 4 comparison

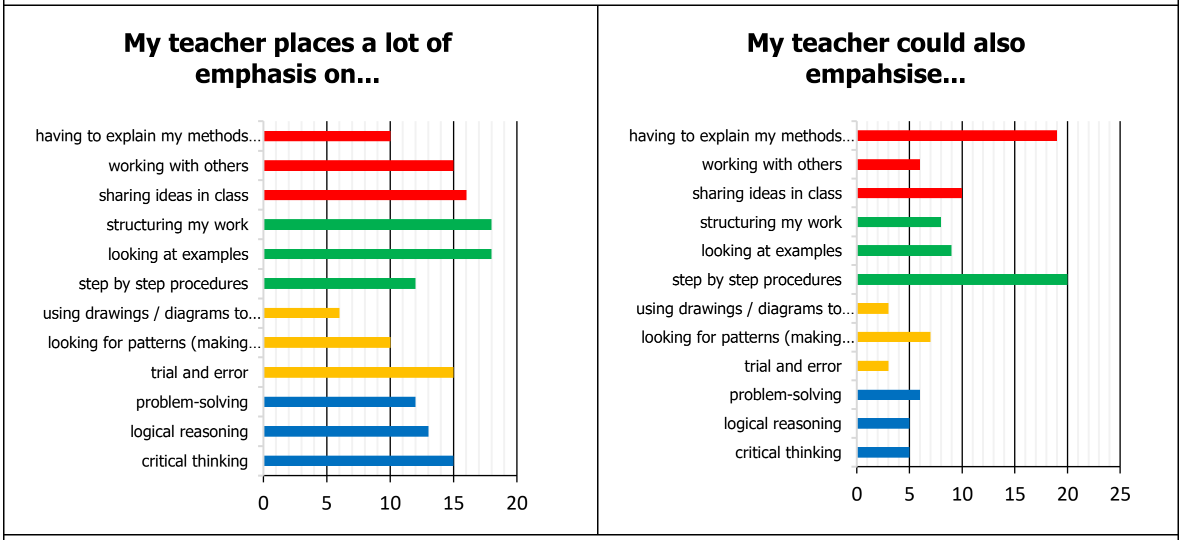
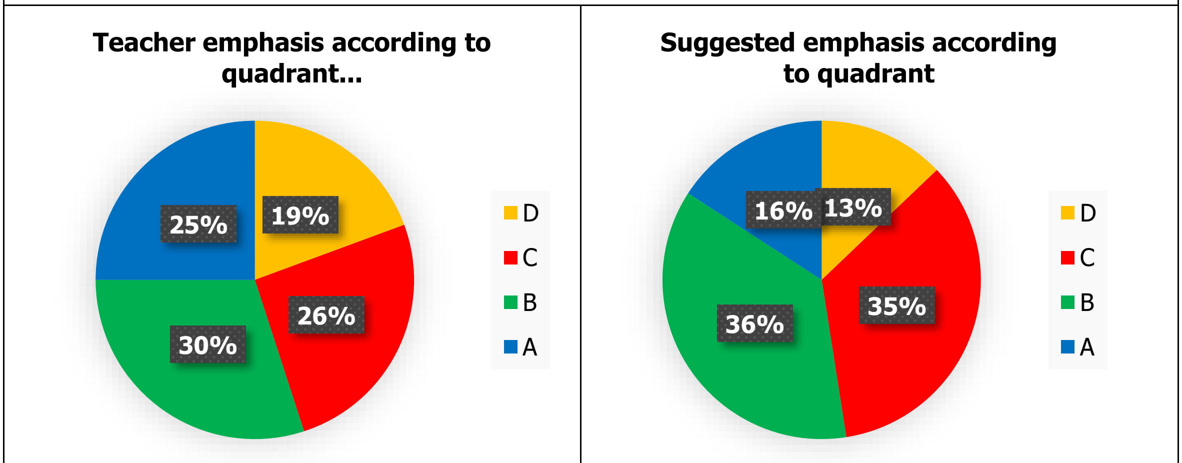


Figure 4.52: Euclid's learner frequencies: Question 2 and Question 4 comparison per quadrant



Left brain: 55% Right brain: 45%
Cerebral: 44% Limbic: 56%

Left brain:52% Right brain: 48%
Cerebral: 29% Limbic: 71%

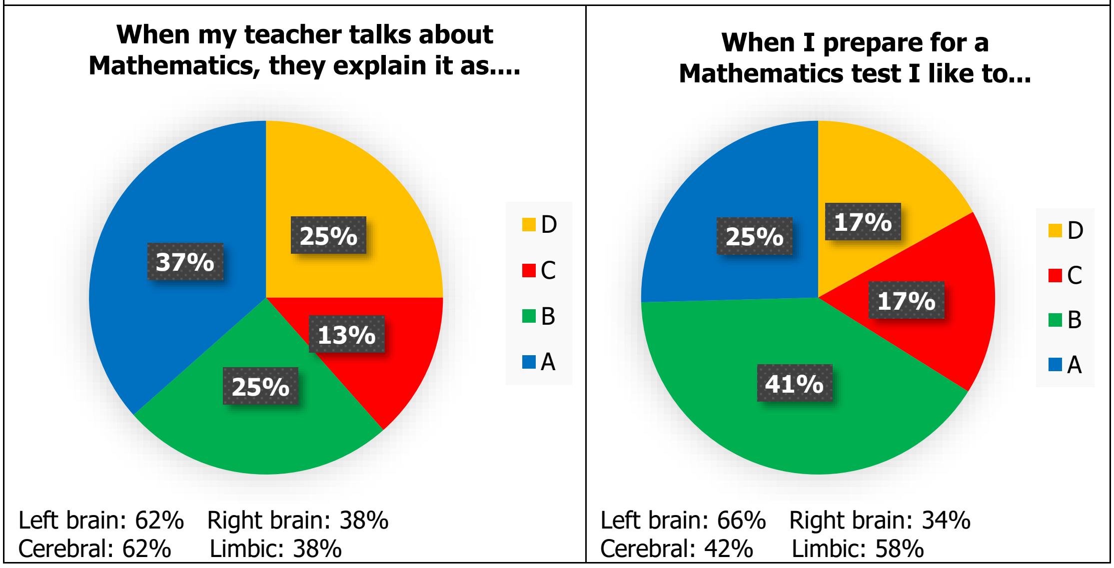
As with the majority of the other teacher participants, Euclid also indicates the key feature of Mathematics as a "continuous process of discovery" as indicated in Table 4.49. Contrary to the other teacher participants, this view of Mathematics is congruent to his HBDI® profile which shows the D-quadrant as his most preferred quadrant.

TABLE 4.49: EUCLID'S PERCEPTION OF THE KEY FEATURES OF MATHEMATICS			
EUCLID: KEY FEATURE OF MATHEMATICS			
A-QUADRANT	**B-QUADRANT**	**C-QUADRANT**	**D-QUADRANT**
			continuous process of discovery

Similar to Euclid's pre-innovation questionnaire results, in Table 4.48, indicating an A-quadrant focus, learners also perceive Euclid's way of explaining of Mathematics as A-quadrant focussed. The Question 1 and Question 3 comparison in Table 4.50 and Figure 4.50 show that although learners perceive Euclid to explain from a predominantly A-quadrant perspective, they prefer to prepare for assessments according to a B-quadrant perspective.

TABLE 4.50: EUCLID'S LEARNER FREQUENCIES: QUESTION 1 AND QUESTION 3 COMPARISON			
LEARNERS' FREQUENCIES **Question 1: WHEN MY TEACHER TALKS ABOUT MATHEMATICS, THEY EXPLAIN IT AS...**			
A-QUADRANT a logical and analytical process	**B-QUADRANT** step-by-step instructions to follow	**C-QUADRANT** an opportunity to share ideas and methods	**D-QUADRANT** a process of discovery and making connections
19 (37%)	13 (25%)	7 (13%)	13 (25%)
LEARNERS' FREQUENCIES **Question 3: WHEN I PREPARE FOR MATHEMATICS TEST I LIKE TO...**			
A-QUADRANT go through the homework questions I got wrong to understand where I went wrong and what to watch out for (I like to focus on the details)	**B-QUADRANT** study examples and step-by-step procedures to solve problems (practise!)	**C-QUADRANT** study with a friend (or friends) so that we can explain to each other	**D-QUADRANT** find connections (differences and similarities) between the different topics so that I can distinguish between them (I like to see the bigger picture)
15 (25%)	24 (41%)	10 (17%)	10 (17%)

Figure 4.50: Euclid's learner frequencies: Question 1 and Question 3 comparison per quadrant

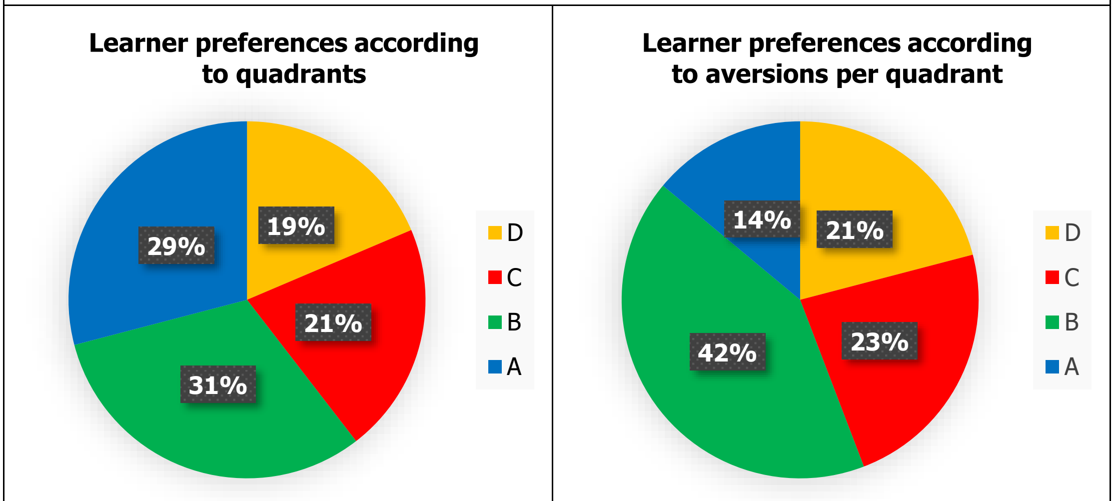


The learner questionnaire results for Question 5 and Question 6 are similar to the results obtained in Question 1 and 3 when considering the left-brain emphasis of all four questions. Question 5 and Question 6 results are compared in Table 4.51 and Figure 4.53.

Table 4.51: Euclid's learner frequencies: Question 5 and Question 6 comparison

LEARNER PERSONAL PREFERENCE FREQUENCIES:			
A-QUADRANT	**B-QUADRANT**	**C-QUADRANT**	**D-QUADRANT**
logic = 11 breaking down = 14	clear guidelines = 15 examples = 12	share ideas =11 play = 7	explore = 1 connections = 15
25 (29%)	27 (31%)	18 (21%)	16 (19%)
LEARNER PERSONAL AVERSIONS FREQUENCIES:			
A-QUADRANT	**B-QUADRANT**	**C-QUADRANT**	**D-QUADRANT**
group work = 7 long discussions = 5	unfamiliar questions = 21 no set method = 15	working in silence = 7 lots of reading = 13	set method = 9 lots of practice = 9
12 (14%)	36 (42%)	20 (23%)	18 (21%)

Figure 4.53: Euclid's learner frequencies: Question 5 and Question 6 comparison per quadrant



Left brain: 60% Right brain: 40%
Cerebral: 48% Limbic: 52%

Left brain:56% Right brain: 44%
Cerebral: 35% Limbic: 65%

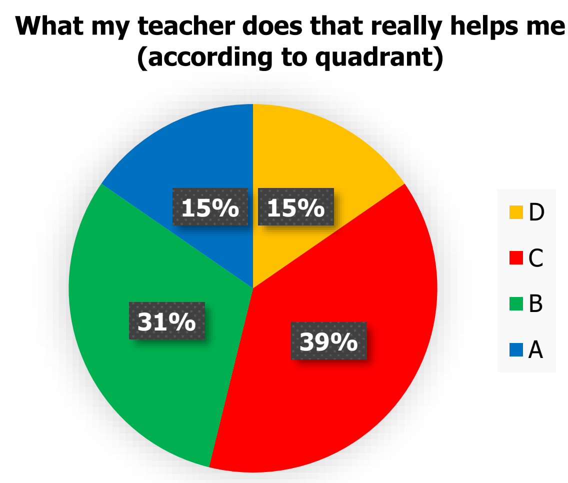
It is only in Euclid's learner questionnaires results for Question 7, that there is an emphasis towards the right-brain quadrants which corresponds to his HBDI® profile. These results are shown Table 4.52 and Figure 4.54.

Table 4.52: Euclid's Question 7 results

LEARNERS' APRECIATION OF THEIR TEACHER'S APPROACH TO TEACHING MATHEMATICS	
A-QUADRANT (6)	**D-QUADRANT (6)**
Problem-solving (6) • He challenges us by giving us a high order thinking questions. Then when we get the "normal level" we find it very easy • He teaches me LOGIC, not MAGIC. • He skips the basic maths and focuses more on the complicated maths. This helps a lot because in tests more complicated questions are asked. • He gives you a start on questions you don't understand, this helps me to solve the question. • He really likes to emphasise his reasoning. • He concentrates on logical thinking.	**Conceptualise (4)** • Uses realistic examples in class that we can apply to maths. (conceptualise) • He would probably be one of the best math teachers I have ever had, and he helps me understand the concept of what I am learning. • Is a great teacher and I really understand concepts that he teaches. By him making connections between different concepts and explaining a method I am able to catch on and understand the topic quite easily. • he can associate things. **Explore (2)** • He always finds different ways that are easier for me to figure out a sum • He gives us difficult examples to do first and only after we've tried he helps us understand how to do it right.
B-QUADRANT (12)	**C-QUADRANT (15)**
Step by step procedures (2) • gives us a pattern to remember • He gives us quick tips and tricks to find the answers quickly.	**Support and encouragement (11)** • makes class fun (support and encouragement) • He makes the class laugh

Repetition (7) • He goes through everything over and over until I understand • Goes through things over and over again until I get it right • Creates tutorials for students that are struggling • Tutorials • When confused with a topic, tutorials are set up to help us. • Provides tutorials • He explains things over and over until I get it right **Worked Examples (3)** • Explains examples well • He uses good examples that comprehensively make you grasp the topic. • When my teacher shows and explains various examples of the work we are currently doing on the board.	• He makes the class a lot of fun (support and encouragement) • He makes the class fun and he explains things very well • Makes maths class fun and interesting (support and encouragement) • Makes lessons entertaining, and makes you want to listen (support and encouragement) Sir challenges me and my thinking and pushes me to go further with my thinking (support and encouragement) • He has his own system, which includes punishments and rewards (support and encouragement) • So if I get a math question wrong my math teacher will sit with me one on one and explain it to me (support and encouragement) • connects with us and pushes us until we get the concept • Makes sure that you understand your work (support and encouragement) • Always takes time to answer my questions in class, and makes sure I understand fully. **Collaboration (4)** • He allows us to talk about all the maths problems • He allows us to discuss our answers together • He lets everyone share their answers and then when we don't get the same answer he lets us discuss and debate on it. • He lets us discuss answers in class

FIGURE 4.54: EUCLID'S QUESTION 7 RESULTS



Left brain: 46% Right brain: 54%
Cerebral: 30% Limbic: 70%

Figure 4.55 shows Euclid's triple dominant profile with a preference for the A-, C- and D-quadrants. Euclid's adjective pair score shows an even stronger preference for the C-quadrant and even lesser preferred B-quadrant. Although learners did not perceive Euclid's C-quadrant as one of his dominant quadrants in any of the preceding questions, they clearly express their appreciation for his C-quadrant approach to teaching Mathematics when asked to answer in their own words. This notion will be further discussed in Chapter 5.

FIGURE 4.55: EUCLID'S HBDI® PROFILE

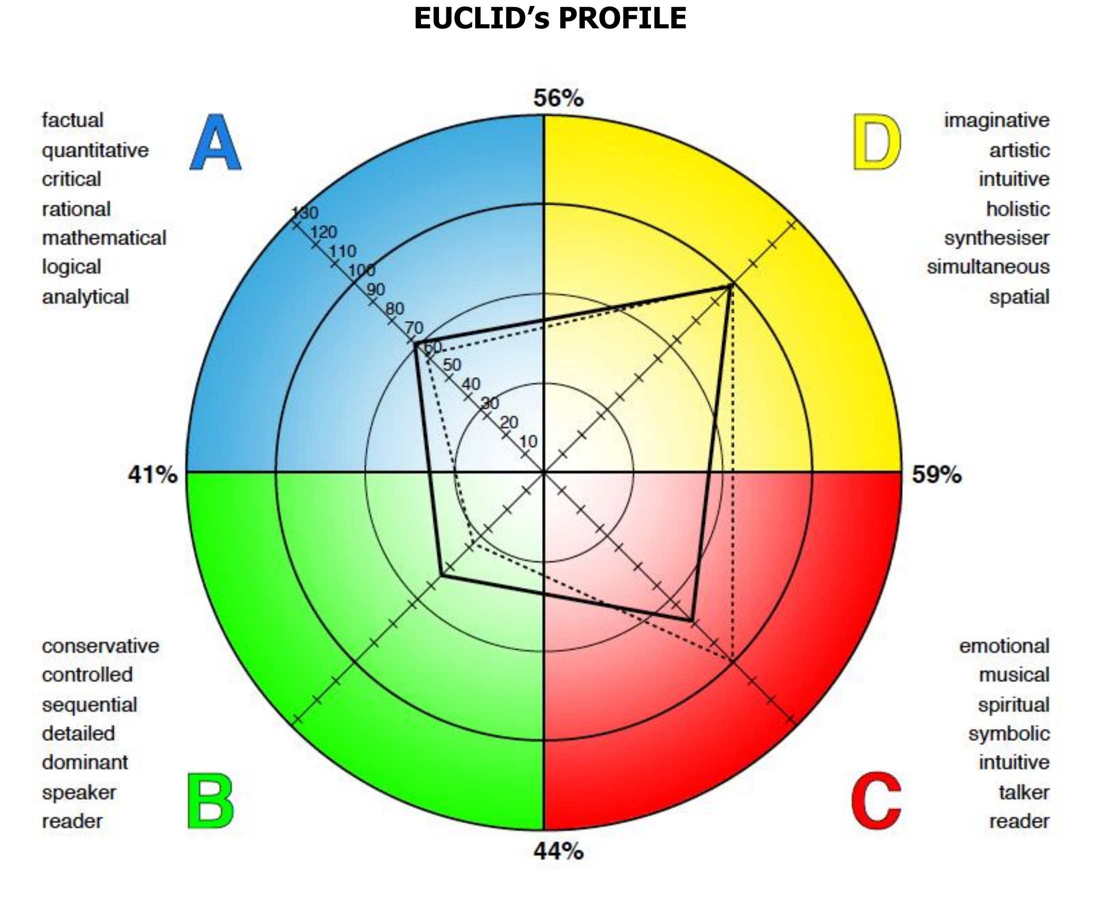
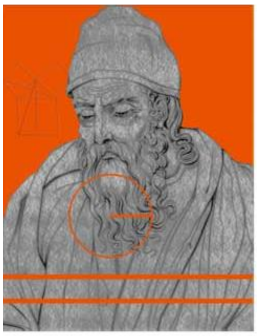


Table 4.53 indicates that Euclid's key card descriptors in the Diversity Game, similar to his HBDI® scores, are more right-brain. Although Euclid tests with a triple dominance, his right-brain preferences for the C- and D-quadrant, testing at 78 and 98 respectively, are higher than his A-quadrant preference which tests at 68.

TABLE 4.53: EUCLID'S HBDI® PROFILE SCORE IN COMPARISON TO HIS DIVERSITY GAME DESCRIPTORS



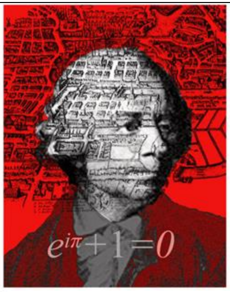
Euclid

DIVERSITY GAME			
A-QUADRANT	**B-QUADRANT**	**C-QUADRANT**	**D-QUADRANT**
		1. harmonizing 2. responsive	3. curious
Herrmann Brain Dominance Instrument® KEY DISCRIPTORS			
A-QUADRANT	**B-QUADRANT**	**C-QUADRANT**	**D-QUADRANT**
mathematical logical analytical		* intuitive musical spiritual	* intuitive imaginative holistic
Herrmann Brain Dominance Instrument® PROFILE SCORE			
A-QUADRANT	**B-QUADRANT**	**C-QUADRANT**	**D-QUADRANT**
68	54	78	98
Herrmann Brain Dominance Instrument® ADJECTIVE PAIRS			
A-QUADRANT	**B-QUADRANT**	**C-QUADRANT**	**D-QUADRANT**
5	3	8	8

4.4.8 Leonhard Euler's HBDI® and Pre-Innovation Questionnaire results

Leonhard Euler's pre-innovation questionnaire results, indicated in Table 4.54, indicate a fairly Whole Brain® perception of Mathematics whilst the patterns and processes he emphasises are more left-brain focussed and in particular, A-quadrant focussed. This is consistent with Leonhard Euler's A-quadrant dominant HBDI® profile in Figure 4.61.

Table 4.54: Leonhard Euler's pre-innovation questionnaire results



Leonhard Euler

LEONHARD EULER

Teaching philosophy: Mathematics must always have learners thinking and discovering concepts. Mathematics is to the mind what poetry is to the heart.

LEONHARD EULER'S PERCEPTION ON THE NATURE OF MATHEMATICS			
A-QUADRANT	**B-QUADRANT**	**C-QUADRANT**	**D-QUADRANT**
relies on subject matter expertise		requires active participation during the learning experience	requires a conceptual (bigger picture) understanding
LEONHARD EULER'S THINKING PATTERNS AND PROCESSES EMPHASISED			
A-QUADRANT	**B-QUADRANT**	**C-QUADRANT**	**D-QUADRANT**
logical reasoning higher order reasoning	step by step procedures		

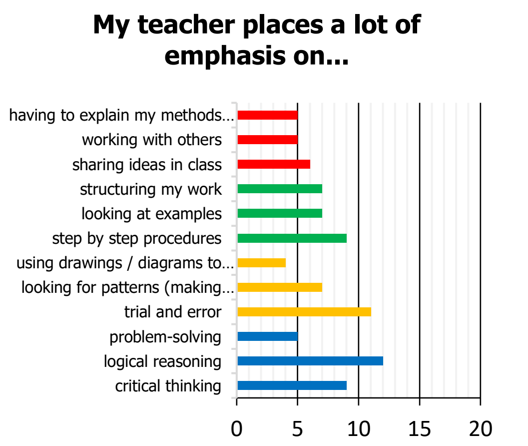
Leonhard Euler's pre-questionnaire results for Question 2 show a fairly even distribution amongst quadrants but with a slight emphasis towards the left-brain quadrants as indicated in Table 4.55. The results of Question 4, in contrast to Question 2, indicate preferences strongly skewed towards the B-quadrant. This is clearly evident in Figure 4.57. Figure 4.56 indicates that the specific descriptor responsible for this B-quadrant emphasis is that of "problem-solving". This is a noteworthy observation, especially when considering that 57% of responses (indicated in Figure 4.58) indicated that learners perceive

Leonhard Euler to explain Mathematics as a process of discovery and making connections.

TABLE 4.55: LEONHARD EULER'S LEARNER FREQUENCIES: QUESTION 2 AND QUESTION 4

LEARNERS' FREQUENCIES Question 2: MY TEACHER PLACES A LOT OF EMPHASIS ON....			
A-QUADRANT	**B-QUADRANT**	**C-QUADRANT**	**D-QUADRANT**
critical thinking = 9 logical reasoning = 12 problem-solving = 5	step by step = 9 examples = 7 structuring my work = 7	explaining = 6 working with other = 5 sharing ideas = 5	drawings /diagrams = 4 finding patterns = 7 trial and error = 11
26 (30%)	23 (27%)	16 (18%)	22 (25%)
LEARNERS' FREQUENCIES Question 4: IF MY TEACHER COULD ALSO EMPHASISE...			
A-QUADRANT	**B-QUADRANT**	**C-QUADRANT**	**D-QUADRANT**
critical thinking = 5 logical reasoning = 6 problem-solving = 19	step by step = 1 examples = 9 structuring my work = 5	explaining = 4 working with other = 2 sharing ideas = 2	drawings /diagrams = 7 finding patterns = 7 trial and error = 4
30 (46%)	15 (23%)	8 (12%)	12 (19%)

FIGURE 4.56: LEONHARD EULER'S LEARNER FREQUENCIES: QUESTION 2 AND QUESTION 4



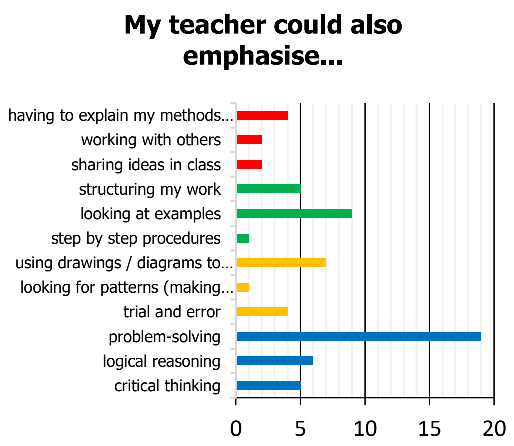
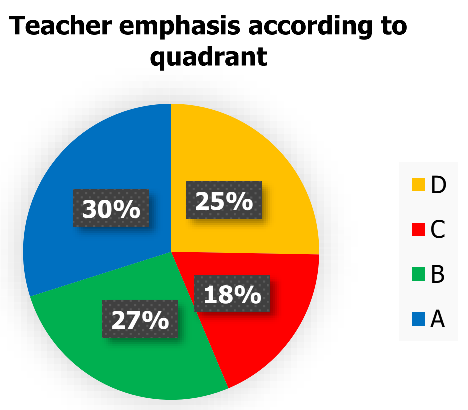
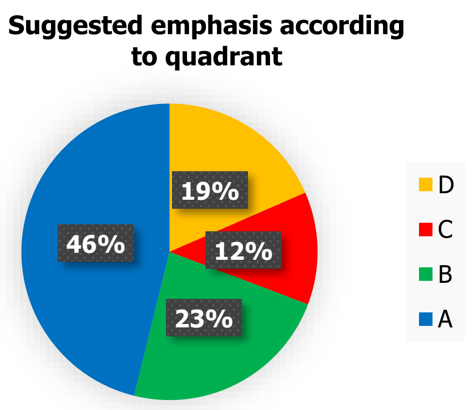


FIGURE 4.57: LEONHARD EULER'S LEARNER FREQUENCIES: QUESTION 2 AND QUESTION 4 PER QUADRANT



Left brain: 57% Right brain: 43%
Cerebral: 55% Limbic: 45%



Left brain: 69% Right brain: 31%
Cerebral: 65% Limbic: 35%

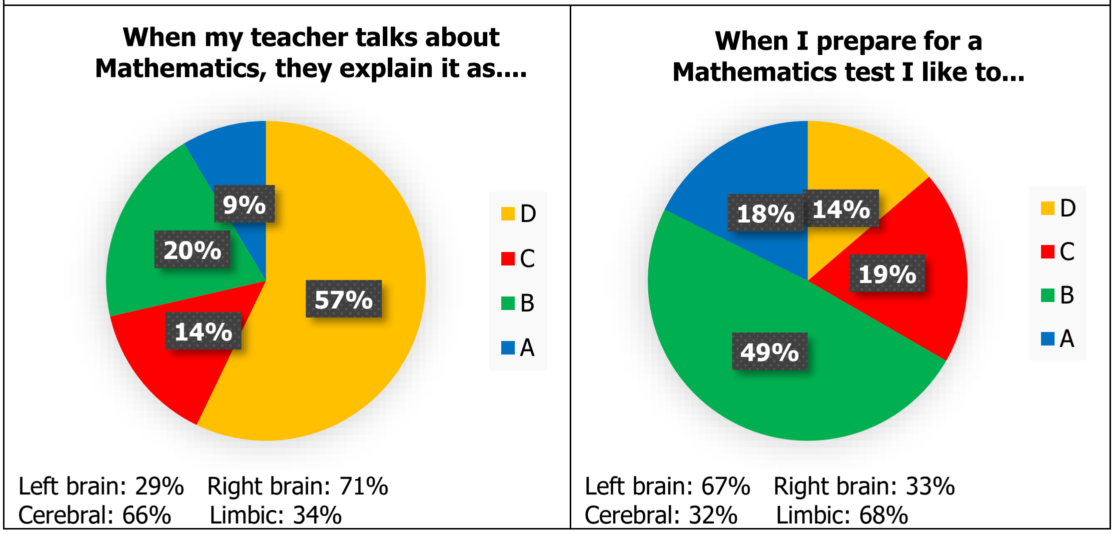
Table 4.56 indicates that Leonhard Euler considers Mathematics to be an exact science. This is congruent to his A-quadrant dominant HBDI® profile.

TABLE 4.56: LEONHARD EULER'S PERCEPTION ON THE NATURE OF MATHEMATICS			
LEONHARD EULER: KEY FEATURE OF MATHEMATICS			
A-QUADRANT	**B-QUADRANT**	**C-QUADRANT**	**D-QUADRANT**
exact science			

Table 4.57 and Figure 4.58 compare the learner questionnaire results for Question 1 and 3. These results indicate a dissonance in the way learners perceive Leonhard Euler to explain Mathematics and how they like to prepare for assessments. This dissonance is discussed in Chapter 5

TABLE 4.57: LEONHARD EULER'S LEARNER FREQUENCIES: QUESTION 1 AND QUESTION 3			
LEARNERS' FREQUENCIES **Question 1: WHEN MY TEACHER TALKS ABOUT MATHEMATICS, THEY EXPLAIN IT AS...**			
A-QUADRANT a logical and analytical process	**B-QUADRANT** step-by-step instructions to follow	**C-QUADRANT** an opportunity to share ideas and methods	**D-QUADRANT** a process of discovery and making connections
3 (9%)	7 (20%)	5 (14%)	20 (57%)
LEARNERS' FREQUENCIES **Question 3: WHEN I PREPARE FOR MATHEMATICS TEST I LIKE TO...**			
A-QUADRANT go through the homework questions I got wrong to understand where I went wrong and what to watch out for (I like to focus on the details)	**B-QUADRANT** study examples and step-by-step procedures to solve problems (practice!)	**C-QUADRANT** study with a friend (or friends) so that we can explain to each other	**D-QUADRANT** find connections (differences and similarities) between the different topics so that I can distinguish between them (I like to see the bigger picture)
9 (18%)	25 (49%)	10 (19%)	7 (14%)

Figure 4.58: Leonhard Euler's learner frequencies: Question 1 and Question 3 per quadrant

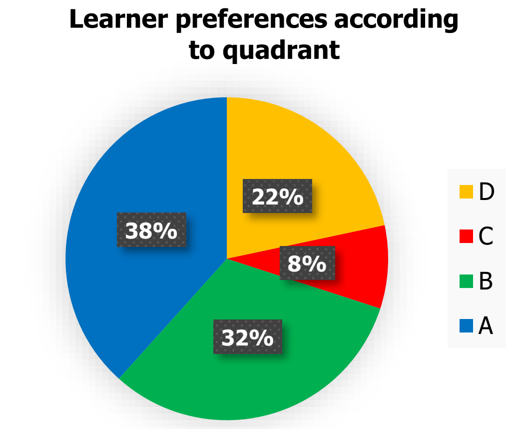


In both the Question 5 and Question 6 results, indicated in Table 4.58 and Figure 4.59 the responses indicate a preference for the A-quadrant. With Leonhard Euler having an A-quadrant preference himself, it is possible that his preference could influence the preferences of his learners. The particularly strong preference for the D-quadrant (at 57%) must be highlighted as it is significantly higher than any D-quadrant preference for any of the other teacher participants. This phenomena initiated several reflective discussions with Euclid which will be further discussed in Chapter 5.

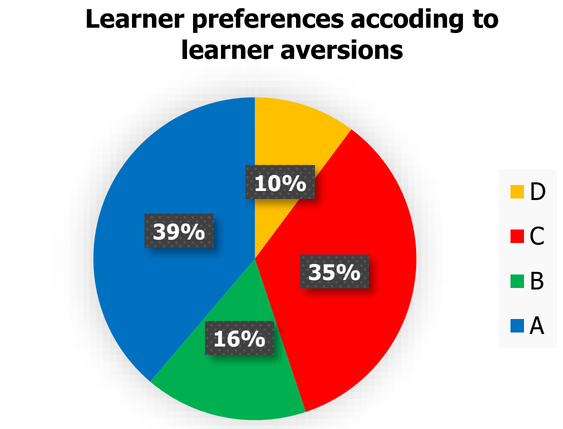
Table 4.58: Leonhard Euler's learner frequencies: Question 5 and Question 6

Question 5: LEARNER PERSONAL PREFERENCE FREQUENCIES:			
A-QUADRANT	**B-QUADRANT**	**C-QUADRANT**	**D-QUADRANT**
logic = 10 breaking down = 13	clear guidelines = 13 examples = 6	share ideas = 4 play = 1	explore = 9 connections = 4
23 (38%)	19 (32%)	5 (8%)	13 (22%)
Question 6: LEARNER PERSONAL AVERSIONS FREQUENCIES:			
A-QUADRANT	**B-QUADRANT**	**C-QUADRANT**	**D-QUADRANT**
group work = 7 long discussions = 12	unfamiliar questions = 6 no set method = 2	working in silence = 5 lots of reading = 12	set method = 2 lots of practice = 3
19 (39%)	8 (16%)	17 (35%)	5 (10%)

FIGURE 4.59: LEONHARD EULER'S LEARNER FREQUENCIES: QUESTION 5 AND QUESTION 6



Left brain: 70% Right brain: 30%
Cerebral: 60% Limbic: 40%



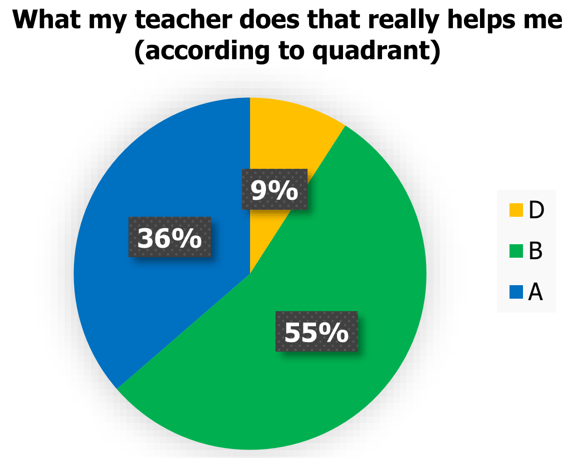
Left brain: 55% Right brain: 45%
Cerebral: 49% Limbic: 51%

From the responses received from learners regarding their appreciation for Leonhard Euler's approach to Mathematics, a B-quadrant emphasis is evident. This emphasis is indicated in Table 4.59 and Figure 4.60.

TABLE 4.59: LEONHARD EULER'S QUESTION 7 RESULTS

LEARNERS' APRECIATION OF THEIR TEACHER'S APPROACH TO TEACHING MATHEMATICS	
A-QUADRANT (4)	**D-QUADRANT (1)**
Problem-solving (1) • Allows me to work by myself • Explaining how to solve more difficult questions, makes me more comfortable with that type of exercise. **Purpose (1)** • Very thorough **Logical (1)** • He was logical	**Conceptualise (1)** • He explained the topics clearly and when I listened I understood what the concept was and how to apply it.
B-QUADRANT (6)	**C-QUADRANT (0)**
Step by step procedures (3) • He tried his hardest to explain how he got to the answer by writing out the full sum and explaining the process with explanations. • doing step by step methods in order to work out something • My Maths Teacher helps to stick to a set instructions so it is very helpful to remember the steps and follow the methods. **Repetition (1)** • Goes over the work that I don't understand over and over again until I get it **Worked examples (2)** • examples • Providing many examples of the work.	

FIGURE 4.60: LEONHARD EULER'S QUESTION 7 RESULTS ACCORDING TO QUADRANT



Left brain: 91% Right brain: 9%
Cerebral: 45% Limbic: 55%

Leonhard Euler tests with a particularly strong preference for the A-quadrant as can be seen in his HBDI® profile in Figure 4.61. His stress profile indicates a somewhat more dominant C-quadrant which indicates an almost triple dominant stress profile with preferences for the A-, B- and C-quadrants.

FIGURE 4.61: LEONHARD EULER'S HBDI® PROFILE

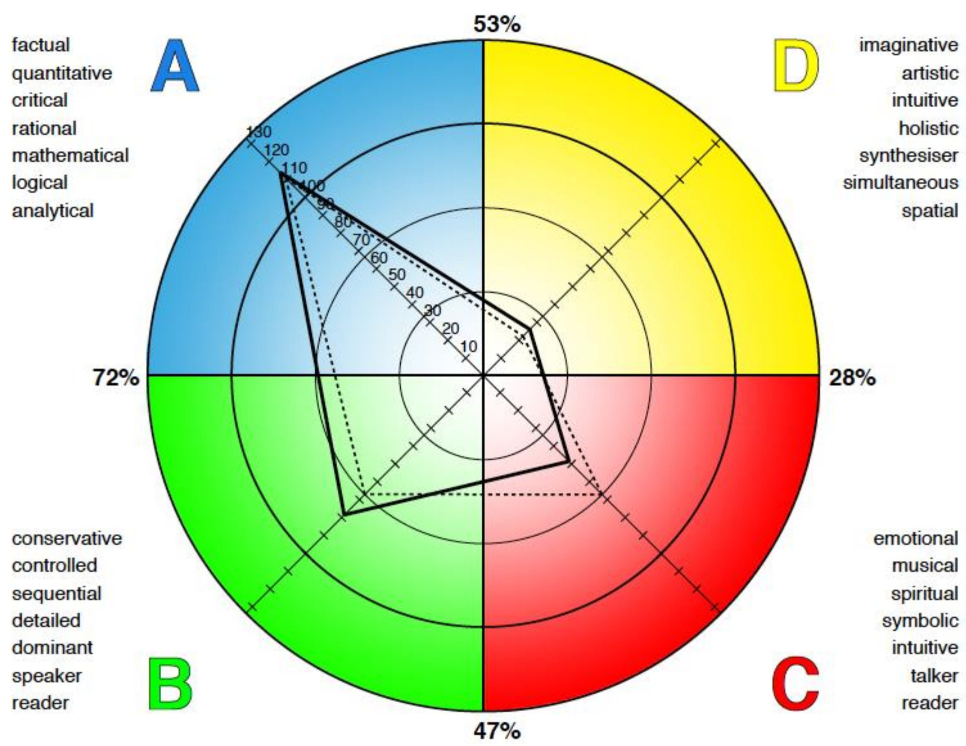
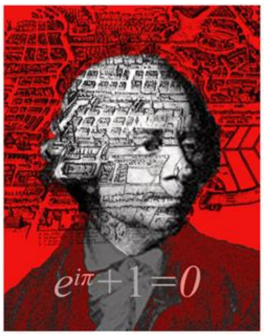


Table 4.60 indicates the congruence between Leonhard Euler's Diversity Game descriptors and his HBDI® profile scores.

TABLE 4.60: LEONHARD EULER'S HBDI® PROFILE SCORE IN COMPARISON TO HIS DIVERSITY GAME DESCRIPTOR



Leonhard Euler

DIVERSITY GAME			
A-QUADRANT	**B-QUADRANT**	**C-QUADRANT**	**D-QUADRANT**
1. mathematical 2. analytical 3. factual			
Herrmann Brain Dominance Instrument® KEY DISCRIPTORS			
A-QUADRANT	**B-QUADRANT**	**C-QUADRANT**	**D-QUADRANT**
* mathematical analytical factual rational logical	sequential detailed	spiritual	
Herrmann Brain Dominance Instrument® PROFILE SCORE			
A-QUADRANT	**B-QUADRANT**	**C-QUADRANT**	**D-QUADRANT**
114	78	48	26
Herrmann Brain Dominance Instrument® ADJECTIVE PAIRS			
A-QUADRANT	**B-QUADRANT**	**C-QUADRANT**	**D-QUADRANT**
10	6	6	2

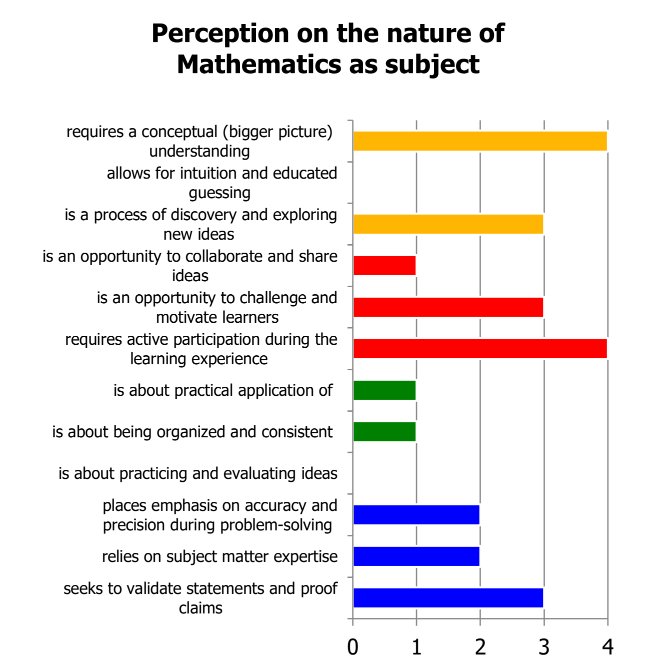
4.5 COLLECTIVE TEACHER PARTICIPANT GROUP'S HBDI® AND PRE-INNOVATION QUESTIONNAIRE RESULTS

Table 4.61 indicates the teacher participant group's pre-innovation questionnaire results on their perception on the nature of Mathematics. There seems to be an emphasis on the C-quadrant, as indicated in Figure 4.62. This is contrast to what the teacher participant group deem to be the key features of Mathematics, as indicated

TABLE 4.61: PERCEPTION ON THE NATURE OF MATHEMATICS

A-QUADRANT	B-QUADRANT	C-QUADRANT	D-QUADRANT
seeks to validate statements and proof claims (3)	is about practicing and evaluating ideas	requires active participation during the learning experience (4)	is a process of discovery and exploring new ideas (3)
relies on subject matter expertise (2)	is about being organized and consistent (1)	is an opportunity to challenge and motivate learners (3)	allows for intuition and educated guessing
places emphasis on accuracy and precision during problem-solving (2)	is about practical application (1)	is an opportunity to collaborate and share ideas (1)	requires a conceptual (bigger picture) understanding (4)
7 (29%)	2 (8%)	8 (34%)	7 (29%)

FIGURE 4.62: PERCEPTION ON THE NATURE OF MATHEMATICS



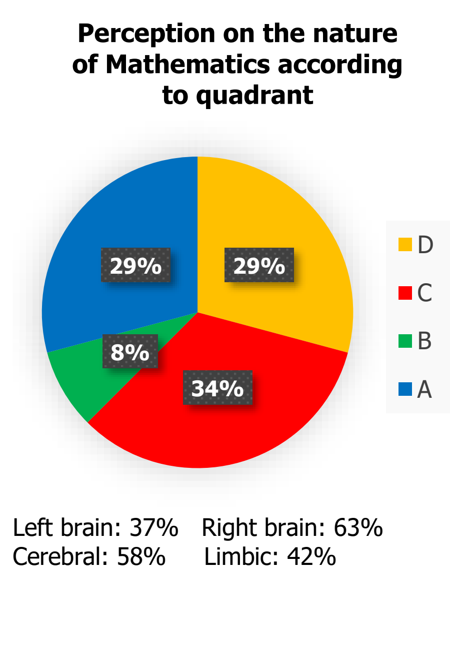
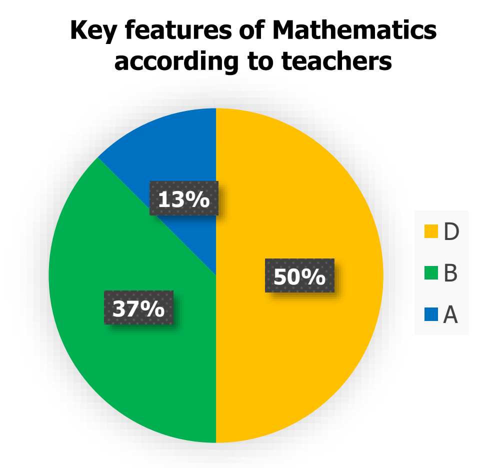


Table 4.62 compares the teacher participant group's view of the key features of Mathematics to that what learners perceive their teachers' view to be. This comparison indicates a clear discrepancy between what learners perceive their teachers' view to be to that of their teachers' view. Figure 4.59 indicates a D-quadrant emphasis of 50%, whilst learner responses indicated a B-Quadrant emphasis of 41%.

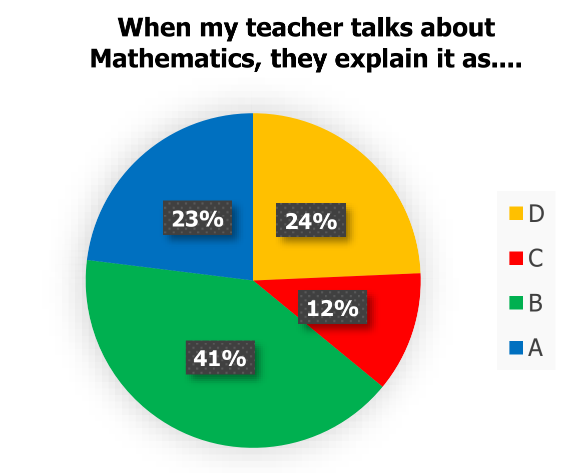
TABLE 4.62: TEACHER PARTICIPANTS VIEW OF THE KEY FEATURES OF MATHEMATICS IN COMPARISON TO WHAT LEARNERS PERCEIVE THEIR TEACHERS' VIEW TO BE ACCORDING TO QUESTION 1 OF THE LEARNER QUESTIONNAIRE

TEACHER FREQUENCIES KEY FEATURES OF MATHEMATICS			
A-QUADRANT exact science	**B-QUADRANT** procedural problem-solving	**C-QUADRANT** human-activity	**D-QUADRANT** continuous process of discovery
1 (13%)	3 (37%)	0 (0%)	4 (50%)
LEARNERS FREQUENCIES Question 1: WHEN MY TEACHER TALKS ABOUT MATHEMATICS, (S)HE EXPLAINS IT AS…			
A-QUADRANT a logical and analytical process	**B-QUADRANT** step-by-step instructions to follow	**C-QUADRANT** an opportunity to share ideas and methods	**D-QUADRANT** a process of discovery and making connections
91 (23%)	162 (41%)	46 (12%)	96 (24%)

FIGURE 4.63: TEACHER PARTICIPANTS VIEW OF THE KEY FEATURES OF MATHEMATICS IN COMPARISON TO WHAT LEARNERS PERCEIVE THEIR TEACHERS' VIEW TO BE



Left brain: 50% Right brain: 50%
Cerebral: 63% Limbic: 37%



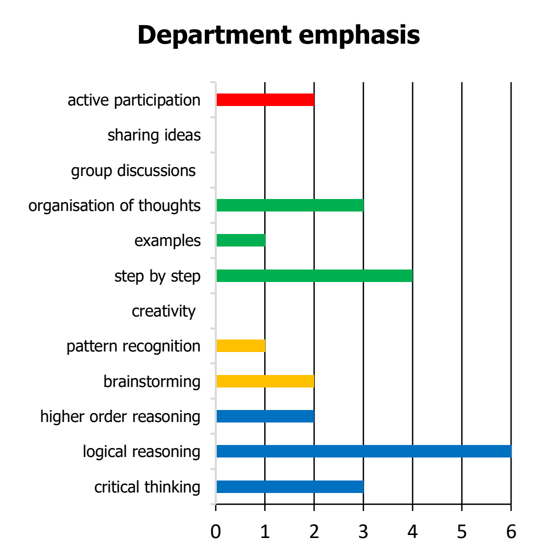
Left brain: 64% Right brain: 36%
Cerebral: 47% Limbic: 53%

Table 4.63 and Figure 4.64 indicate the teacher participants' view of the thinking patterns and processes they encourage to be predominantly A-quadrant focussed. Learners however perceive their teachers' emphasis to be more evenly spread amongst the four quadrants with an emphasis towards the B-quadrant. This indicated in Figure 4.65.

TABLE 4.63: TEACHER PARTICIPANTS PERCEPTION OF THE THINKING PATTERNS AND PROCESSES THEY ENCOURAGE IN COMPARISON TO WHAT LEARNERS PERCEIVE THEIR EMPHASIS TO BE ACCORDING TO QUESTION 2 OF THE LEARNER QUESTIONNAIRE

TEACHER FREQUENCIES THINKING PATTERNS AND PROCESSES ENCOURAGES			
A-QUADRANT	**B-QUADRANT**	**C-QUADRANT**	**D-QUADRANT**
critical thinking = 3 logical reasoning = 6 higher order reasoning = 2	step by step = 4 examples = 1 organization of thoughts = 3	group discussions = 0 sharing ideas = 0 active participation = 2	brainstorming = 2 pattern recognition = 1 creativity = 0
11 (46%)	8 (33%)	2 (8%)	3 (13%)
LEARNERS' FREQUENCIES Question 2: MY TEACHER PLACES A LOT OF EMPHASIS ON....			
A-QUADRANT	**B-QUADRANT**	**C-QUADRANT**	**D-QUADRANT**
critical thinking = 82 logical reasoning = 97 problem-solving = 97	step by step = 179 examples = 139 structuring my work = 66	explaining = 104 working with other = 45 sharing ideas = 73	drawings /diagrams = 60 finding patterns = 87 trial and error = 73
276 (25%)	384 (35%)	222 (20%)	220 (20%)

FIGURE 4.64: TEACHER PARTICIPANTS PERCEPTION OF THE THINKING PATTERNS AND PROCESSES THEY ENCOURAGE IN COMPARISON TO WHAT LEARNERS PERCEIVE THEIR EMPHASIS TO BE ACCORDING TO QUESTION 2 OF THE LEARNER QUESTIONNAIRE



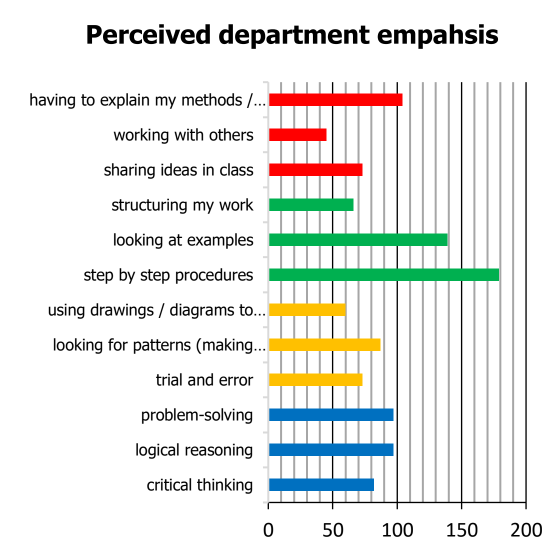
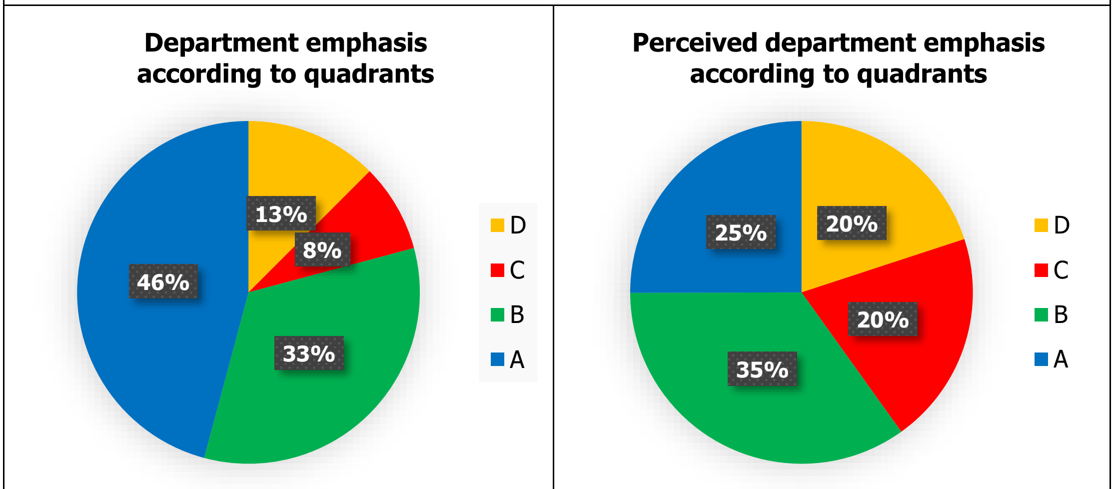


FIGURE 4.65: TEACHER PARTICIPANTS PERCEPTION OF THE THINKING PATTERNS AND PROCESSES THEY ENCOURAGE IN COMPARISON TO WHAT LEARNERS PERCEIVE THEIR EMPHASIS TO BE ACCORDING TO QUADRANTS

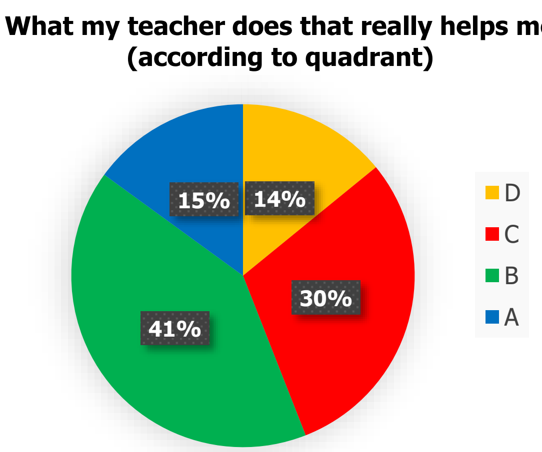


Left brain: 79% Right brain: 21%
Cerebral: 59% Limbic: 41%

Left brain: 60% Right brain: 40%
Cerebral: 45% Limbic: 55%

As was evident through the data analysis of each teacher participant, learner questionnaire results for Question 7 indicated predominantly B-quadrant focussed sentiments for seven of the eight participants. For this reason, the teacher participant group's Question 7 results also indicate a predominantly B-quadrant focus as indicated in Figure 4.66.

FIGURE 4.66: THE TEACHER PARTICIPANT GROUP'S QUESTION 7 RESULTS ACCORDING TO QUADRANT

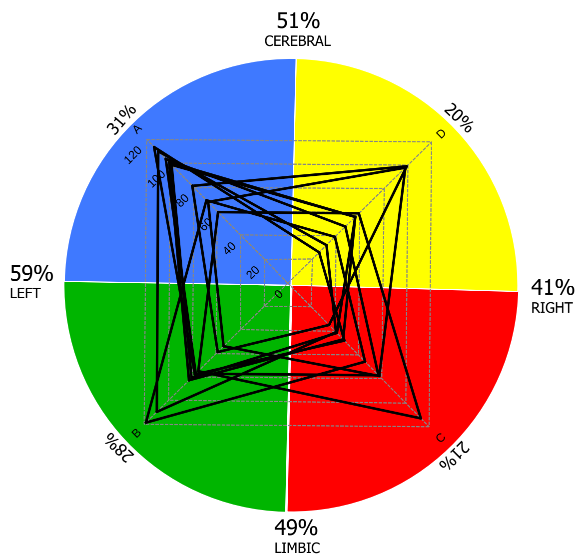


Left brain: 56% Right brain: 44%
Cerebral: 71% Limbic: 29%

Figure 4.67 show the composite team profiles both according to profile scores and adjective pair or stress profile scores. The composite profile summary indicates a stronger preference for the left-brain quadrants with 59% in comparison to a 41% preference for the right-brain quadrants. The cerebral and limbic quadrants are almost equally distributed with a 51% and a 49% preference respectively. Although the right-brain and left-brain distribution remains almost the same for the teacher participant group's stress profile, the cerebral and limbic distribution indicates an increase in limbic preferences.

FIGURE 4.67: THE TEACHER PARTICIPANT GROUP'S COMPOSITE PROFILE SCORES IN COMPARISON TO THEIR ADJECTIVE PAIR SCORES

HBDI® PROFILE SCORES
MATHEMATICS DEPARTMENT
PROFILE SUMMARY



HBDI® ADJECTIVE PAIR SCORES
MATHEMATICS DEPARTMENT
STRESS PROFILE SUMMARY

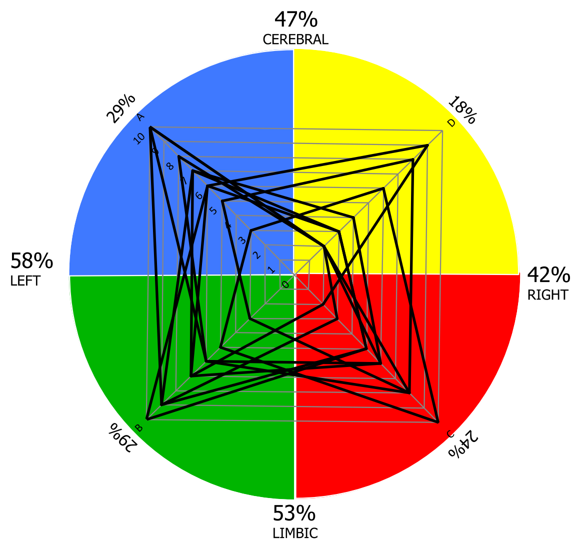
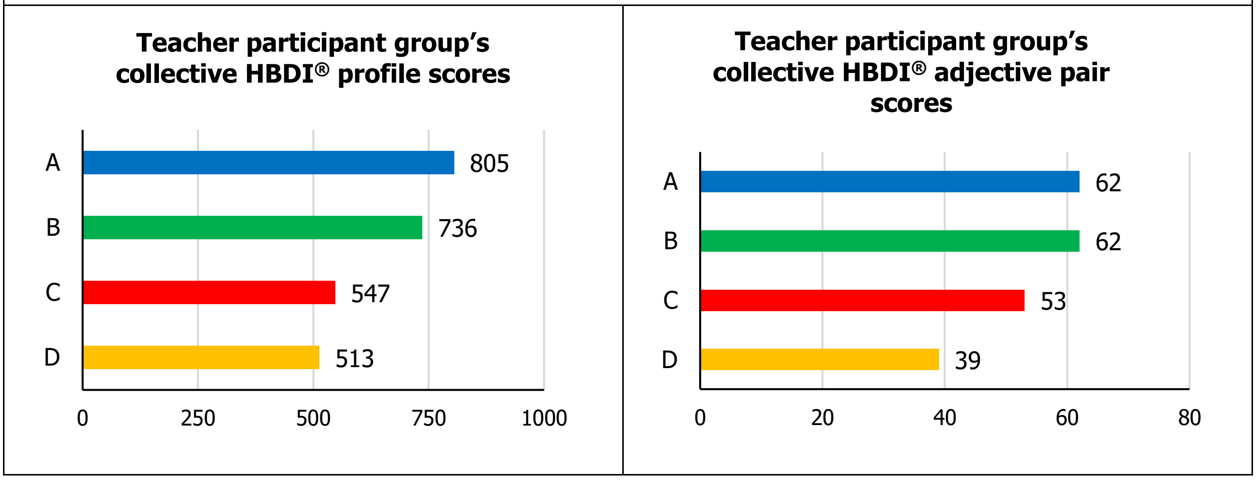


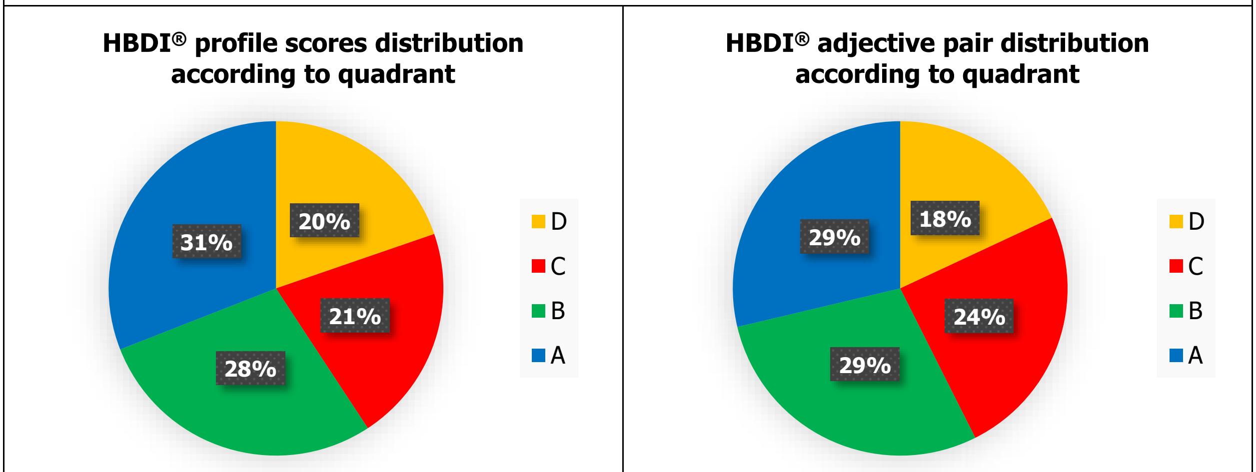
Figure 4.68 indicates the ranking for the quadrant preferences according to the teacher participant group's collective HBDI® profile scores in comparison to the participant group's collective HBDI® adjective pair scores. Whereas the collective HBDI® profile scores indicate the A-quadrant as the teaching team's more preferred quadrant, the HBDI® adjective pair scores indicate an equal preference for the A- and B-quadrants.

FIGURE 4.68: THE TEACHER PARTICIPANT GROUP'S QUADRANT RANKING ORDER FOR THEIR HBDI® PROFILE SCORES IN COMPARISON TO THEIR HBDI® ADJECTIVE PAIR SCORES



The comparison between the teacher participant group's HBDI® profile scores per quadrant and their HBDI® adjective pair scores per quadrant is indicated in Figure 4.69.

FIGURE 4.69: THE TEACHER PARTICIPANT GROUP'S QUADRANT RANKING ORDER FOR THEIR HBDI® PROFILE SCORES IN COMPARISON TO THEIR HBDI® ADJECTIVE PAIR SCORES PER QUADRANT



Left brain: 59% Right brain: 41%
Cerebral: 51% Limbic: 49%

Left brain: 58% Right brain: 42%
Cerebral: 47% Limbic: 53%

4.6 Conclusion

The data collected in this chapter served two purposes. Firstly, it gave insight into the thinking processes of teacher participants and how these thinking preferences are perceived by learners in their respective classes. Secondly, it was a means of initiating reflective practice, which means that one's practice could potentially change. The analysis, interpretation as well as reflection on this data collection process will be further discussed and in Chapter 5.

CHAPTER 5

"Without reflection, we go blindly on our way, creating more unintended consequences, and failing to achieve anything useful."

Wheatley (2014)

5.1 INTRODUCTION

In this chapter, I weave together the strands of my reflections on my own teaching, my reflection on the teacher participants' teaching, as well as the teacher participants' reflection on their own teaching. These collective, reflective processes are both part of the research and the aim of the research itself. Since these reflections are grounded within Herrmann's Whole Brain® model, it can therefore be seen as "whole brain scholarly reflection" (Du Toit, 2012, p. 1221).

The reflections also include the reflective practice of teacher participants and give some insights into the ways each participant informed their practice after being introduced to Herrmann's Whole Brain® theory. The notion of theory informing practice, through scholarly reflection, is therefore also discussed. This chapter therefore looks at the different reflective strands that form the collective reflective practice, as discussed in Chapter 3 and illustrated through the Randewijk Rope Model (as can be seen in Figure 1.3 and Figure 3.1).

5.2 MY LIVING THEORY

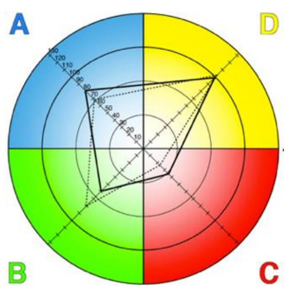
Since my reflections on Herrmann's Whole Brain® theory initiated this research, my own reflection on the process was at the centre of the collective reflective practice. As this is a continuous process of reflection and growth, I consider this process my living theory.

How I perceived myself and my teaching was not necessarily aligned with how my learners perceived my teaching to be. Although my Herrmann Brain Dominance Instrument® profile showed a preference for the A- and D-quadrants, learners perceived my teaching to be B- and D-quadrant dominant, which correlate with my adjective pair score or stress profile. This notion highlighted the following notions for me:

1. In the classroom, teachers are bound by time and curriculum pressures, meaning that they are required to make certain decisions that do not necessarily reflect how they would teach without these constraints. Schoenfeld (2011, p. 459) suggests that teacher decisions are influenced by three components: "resources, goals and orientations". Although the same resources are available to all teacher participants in this study, the goals they have set for themselves in utilising these resources could influence their teaching. Goals can also be linked to the time allocated for learner feedback or the development of conceptual understanding, whereas orientation is a teacher's perception about the needs of learners according to the teacher's belief regarding learners' abilities. In short, a variety of different components can cause teachers to base their decision making on stresses they perceive to be present in their teaching environment.

   It is therefore highly likely that a teacher, operating under these constraints, would teach according to their Herrmann Brain Dominance Instrument® adjective pair score, or stress profile. When comparing my HBDI® adjective pair score, to my learner questionnaire results for Question 2 and Question 7, the emphasis on the B- and D-quadrant is quite apparent. This is indicated in Figure 5.1.

FIGURE 5.1: MY PERSONAL HBDI® PROFILE IN COMPARISON WITH LEARNER FEEDBACK AND TEACHER EMPHASIS ACCORDING TO QUADRANT

<table>
<tr>
<td>
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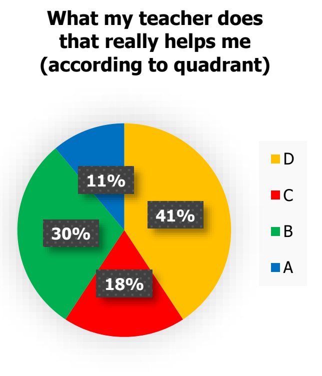
<td>
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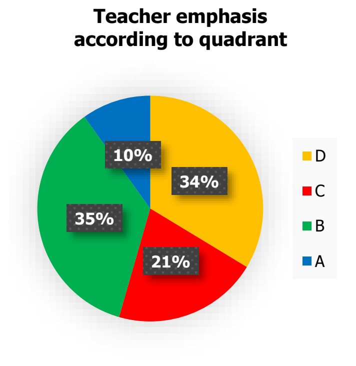
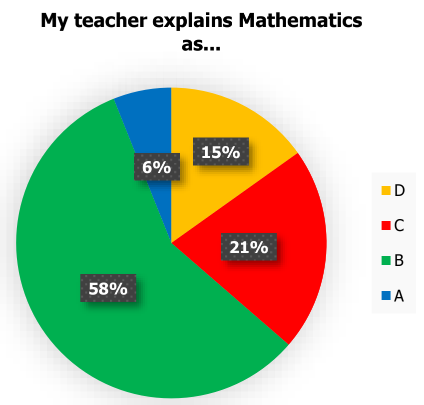
<td>
</td>
</tr>
<tr>
<td>Herrmann Brain Dominance Instrument® profile: Emmy Noether</td>
<td>Question 7: Learner appreciation</td>
<td>Question 2: Learner perceptions on thinking patterns and processes encouraged</td>
</tr>
</table>

2. The input that goes into planning a learning and assessment opportunity, and what is perceived by learners in the classroom, does not necessarily correlate. Although learners perceived my thinking patterns and processes to be both B- and D-quadrant dominant, at 35% and 34% respectively, 58% of learners perceived my view of Mathematics as step-by-step instructions to follow, as indicated in Figure 5.2. According to the learner feedback, my A-quadrant came through as my weakest quadrant. Upon reflecting on how I analyse a topic before introducing it to the learners in my class, using the A-quadrant, I concluded that learners are not necessarily privy to this process. Thinking patterns and processes that learners deem to be my emphasis, which are B- and D-quadrant dominant, are the result of my A-quadrant analysis. As a teacher focussed on reflecting on my teaching practice, I am continuously analysing both the manner in which I teach a particular topic as well as the manner in which learners react to my teaching. I also keep a record of common misconceptions that learners have on the particular topic. This analysis (A-quadrant) helps me to put structures in place (B-quadrant) and to develop innovative learning and application opportunities (D-quadrant). Yet, I cannot disregard learners' perceptions that my perception of Mathematics is B-quadrant dominant. It could also be possible that my research into Whole Brain® teaching and learning could have caused me to overcompensate in quadrants other than the

A-quadrant which is traditionally viewed as the quantitative or mathematical quadrant. Being aware of Whole Brain® teaching and learning, within the framework of constructivist learning theories, could therefore have the potential for one to overcompensate to address areas of potential shortfalls or limitations.

FIGURE 5.2: LEARNER QUESTIONNAIRE RESULTS FOR QUESTION 2



3. Since learners in my classes have indicated that they predominantly prefer to prepare for Mathematics assessments using thinking patterns and processes associated with the B-quadrant, it could be argued that learners therefore relate to my B-quadrant manner of teaching because of their own preferences. Their preferences could therefore possibly skew their perception of my teaching. Contrary to this, one can argue that my emphasis has influenced my learners' manner of preparing for assessments. Regardless of whether my learners' preferences skewed their perception of my teaching or if my perceived emphasis influenced their method of test preparation, the correlation between learner preferences and learner perceptions on the teacher emphasis, is noteworthy. It should also be noted that an approach to Mathematics that is predominantly focussed on one quadrant could yield possible shortfalls, since it neglects to develop a Whole Brain® approach to Mathematics. Now that I am aware that there is a B-quadrant emphasis in my classroom, I can aim to balance this by also drawing learners'

attention to thinking patterns and processes associated with the other three quadrants. In doing so I aim to assist learners who have thinking preferences for the A-, C- and D-quadrants.

4. The teacher appreciation feedback from my learners has a strong correlation with my Herrmann Brain Dominance Instrument® profile with the D-quadrant comments, which is my dominant quadrant, coming through at 41% of all the comments given. Where one can argue that learners could have been biased when having to choose categorised key words in the multiple-choice questions, this bias would not be present when having to express, in their own words, what their teacher does to aid their understanding of Mathematics. Visual representations are an important part of my personal process of understanding challenging problems. It aids my process of analysis and organisation of information. This approach is therefore also evident in my teaching. From experience, I know that my attention to detail (associated with the A-quadrant) is sacrificed when I am under pressure, for the goal of developing a conceptual understanding (associated with the D-quadrant). In my teaching, I tend to sacrifice formal vocabulary and analysis (associated with the A-quadrant), for more time on application and different methods of solving specific problems (associated with the D-quadrant). This approach could possibly explain why learners also focus their feedback towards the D-quadrant, rather than the A-quadrant. As with the feedback on learners' perception of my teaching emphasis, 30% of responses indicate an appreciation for my B-quadrant focus.

5. Another possible explanation for the dominance of B-quadrant feedback from learners could be ascribed to learners generally struggling to reach Bloom's and Krathwohl's conceptual level of understanding in Mathematics. Procedural knowledge, such as step-by-step guidelines, do not require learners to conceptualise or synthesise knowledge, which, was originally thought to be the highest level of understanding, but

according to Krathwohl (2002) is secondary only to metacognition. This preference for the B-quadrant also came through as the strongest quadrant according to learners' perception of the whole Mathematics Department's emphasis as well as in the learner appreciation section of the teaching team.

6. What was interesting to me, is that my learners did not perceive my C-quadrant to be my weakest quadrant, although this shows almost as an aversion on my Herrmann Brain Dominance Instrument® adjective pair score. One learner wrote: "She always had a super bubbly personality and always focused on helping each and every individual on the specifics that each person struggled with". This was once again a reminder that the Herrmann Brain Dominance Instrument® is not a personality test, but an indicator of thinking preferences. A teacher can therefore still have a warm and caring personality, but when faced with decisions, base their decisions on a cerebral rather than a limbic understanding of the situation.

This reflective analysis and possible explanations for phenomena in my own teaching, aided my understanding and analysis of my colleagues' feedback. This is what makes participatory action research so powerful, that the researcher is immersed in the research process.

5.3 THE LIVING THEORY OF THE TEACHER PARTICIPANTS

What became apparent in my interaction and communication with the teacher participants, was that those who tested with a higher C-quadrant score gave more detailed reflective responses to both verbal and written questions. This in itself supported the results of the Herrmann Brain Dominance Instrument® profile, since the C-quadrant is synonymous with thinking preferences such as "expressive" and "emotional involvement" (Herrmann, 1990, p.3). Providing feedback on C-quadrant dominant participants therefore proved to be much richer. Yet, one should be mindful not to assume that participants who are not C-quadrant dominant did not experience the research innovation as a reflective process. They might merely have been limited in expressing their thoughts.

5.3.1 Sophie Germain – our strength is also our weakness

Sophie Germain tested with the highest C-quadrant score on the Herrmann Brain Dominance Instrument® of the entire teacher participant group. Sophie Germain also chose the key descriptor of "emotional" for herself and explains her reasoning for this as follows:

> *I tend to get emotionally involved with everything I do from watching a TV series to teaching my learners.*
>
> *I believe the emotional value can be both negative and positive when it comes to teaching. I share the experiences with my learners, I try to keep them motivated and I console them when they are upset and down. However, due to my emotions I can also overreact. I do however believe that any key descriptor can have both a positive and negative quality.*

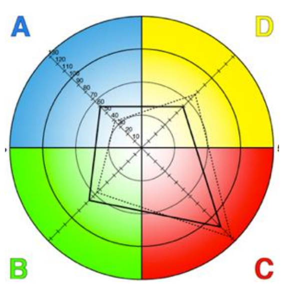
Personally, I always deemed "emotional" to have a negative connotation. For someone, such as myself, who has a particularly low C-quadrant score, this objective view of emotions came as a refreshing new understanding of both the word as well as the C-quadrant. Sophie Germain's honest and reflective view of how each key descriptor carries both positive and negative qualities, brought to the fore the importance of not using the Herrmann Brain Dominance Instrument® as a classification and judging tool, but rather as a tool which aids understanding of differences.

One should also not assume that all teachers who teach Mathematics are necessarily strong A- and B-quadrant teachers. The teaching profession is, after all, about human connection. Sophie Germain explains the advantages of her strong (red) C-quadrant as an inseparable part of her teaching:

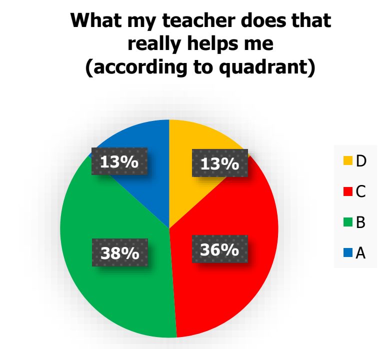
> *I don't think I would be as an effective educator without my red quadrant. My red quadrant is what causes me to love my career and love the environment I am working in. I see my learners every single day. It is so important to have a good relationship with them, whether it is because you want them to succeed as a learner, or if you want to succeed as an educator. Learners will never remember the content you taught them, but the life skills you showed them.*

There is a strong correlation between Sophie Germain's Herrmann Brain Dominance Instrument® profile score and that of the learner feedback, especially when analysing the learner appreciation comments and the perceived teacher emphasis as indicated in Figure 5.3. The learner appreciation comments are almost in exact quadrant distribution to that of her Herrmann Brain Dominance Instrument® profile, supporting the hypothesis that a teacher's thinking preferences are evident in their teaching.

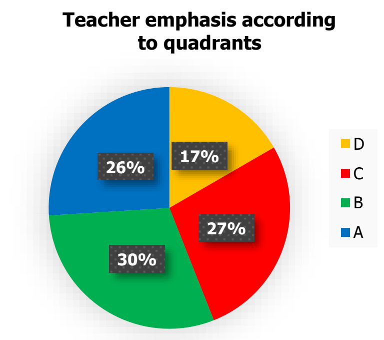
FIGURE 5.3: SOPHIE GERMAIN'S HBDI® PROFILE IN COMPARISON WITH LEARNER FEEDBACK AND TEACHER EMPHASIS ACCORDING TO QUADRANT



Herrmann Brain Dominance Instrument® profile: Sophie Germain



Question 7: Learner appreciation



Question 2: Learner perceptions on thinking patterns and processes encouraged

The way Sophie Germain approaches her planning for her teaching and how it reflects in her teaching is also congruent. She explains how her organised, step-by-step planning had helped her to set up a new department and subject at her first teaching position.

> *It was my first year teaching, and I had to introduce the CAPs subject Technology for the first time at the school, and on top of that I was the only one in the department. There was not too much of a hand over as the school previously taught woodwork, therefore I had no resources to use except the CAPs*[3] *technology outline. As a first year teacher, I was extremely overwhelmed and was not sure where to begin, however my green quadrant kicked in over the December holidays before I started teaching, and it was this thought process that got me through the year.*
>
> *I began by asking the high school I went to for old books in the subject, which they happily gave to me. I then started to create my own resources, first hard copy resources, then electronic resources. I ensured that before each quarter all my draft lesson plans were completed with an aim for each lesson. I slowly started to build the department up on my own.*
>
> *It has gotten me through some 'harder' times as a new educator and has also helped me evolve into the educator I am today. I don't think I would have made it in my second teaching position without my green quadrant. I also believe that providing steps or a strategy for learners helps them, especially the weaker ones. For my mathematically challenged learners I always follow a 'green' process that I hope helps them along the way.*

The Herrmann Brain Dominance Instrument® created more than merely an awareness about a Whole Brain® approach to teaching, learning and assessing

[3] CAPs is the South African Curriculum and Assessment Policy that outlines the assessment criteria for each subject or learning area.

with Sophie Germain. It started a reflective inquiry where she started questioning her current practice.

> *It helps me understand sometimes why learners do not learn in the same way as I would have. However, the difficult thing is not knowing this, it is more how you can change your thought process. I can easily say that I need to think outside of the box in more of my teaching methods, but where do I start? Which topics do I think outside the box with? How do I approach the topic outside the box?*

Upon a follow-up conversation with Sophie Germain a year after she had moved to a different school, she seemed more confident in the ways that she explored different approaches besides her B- and C-quadrant dominance. Sophie Germain's D-quadrant preference strengthened when she was under pressure, as can be seen from her adjective pair score. However, the exploratory D-quadrant is seen to be opposing to the well-defined and structured B-quadrant, which came through strongly in the response from Sophie Germain's learners. From her interaction with and reflections on Herrmann's Whole Brain® approach, she developed additional strategies to her teaching approach:

> *…there are many occasions that once I think my learners are fully equipped with the basics, they need to try and apply their skill set in harder application questions. When doing so I make room for learners to make mistakes, because if they do I will explain why the process is incorrect and through some trial and error we come to the correct answer. I am also a very firm believer that diagrams are necessary in Mathematics. Some learners are visual learners and I believe that this not only helps them understand the topic, but when it comes to studying for a test or exam, they can easily look back and remember the process.*

> *…in my new school a lot of focus has been placed on differentiation of learners in learning styles and abilities. If I had known then what I know*

> *now* (referring to the learners' feedback a year earlier)*, I do believe that I could have really catered for both parties* (referring to the opposing B- and D-quadrant needs of learners.)

As a young teacher, eager to improve her teaching practice, Sophie Germain welcomed the opportunity to receive feedback from her learners on their perception of her learning. This, in comparison to a better understanding of her own thinking and learning preferences, gave her the confidence to explore new strategies and grow as a result of it.

5.3.2 MARIA AGNESI – REFLECTION LEADS TO EXPLORATION AND PERSONAL DEVELOPMENT

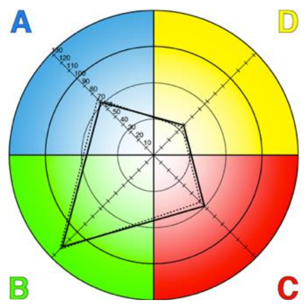
At the time of the innovation, Maria Agnesi had just been appointed as subject leader for Mathematics, despite not having had a very long teaching career and therefore the teaching experience associated with that. Yet, Maria Agnesi excelled in this administrative position largely due to her strong B-quadrant thinking preference. Maria Agnesi thought of herself as "boring" whilst we were engaging in the Think Adventure Diversity Game but came to realise that what she deems as "boring", is in fact a strength that has given her the competency of heading up a department of teachers more experienced than her.

> *I no longer consider myself "boring", but rather "different" to others. I am proud of my organisational skills, my administrative ability and the practicality in the way I work. I know I am an efficient person and a hard worker and I have realised that I should continue to use this to my strength.*

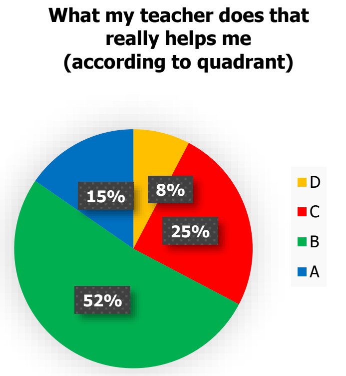
The learner feedback on Maria Agnesi's teaching and assessment approach show a strong correlation to her Herrmann Brain Dominance Instrument® profile with 52% of learners expressing their appreciation for thinking patterns and processes associated with the B-quadrant. This is indicated in Figure 5.4.

Along with the teacher emphasis of B-quadrant thinking patterns and processes at 40%, 48% of learners deemed Maria Agnesi's explanation of mathematical concepts to be that of studying examples and step-by-step procedures to solve problems.

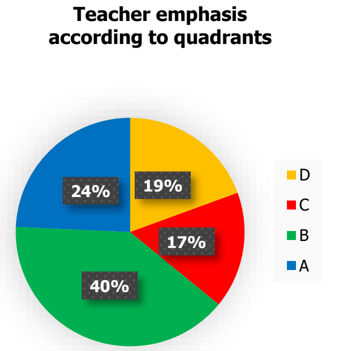
FIGURE 5.4: MARIA AGNESI HBDI® PROFILE IN COMPARISON WITH LEARNER FEEDBACK AND TEACHER EMPHASIS ACCORDING TO QUADRANT



Herrmann Brain Dominance Instrument® profile: Maria Agnesi



Question 7: Learner appreciation



Question 2: Learner perceptions on thinking patterns and processes encouraged

Upon reflecting on the possible limitations of her mono-quadratic profile, Maria Agnesi expressed the following:

> *I struggle to be creative with examples and questions. This is definitely something I need to work on - something I have tried is asking the learners to give me ideas for questions which really helps because it allows me to see who my potential yellow-quadrant learners are. I do believe that there is not always a need for such structure in a Maths lesson - that you can throw learners in the deep end and get them to swim their way out - learners can be given a question without any prior notes or knowledge provided by the teacher and find the solution in their own way. This is something I have had to make peace with in my career - letting go of the reigns of control sometimes and allowing the learners to do the teaching. This is when some of my best lessons have happened.*

Once again, the awareness initiated by the Herrmann Brain Dominance Instrument® profile, started a reflective practice process with Maria Agnesi. She started feeling more comfortable exploring strategies outside her normal practice:

> *Knowing about HBDI® and being constantly aware of it has made the process of preparation of lessons and assessments far more interesting and has forced me to work differently (and harder!) but it has only improved those processes for me.*

Maria Agnesi points to an important aspect of professional development, when she says that she has had to work "harder" as a result of her reflective awareness of her own and her learners' thinking and learning processes. Reflective practice is therefore far removed from an autopilot approach where teachers deliver the same content in the same manner year after year. Considering Dewey's explanation of reflective thought that teachers should aim "to integrate thought and action, theory and practice, the academy and the everyday world" (Schön, (1992, p. 123), we can see that it requires a great deal of reflection on one's practice and therefore also that teachers practise metacognition.

Maria Agnesi did not only come to the conclusion that she herself could build on thinking processes beyond her preferences, but also that Mathematics itself is a whole-brain endeavour:

> *Discovery is extremely important in Mathematics - I think I just need to allow more time for that to happen in my lessons, or in the homework I assign. Being able to think for oneself is a strong tool, especially in Mathematics and to strengthen that skill, one needs to be exposed to as many different and challenging questions as possible in order to practise and develop that skill.*

This comment speaks to mathematical challenges (A-quadrant), skills and practice (B-quadrant), discovery (D-quadrant), exposure and even confidence in thinking for oneself (C-quadrant). Herrmann's Whole Brain® theory therefore has the potential not only to impact on a teacher's perception of themselves, but also to impact on the manner in which they view their learners and the nature of the subject they teach.

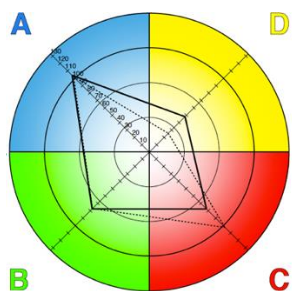
5.3.3 Ada Lovelace – integrated learning is powerful learning

Ada Lovelace tested with a triple dominance Herrmann Brain Dominance Instrument® profile score, which means that she has a dominance in three of the four quadrants, namely A-, B- and C-quadrant. Furthermore, Ada Lovelace chose "adventurous", a D-quadrant descriptor, as her key descriptor during the Diversity Game, yet, in her profile, she tested with a strong preference for the blue quadrant, with her key descriptor being "logical". This seeming inconsistency is in fact consistent with who Ada Lovelace is:

> *I enjoy accepting challenges (projects), even if it is something I have no experience with. Solving problems/challenges gives me a sense of "adventure" wherein I try to incorporate something exciting or a new concept into the solution.*

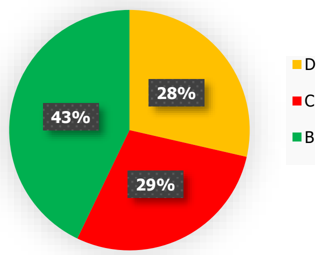
When comparing Ada Lovelace's HBDI® profile, to that of the learner questionnaire results for Question 2 and Question 7, there does not seem to be a strong correlation, as indicated in Figure 5.5.

Figure 5.5: Ada Lovelace's HBDI® profile in comparison with learner feedback and teacher emphasis according to quadrant



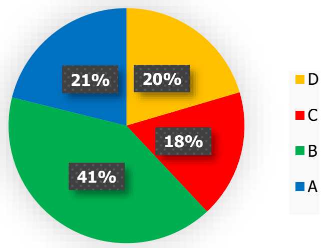
Herrmann Brain Dominance Instrument® profile: Ada Lovelace

What my teacher does that really helps me (according to quadrant)



Question 7: Learner appreciation

Teacher emphasis according to quadrants



Question 2: Learner perceptions on thinking patterns and processes encouraged

Two trends, similar to my own, emerged from the feedback from Ada Lovelace's learners:

1. Learners perceive Ada Lovelace to have a B-quadrant focus.
2. Learners expressed their appreciation for thinking patterns and processes from all the quadrants except the A-quadrant which is traditionally seen as the "Mathematics" quadrant and, according to Ada Lovelace's profile, is her strongest quadrant.

As mentioned before, learners generally struggle with conceptual understanding in Mathematics and approach the subject from a more procedural perspective. This preference was evident when looking at the entire learner participant data set but came through more prominently from both my and Ada Lovelace's learner feedback. Furthermore, learner perceptions on the delivery of content is not necessarily congruent with a teacher's perception of Mathematics, or their process of creating learning opportunities:

I incorporate real world examples as much as I can in my lessons. When solving problems, learners are encouraged to use their own methods, however, some direction is required and that is where the set of *instructions comes in along the way. I am definitely a logical thinker who believes that problems can be solved using a set of steps but that is by no means my view of Mathematics.*

As her pseudonym suggests, Ada Lovelace is also involved in computer programming and robotics from which she brings a rich set of approaches to the Mathematics classroom. She also has extensive post-graduate qualifications and is actively involved in exploring project-based learning across learning areas. As discussed in the literature review, higher levels of understanding, as one is confronted with during post-graduate studies, requires a Whole Brain® approach. Without necessarily identifying it as Whole Brain®, Ada Lovelace seems to approach her teaching from a Whole Brain® perspective. She creates opportunities that are in contrast with a traditional approach of teaching Mathematics, which could also explain why learners show appreciation for her approach of the three quadrants that are not traditionally seen as mathematical ways of thinking.

At this point, I need to emphasise that although someone has developed a Whole Brain® approach to teaching (or research), they still have certain preferences that guide their thinking and decisions. This is also exactly what this research innovation aims to do: to initiate reflective Whole Brain® thinking, whilst building on preferences and developing aversions. The process might have been more evident during the course of this study when looking at Sophie Germain's responses at the start and end of the study, but because of Ada Lovelace's experience, qualifications and continuous professional development, she has already developed certain reflective Whole Brain® approaches to teaching long before this research innovation.

In my interaction with Ada Lovelace, it became evident that Ada Lovelace's curiosity is the spark that drives her to question, research and accept challenges. Where her D-quadrant therefore *initiates* her thinking, her thinking is governed by rigorous analysis (A-quadrant) and organisation (B-quadrant) in order to make connections with the learners in her classroom (C-quadrant).

> *I have been thinking a lot about how I could make my lessons more exciting/fun. I have found that Mathematics in itself allows for very little creativity especially in the FET phase where the work is more structured with a time constraint. However with the GET phase, creativity is possible especially when integrating the subject across other subjects in the curriculum. I have tried this out last year in collaboration with the English Department where we included activities in Mathematics that needed clues to be solved in order to unlock the Google Edu Box. Through one of the VR* (virtual reality) *apps, I included an area/perimeter application through the app. It was exciting for the learners and for me as well.*

Ada Lovelace has also come to the realisation that teachers often become isolated in their teaching and therefore also their thinking. Teachers are not always aware of how or what their colleagues teach – especially in high schools where teachers normally only teach one or two subjects. She ascribes her reflective practice to exposure to other subjects and exploring ways of integrating different subjects in order to enhance her learners' learning experience:

> *My change in thinking has definitely been inspired through observation of lessons in other subjects and a need to try out methods used in other subjects in my subject. Hence, the process of "discovery" to make the content more exciting and relevant.*

> *I have tried to integrate Mathematics with English and thoroughly enjoyed the experience. Learning in this way, becomes a more relevant experience for the educator as well as for the learners.*

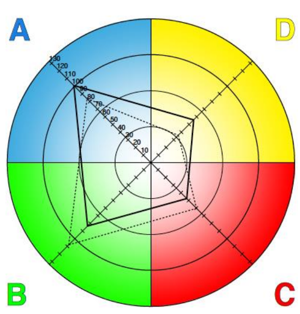
Integrating different subjects most definitely feeds into a Whole Brain® approach to learning. It links with Herrmann's "contextual approach" (Herrmann, 1995, p. 6), as well as Dewey's "constructivist approach" (1992, p. 123). During the innovation process, Ada Lovelace became aware that much of what she had already been doing in her teaching and research, can be succinctly summarised in the Whole Brain® model. She also states that:

> *It has made me realise that so much more goes into teaching than just "delivery". Due consideration needs to be given to how to deliver or teach lessons because different learners prefer learning in different ways*

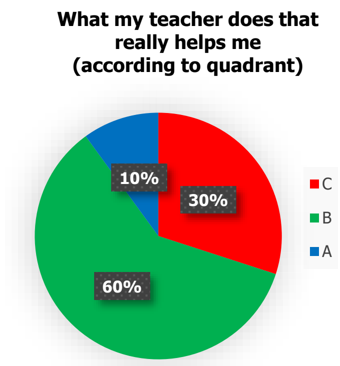
5.3.4 Hypatia – there is a balance between structure and conceptualisation

Hypatia tested with a left dominant profile, with her A-quadrant preference being the strongest, but shifting towards a B-quadrant dominance under stress according to her adjective pair score. What should also be noted about her adjective pair score, is that her D-quadrant tests almost as an aversion. Her adjective pair scores are in a very similar proportion to what learners appreciate about her teaching, as can be seen in Figure 5.6. Although the link between adjective pair scores and learner appreciation were also present in Sophie Germain, Maria Agnesi and my own data, it is more closely congruent in Hypatia's data. This differs from learners' perception of Hypatia's emphasis which has a stronger congruence to her normal HBDI® score.

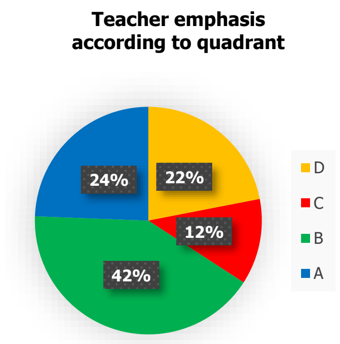
FIGURE 5.6: HYPATIA'S HBDI® PROFILE IN COMPARISON WITH LEARNER FEEDBACK AND TEACHER EMPHASIS ACCORDING TO QUADRANT



Herrmann Brain Dominance Instrument® profile: Hypatia



Question 7: Learner appreciation



Question 2: Learner perceptions on thinking patterns and processes encouraged

Hypatia's perception of Mathematics is a focus on practical application, an opportunity to challenge and motivate learners and requiring a conceptual (bigger picture) understanding. Yet, in the classroom she places a lot of focus on step-by-step instruction. She explains this as follow:

> *The whole Maths syllabus is step-by-step building towards the required skills. You need to be organised and plan well in order to eventually link the information taught so that it all comes together and the learner understands how it relates. It is almost like "planning" how you can give them the bigger picture, as opposed to accidental discovery.*

Hypatia's thinking is in line with Bruner's "spiral curriculum" (Bruner and Kenney, 1965, p. 52) where concepts keep being added in order systematically to develop a more comprehensive understanding of a bigger idea. It also speaks to the balance between the B- and D-quadrants: giving structure to enable conceptualisation. Too much structure could cause learners to have an over-dependency on rote learning procedures, which could inhibit them to develop a conceptual understanding. But, too much accidental discovery could lack structure and details necessary for conceptual understanding. This links to Strogatz explanation of understanding the technique before composing music (Lahey, 2014).

Boaler and Selling (2017, p. 81) refer to the importance of learners having the freedom of "human agency" in order to theorise and apply what they have learnt since "this agency proved to be important to their motivation and engagement." They found that learners in environments that focussed mainly on rules and structures felt constrained and imprisoned.

Hypatia recognises that if teachers want their learners to reach Krathwohl's (2002) highest level of understanding, or engage in metacognition, they will have to go beyond mere factual and procedural knowledge, left-brain dominant, understanding of a topic. She states that:

> *Should you wish to take it a step further, become better and do in-depth problem-solving, you need to be able to access your right-brain quadrants and think "out-of-the-box". Accessing the other side of your preferred brain quadrant is what will take you from being good to becoming great as a teacher and/or learner.*

She admits that it is not always an easy process and gives two reasons for this:

1. *Sometimes it is very successful, but unfortunately, because it does not come naturally, not all of my efforts succeed.*

2. *I also find that when I have time on my side, it is easier to play around and experience, but as soon as I am under pressure, I revert to my own preferred method.*

This is similar to Maria Agnesi's observation that planning for Whole Brain® lessons are indeed "harder". It requires a continuous awareness or reflection on both one's own thinking as well as reflection on your learners' thinking:

My exposure to HBDI® has made me aware of the fact that I have to make an effort to access different learning styles that learners relate to. Where it has made a huge difference is when I teach tutorials and work with a learner that does not understand my first explanation, I will then dig into my more creative side and try and access a different approach to teaching / learning.

Hypatia's strong analytical focus plays an important role in her teaching. In the learner feedback, learners clearly indicated that they "go through the homework questions (they) got wrong to understand where (they) went wrong and what to watch out for". This was not an option that came through particularly strongly in feedback regarding other teacher participants. Hypatia, however, places a lot of emphasis on analysis in her teaching:

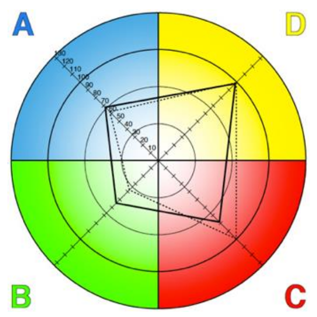
I verbally put a lot of emphasis on the importance of analysing homework and assessments with a specific focus on looking at mistakes made. I encourage them verbally that the only way to learn is through your mistakes. The rest is work that they already know. Where possible, throughout the year, I request that they mark the sections that they get wrong clearly and that before a next assessment, they spend time on that. In addition to this, I also, when I give test feedback, do not go through the whole test. I only focus on common mistakes made by the majority. When the learners answer homework questions, I insist that they show steps and calculations.

Hypatia uses her strong analytical focus to place emphasis on the importance of feedback to learners, which according to Hattie and Yates (2014) is the most valuable indicator of learner achievement. This is yet another reminder that Herrmann's Whole Brain® model should not purely be used to point out areas of improvement, but to celebrate successful strategies and to share these strategies as part of the collective practice.

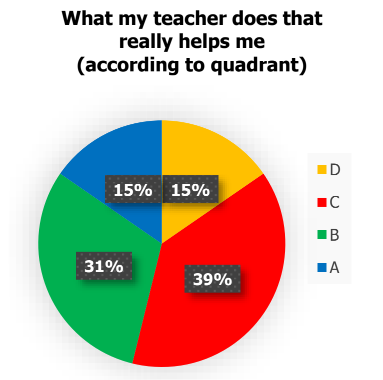
5.3.5 Euclid – stay balanced in your approach

Euclid is by far the most right brained member of the teacher participant group as well as being triple dominant. Although Euclid's least preferred quadrant is the B-quadrant, he has worked on developing structures both for himself and his learners and for this reason feedback from his learners does not give any indication that his B-quadrant lacks in any way. Euclid's approach to Mathematics is in fact fairly evenly spread across the four quadrants, yet his learners show an appreciation for his interpersonal (C-quadrant) focus to teaching, as can be seen in Figure 5.7.

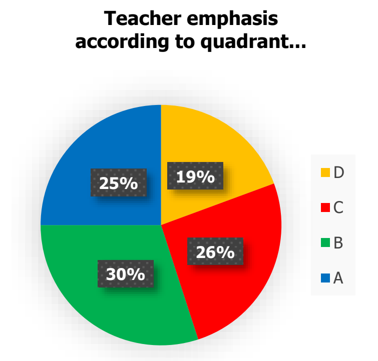
Figure 5.7: Euclid's HBDI® profile in comparison with learner feedback and teacher emphasis according to quadrant



Herrmann Brain Dominance Instrument® profile: Euclid



Question 7: Learner appreciation



Question 2: Learner perceptions on thinking patterns and processes encouraged

Euclid explains how his strong C-quadrant focus has facilitated his connection with his learners:

> *Learners need to trust and feel protected. They also need to feel nurtured and respected. I found early on in teaching that I am quite a comedian. This helps me to create a fresh, light-hearted space for learning to happen. I care deeply for those under my care. You can't fool children, they sense this. I also have a good sense of timing, when to say something and when not to. I understand human behaviour well and teaching is more about human beings than the content we teach.*

Having someone such as Euclid in a team where most other teacher participant members have a more left dominant focus, brings a balance to the collaborative team. Unfortunately, it also has the potential to make the balancing member feel isolated. Euclid has unfortunately also experienced the negative side of his profile:

> *I do find myself in conflict with staff members who have a different profile to me. Being imaginative and intuitive means I sometimes clash with people more conservative. It's a constant learning curve trying to handle this conflict and I find it quite draining at times. Yes, I do find it difficult. I struggle with the education system that is so focused on assessment and I find this sometimes punitive.*

For this reason, an awareness of how all members should aim to facilitate learning from all four quadrants is so important, since this creates an appreciation for differences and an opportunity to learn from each other.

This was especially significant from my own teaching perspective, since my C-quadrant does not test particularly strongly. Observing Euclid's lessons and seeing him engage with his learners and how he encouraged them to engage both with him and the concepts being learnt, was different from any other Mathematics lessons I have observed. In one particular lesson, Euclid worked with a small group of girls on their understanding of straight line geometry. He set the classroom up in such a manner, that it created a small circle. Instead of standing in front of the class, Euclid sat in the circle with the girls and encouraged them to use their iPads to connect to the AppleTV and data projector in order to display their own work on the screen. The girls were encouraged to talk through their understanding of a particular problem. Where one would assume that the girls would be anxious to do so in fear of being wrong or judged by their peers, the environment felt safe and all the girls eagerly engaged with each other in order to better their own and their collective understanding.

But this classroom environment also comes at a cost. Euclid, like Sophie Germain, explains that his strength can also be his weakness:

> *I think that sometimes I get burnt out because I give so much of myself. I sometimes need to take a step back and say no. I see a need so clearly and seem to intuitively want to respond. When I sense anxiety, I want to alleviate it. I feel an enormous sense of compassion for others and suffer with them when they suffer. These preferences have given great depth to my vocation.*

Euclid also touches on the importance of boundaries. Knowing oneself and engaging in reflective practice, makes it possible to identify situations that are not sustainable. As Euclid's adjective pair score indicates, his focus shifts towards the interpersonal C-quadrant and away from the "safekeeping" B-quadrant Herrmann (1990, p. 122). Building connections with learners is vital in creating a safe learning environment, but as a teacher one should not get overly involved either. Any over-involvement draws away from the balance advocated by Herrmann's Whole Brain® theory.

Euclid's reflection on his classroom practice serves as a reminder of the importance of balance in one's approach.

5.3.6 CARL GAUSS – A TYPICAL MATHEMATICS TEACHER?

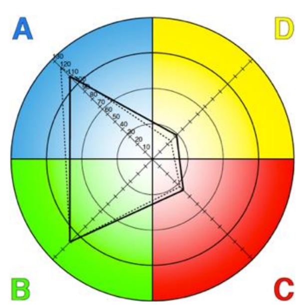
Where Euclid, testing fairly high in the right-brain modes, saw his role as Mathematics teacher as "more about human beings than the content we teach", Carl Gauss sees his left-brain dominant preference as linking well with his role as Mathematics teacher:

What I do every day, my job, links well to the quadrants I prefer.

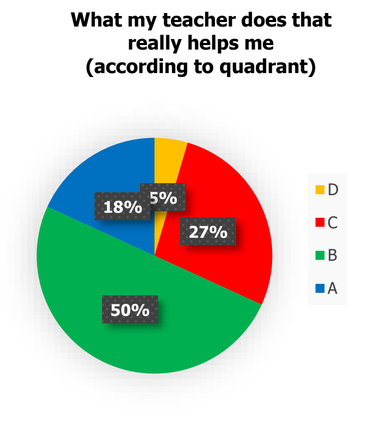
One would almost think that the views are opposing, but in fact both teacher participants are in agreement that their preferences are advantages to being a Mathematics teacher. As mentioned earlier, the seemingly opposing concepts of the abstract discipline of Mathematics with the humanitarian pursuit of teaching, is what necessitates a Whole Brain® approach to Mathematics teaching. This raises the question: Is there a typical profile of a Mathematics teacher?

Figure 5.8 shows a comparison of Carl Gauss's HBDI® profile, with his learner appreciation feedback and his perceived emphasis according to quadrant. Carl Gauss's HBDI® profile preferences for the A and B-quadrants correlates with the way learners perceive Carl Gauss to teach. Although learners perceive his emphasis to be more A- than B-quadrant focussed, 50% of Question 7 responses indicated that learners appreciate Carl Gauss's B-quadrant approaches.

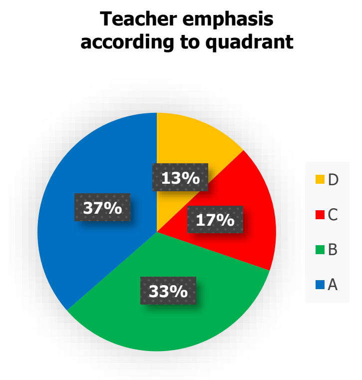
Figure 5.8: Carl Gauss's HBDI® profile in comparison with learner feedback and teacher emphasis according to quadrant



Herrmann Brain Dominance Instrument® profile: Carl Gauss



Question 7: Learner appreciation



Question 2: Learner perceptions on thinking patterns and processes encouraged

As with the other teacher participants, Carl Gauss takes pride in his preferences, and acknowledges that his preferences need to be balanced with his lesser preferred quadrants:

I would see my ability blue and green as making sure I do my job and yellow and red as modes to assist me when necessary, not primary modes. And so, looking at my job, I am happy with what I use all the time and what I use to assist me when I need a bit more.

Despite taking pride in his preferences, Carl Gauss showed great interest in learning about a Whole Brain® approach to Mathematics teaching throughout the process of the Whole Brain® innovation. During the Diversity Game, he chose the word "curious" as one of his key descriptors, despite his D-quadrant (with which the word "curious" is normally associated with) testing as his least preferred quadrant.

I am curious because I don't just want an answer to a problem, I would like to know how it works, what makes it tick.

This curiosity, similar to that which Ada Lovelace expressed, sparked a reflective approach with Carl Gauss. Where Carl Gauss has been quiet and reserved in the past, he has moved beyond his preferences in order to facilitate a more holistic Whole Brain® approach.

When I am planning lessons, I can purposefully incorporate humour, colour and pictures. I am also aware of how personally I relate to learners. I have moved away from only being "cold and calculating". There has to be room for play and discovery.

For Carl Gauss, a Whole Brain® approach to facilitating learning of Mathematics might appear very different to the manner in which Euclid approaches Whole Brain® learning of Mathematics. Each individual seems to have their preferences as their baseline teaching from where they employ enhancing strategies from their lesser preferred quadrants. Although the emphasis might be slightly different, the reflective nature to the learning approach is the same: creating a Whole Brain® learning environment.

In Carl Gauss's learner feedback, as with the collective feedback from the teacher participant group, many learners indicated that they prefer to have clear examples and step-by-step procedures to help them learn and that they are not comfortable when they have to explore questions that look different to what they have seen before. This poses a problem, since it means that learners are not progressing from procedural to conceptual knowledge and ultimately to a metacognitive understanding.

The teacher participant group all acknowledge that there are many factors contributing to learners not progressing to conceptual and metacognitive understanding, which includes the ability of the group, time constraints as well as the volume of work that needs to be covered. Carl Gauss likes to give investigations to his learners as assessment tasks that challenge them to answer questions through exploration and trial and error in order to address this problem. He also expresses the following powerful, yet simple idea:

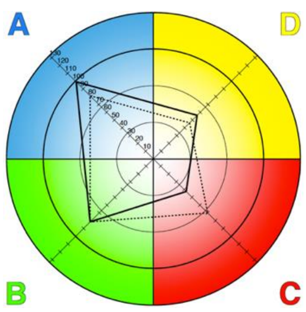
> *To encourage learners' curiosity, we need to show and demonstrate curiosity ourselves and show them that it is ok to play in Maths, to try things and also to fail sometimes. When learners experience the euphoria of success when solving a problem that we didn't initially have any idea about.*

Carl Gauss emphasises two ideas. Firstly, that the teacher's approach to Mathematics, will impact on their learners' approach to Mathematics. Secondly, for learners to experience Mathematics and not merely do Mathematics, teachers need to create opportunities for heuristics, as advocated by Schoenfeld (1988) and discussed in Chapter 2.

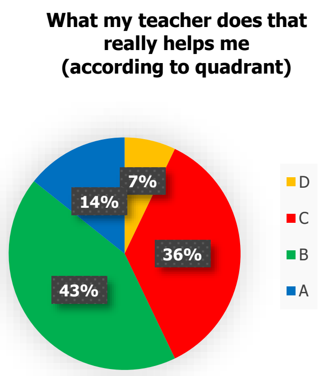
5.3.7 Blaise Pascal – the truly whole-brained person is situational

Blaise Pascal, like Euclid, has adopted certain learnt behaviours necessary for improved practice. Where Euclid adopted B-quadrant strategies, Blaise Pascal adopted C-quadrant strategies that came through both in the Diversity Game as well as his learner appreciation feedback. This is contrary to Blaise Pascal's left brain dominant HBDI® profile which correlates with learners' perception of his emphasis when it comes to teaching Mathematics.

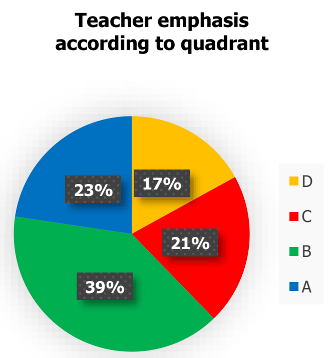
Figure 5.9: Blaise Pascal's HBDI® profile in comparison with learner feedback and teacher emphasis according to quadrant



Herrmann Brain Dominance Instrument® profile: Blaise Pascal



Question 7: Learner appreciation



Question 2: Learner perceptions on thinking patterns and processes encouraged

Blaise Pascal chose the C-quadrant descriptors "passionate" and "harmonising" during the Diversity Game, instead of the A- and B-quadrant descriptors he chose when completing the HBDI® questionnaire in private. When inquiring about this, Blaise Pascal explained it as "learnt behaviour" that is most likely due to his managerial position, and resultant experience in this position.

It seemed as if the HBDI® Think Adventure group activity prompted Blaise Pascal to adopt the role of "passionate harmoniser" within the teacher participant group contrary to his left-brain dominance and key descriptors of dominant, detailed, critical, rational, mathematical, logical and analytical indicated by a "x" as seen in his HBDI® profile extract in Figure 5.10.

FIGURE 5.10: BLAISE PASCAL'S HBDI® DESCRIPTORS

factual		conservative		emotional		imaginative	x
quantitative		controlled		musical		artistic	
critical	x	sequential		spiritual		intuitive	
rational	x	detailed	x	symbolic		holistic	
mathematical	x	dominant	*	intuitive		synthesiser	
logical	x	speaker		talker		simultaneous	
analytical	x	reader		reader		spatial	

Blaise Pascal's adjective pair score shows a shift towards the C-quadrant, but his C-quadrant score is still below his A- and B-quadrant adjective pair scores. The shift towards the C-quadrant could therefore be indicative of why Blaise Pascal chose C-quadrant descriptors, although it is more than likely the group dynamic that caused Blaise Pascal to adopt C-quadrant descriptors that he felt was necessary during the activity.

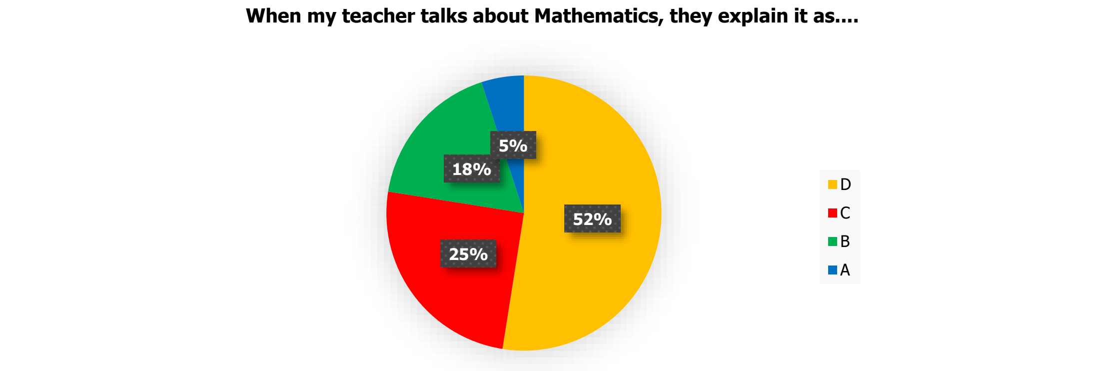
Blaise Pascal is an extrovert who has chosen the key descriptor of "dominant" in his HBDI® questionnaire (indicated with a * above). This key descriptor has more than likely contributed towards his pursuit of a managerial position. As with Sophie Germain explaining that "emotional" can be both positive and negative, "dominant" should be viewed in the same manner. The word can have both a meaning of superiority as well as being influential and being influential is what many a teacher and leader strives to be.

Herrmann (1996) advocates that, especially those in a managerial position, should have a Whole Brain® approach to leadership. What Blaise Pascal refers to as "learnt behaviour", Herrmann calls "being situational" (Herrmann, 1996, p. 156). Herrmann explains this as having "the advantage of a dominant preference that provides you with a leading response to everyday situations, but that you are not limited by that dominance (Herrmann, 1996, p. 38). According to Herrmann, a "truly whole-brained person" (Herrmann, 1996, p. 39) is someone that is confident in their strengths, willing to explore those areas in which they are not dominant and deploy their non-dominant thinking preferences situationally. "Knowing your preferences and your mental options positions you to supplement your existing competencies with needed situational competences" (Herrmann, 1996, p. 39). This once again reaffirms the need for reflective practice or in the words of Aristotle (n.d.) who states that "knowing yourself is the beginning of all wisdom."

Blaise Pascal's knowledge about himself as well as the demands of his position, most likely prompted him to complement his A- and B-quadrant preferences with his lesser dominant C-quadrant preferences, to make his leadership style influential rather than superior. This leadership approach was evident during the HBDI® Think Adventure, despite the activity not requiring Blaise Pascal to assume his leadership position. Herrmann (1996, p. 39) explains that individuals working towards becoming CEO's of a company tend to apply "situational competencies" in order to align themselves with existing "management culture". This can also be applied to school management cultures. It is not necessarily a conscious decision, but, as Herrmann (1996, p. 39) explains it: "they intuitively sensed that 'when in Rome, you behave as a Roman'".

In the learner feedback as indicated in Figure 5.11, more than 50% of Blaise Pascal's learners, perceive Blaise Pascal to explain Mathematics as "a process of discovery and making connections". This despite the fact that Blaise Pascal himself chose "procedural problem-solving" as the key feature of Mathematics in the pre-innovation questionnaire, which correlates with his left-brain dominance.

FIGURE 5.11: LEARNER QUESTIONNAIRE RESULTS FOR QUESTION 2



Interesting to note is that during the course of this innovation, Blaise Pascal himself was busy with post-graduate research which had a strong focus on conceptual understanding. Blaise Pascal explains this focus as follows:

> *Teachers often focus on developing the pupil's procedural knowledge only. How we do sums dictates the learning process. However, giving my classes information on why we do the sums, gives them greater insight into conceptual knowledge required for effective learning. Why do we need to do equations? We do it because we apply it in graphs, probability, geometry etc in higher grades. Learners have a breakdown in method if they only have procedural knowledge. We need to spend more time on why we do Mathematics. Where does it fit in? Give pupils the bigger picture of Mathematics.*

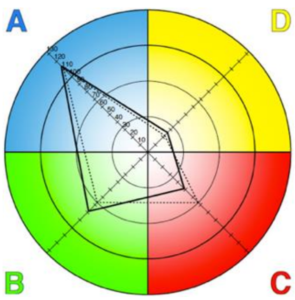
Both Blaise Pascal's personal managerial development as well as his personal academic development seem to transpire into his daily classroom practice. This is similar to the data received from Ada Lovelace's learners. Although Ada Lovelace's least preferred quadrant is her D-quadrant, her post-graduate focus towards integrated learning has brought a D-quadrant focus to her teaching. This notion that a teacher's professional development can both intentionally and unintentionally impact on their practice brings to the fore the importance of quality professional development.

5.3.8 Leonhard Euler – working towards conceptual understanding or metacognition?

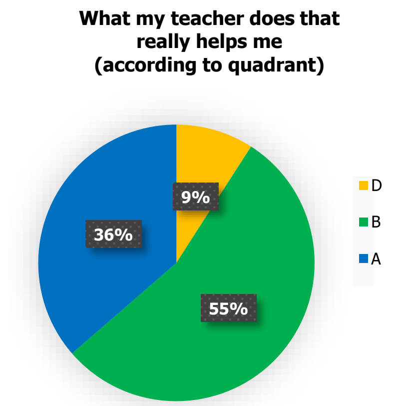
Leonhard Euler has a remarkable mind. Not only does he hold post-graduate qualifications in advanced Mathematics, but he has also received national accolades for his general knowledge. His ability to do mental calculations faster than his learners can import data into their calculators has earned him deep respect and legendary status in the school.

It was not surprising than Leonhard Euler tested with a high A-quadrant score in the HBDI® questionnaire and with a double dominant left-brain dominance. These preferences are also appreciated by his learners as can be seen in Figure 5.12. Despite these distinct preferences, Leonhard Euler's perception on the nature of Mathematics is fairly Whole Brain® as he perceives it to rely on subject matter expertise (A-quadrant), requiring active participation during the learning experience (C-quadrant) and requiring a conceptual (bigger picture) understanding (D-quadrant.) This is also aligned to the thinking patterns and processes his learners perceive him to emphasise in the classroom.

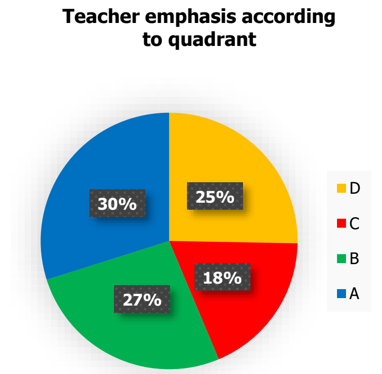
FIGURE 5.12: LEONHARD EULER'S HBDI® PROFILE IN COMPARISON WITH LEARNER FEEDBACK AND TEACHER EMPHASIS ACCORDING TO QUADRANT



Herrmann Brain Dominance Instrument® profile: Pascal



Question 7: Learner appreciation

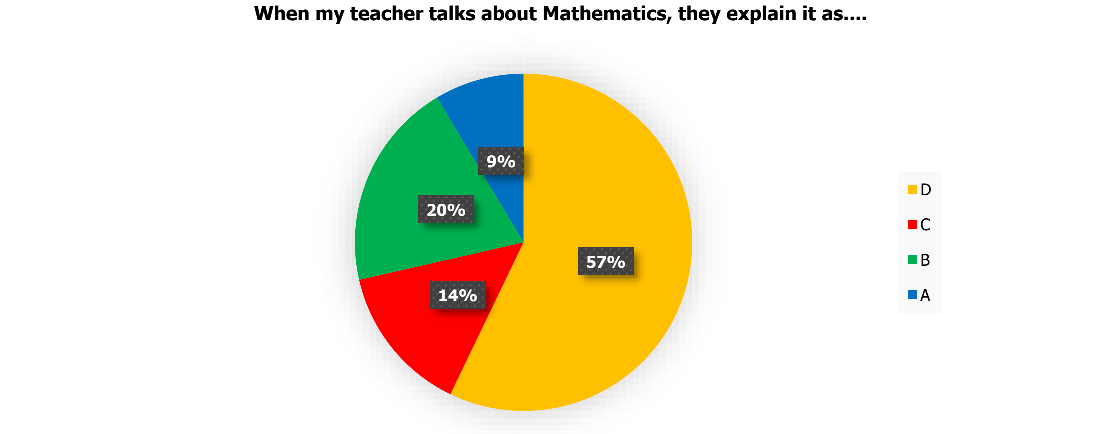


Question 2: Learner perceptions on thinking patterns and processes encouraged

Leonhard Euler's philosophy for teaching Mathematics is also somewhat contrary to his thinking preferences when he says, "Mathematics must always have learners thinking and discovering concepts. Mathematics is to the mind what poetry is to the heart". This philosophy certainly is more right-brained when looking at words such as 'discovery' (associated with the D-quadrant) as well as the association of Mathematics to 'poetry' (associated with the C-quadrant).

This appreciation for Mathematics as a Whole Brain® approach, prior to the innovation, is also evident in the pre-innovation questionnaire data from Ada Lovelace, Hypatia and Carl Gauss. This view of Mathematics definitely aided the process of this innovation since it provided a foundation which could be reinforced and built upon, both through theory and reflective practice.

FIGURE 5.13: LEARNER QUESTIONNAIRE RESULTS FOR QUESTION 2



In the learner feedback as indicated in Figure 5.13, 57% of learners indicated that they perceive Leonhard Euler to explain Mathematics as a process of discovery and making connections. This is noteworthy since this is a D-quadrant view of Mathematics, and a perceived strong focus of his teaching contrary to his A- and B-quadrant thinking preferences. There are two possible interconnected explanations to this: firstly, making connections aids to the process of conceptualisation, as advocated by Caine and Caine (1991), and conceptualisation is, according to Krathwohl (2002), one of the uppermost levels of understanding. Secondly, Leonhard Euler's exceptional mathematical ability combined with his exceptional general knowledge, can most definitely aid the ability of making connections between concepts and also the application of these concepts in Mathematics. Although making connections is therefore not Leonhard Euler's preferred mode of thinking, the level at which he analyses (A-quadrant) and memorises facts (also A-quadrant), could transpire, almost accidently, into making connections (D-quadrant).

Many teachers have come across Bloom or Krathwohl's taxonomy (Bloom, 1956; Krathwohl, 2002) either in their teacher training or within professional development courses and the aim is almost always to help learners to progress from factual and procedural knowledge to a conceptual understanding. Assessments are often set according to this taxonomy, but, as many teachers and researchers, such as Caine and Caine (1991) Bruner (2009), Dienes and Perner (1999) and Boaler (2008) have noted, the difficulty lies in helping learners progress to conceptual understanding.

Herrmann (1996, p. 167) speaks of a "misalignment" when a company's vision, mission and values are not in line with daily operations, employee- and customer perceptions. If we consider the teacher to be the CEO of his or her classroom and the learners as the employees, we could potentially also have a misalignment when it comes to the classroom's vision, mission and values in comparison to learner satisfaction. As with the learner feedback from the other teacher participants, Leonhard Euler's learners also prepare for assessments using predominantly B-quadrant skills of studying examples and working through step-by-step procedures to solve problems. This indicates a procedural approach to Mathematics whereas learners perceive Leonhard Euler to have a conceptual approach to Mathematics. As Hypatia pointed out, the procedural approach is an important process in reaching a conceptual understanding and there should be a balance between structure and conceptualisation.

The teacher, as the CEO of the classroom, has a responsibility not to create a tug-of-war between the comfort learners find in procedural fluency and the teacher's goal of learners having to achieve a conceptual understanding. By thinking of conceptual understanding as the highest level of understanding and a teacher's vision or mission, there is an overemphasis on the D-quadrant, when in fact the emphasis should be on a Whole Brain® metacognitive understanding. Just as the CEO of a company should work toward Whole Brain® leadership and creating a Whole Brain® environment where employees all feel that their contribution is valued, so the Mathematics teacher should do the same in the context of the Mathematics classroom. Developing a metacognitive understanding of Mathematics means that one should have factual knowledge (A-quadrant), procedural knowledge (B-quadrant) and conceptual knowledge (D-quadrant), all within an environment that is collaborative and motivational (C-quadrant.)

Although conceptual understanding is therefore not the ultimate goal, it does not mean that the goal post is shifted even *higher*. Instead we can view both procedural and conceptual knowledge as vital aspects of a *broader* Whole Brain® metacognitive understanding of Mathematics.

5.4 COLLECTIVE REFLECTIVE THOUGHTS

A few of the general trends were already mentioned through the course of this chapter but are highlighted here along with other general trends.

5.4.1 THE DIVERSITY GAME IS NOT A PROFILE INDICATOR

What became apparent through the data analysis is that although the Diversity Game is an effective way of introducing and explaining the Whole Brain® model, it should not be used as a profiling tool. For five of the eight participants, the Diversity Game results were not congruent with their profile scores. This can be seen in the Table 5.1.

As discussed earlier, the HBDI® Think Adventure, was a group activity that could potentially cause participants to use situational preferences that they deem necessary to the group dynamic, as in the case of Blaise Pascal.

Since the HBDI® Think Adventure was preceded by the pre-innovation questionnaire as well as the HBDI® questionnaire, it also brought about a sense of curiosity and expectancy (associated with the D-quadrant) as to what was to come. Three of the participants, Sophie Germain, Ada Lovelace and Carl Gauss, chose D-quadrant descriptors contrary to their HBDI® profile, namely imaginative, adventurous and curious respectively. This is the potential danger of the Diversity Game in that *expectations* should not be construed as *thinking preferences*. The Diversity Game, especially when conducted in the context of a Think Adventure, is vastly different to when an individual completes the extensive HBDI® questionnaire within a quiet environment on their own. Any "adventure" brings along with it a range of positive and or negative expectations that is different to how an individual functions at home or in a work environment. This does not negate the use of the Diversity Game, as it remains a valuable tool in opening up reflective discussions on differences and similarities. Rather, the potential for a skewed result should be recognised and, as with the HBDI® profile score, should not be used to confine individuals to a specific quadrant.

TABLE 5.1: PROFILE AND ADJECTIVE PAIR SCORES IN COMPARISON TO DIVERSITY GAME DESCRIPTORS

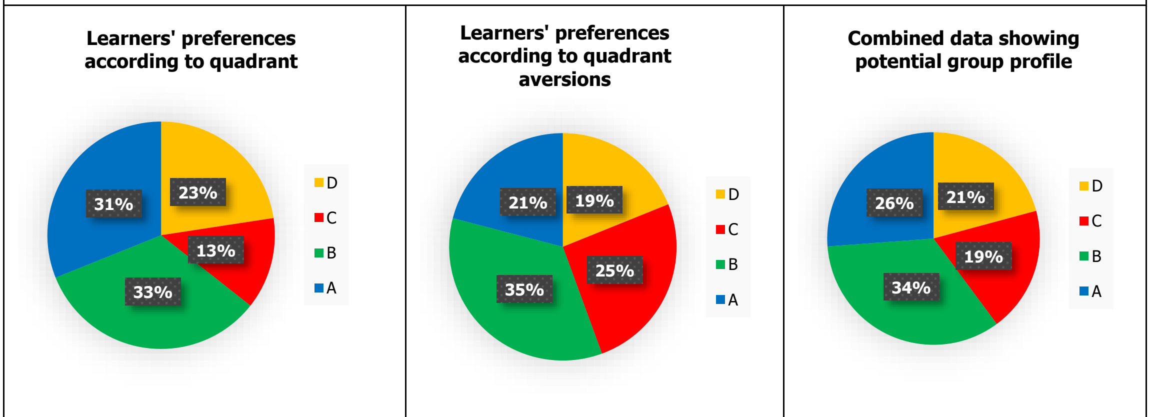
		A-quadrant	B-quadrant	C-quadrant	D-quadrant
Profile	**Sophie Germain**	59	75 (dominance)	113* (dominance)	59
Adjective Pair		3	5	10*	6
Diversity Game				passionate emotional	imaginative
Profile	**Maria Agnesi**	69	119* (dominance)	66	39
Adjective Pair		6	10*	5	3
Diversity Game			organised administrative practical		
Profile	**Ada Lovelace**	104* (dominance)	77 (dominance)	77 (dominance)	48
Adjective Pair		8	6	8	2
Diversity Game		problem-solver critical			adventurous
Profile	**Hypatia**	101* (dominance)	83 (dominance)	47	56
Adjective Pair		7	9	5	3
Diversity Game		logical rational	detailed		
Profile	**Leonhard Euler**	114* (dominance)	78 (dominance)	48	26
Adjective Pair		10*	6	6	2
Diversity Game		mathematical analytical factual			
Profile	**Carl Gauss**	110* (dominance)	110* (dominance)	41	32
Adjective Pair		10*	9	3	2
Diversity Game		mathematical	disciplined		curious
Profile	**Blaise Pascal**	99 (dominance)	81 (dominance)	42	56
Adjective Pair		7	7	6	4
Diversity Game			persistent	passionate harmonizing	
Profile	**Euclid**	68 (dominance)	54	78 (dominance)	98 (dominance)
Adjective Pair		5	3	8	8
Diversity Game				harmonizing responsive	curious

The * is indicative of strong preferences

5.4.2 A classroom "comprises a composite whole brain"

Herrmann (1996, p. 150) states that "(w)hen a large enough group of learners is considered as a whole, it inevitably comprises a composite whole brain". Although the learners were not formally tested with the Herrmann Brain Dominance Instrument®, certain questions in the learner questionnaire were asked to gain some insight into what motivates learners to learn and what makes it difficult for them to learn as derived from Herrmann's Whole Brain® model. Although asking what makes learning difficult is opposing to what motivates learning, both questions allow some insight into learners' thinking preferences. These results show a fairly balanced spread amongst the four quadrants, especially when combining the results of the two questions. The learner preferences indicate both an A- and B-quadrant emphasis, whereas the learner preference according to aversions, indicate a B-quadrant emphasis. When combining the two data sets, a preference for the B-quadrant is also prevalent. Learner preferences results, learner preferences according to aversions results as well as the combined preferences and preferences according to aversions results can be seen Figure 5.14.

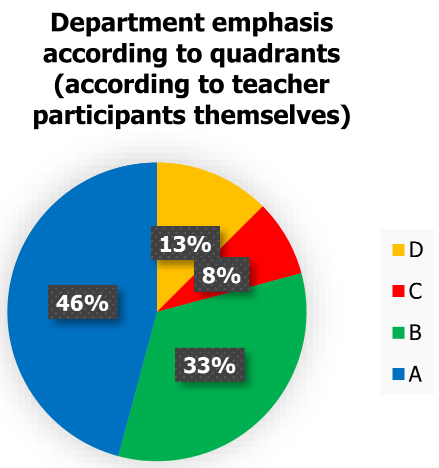
Figure 5.14: Learner preferences, learner aversions and combined data showing learner group profile

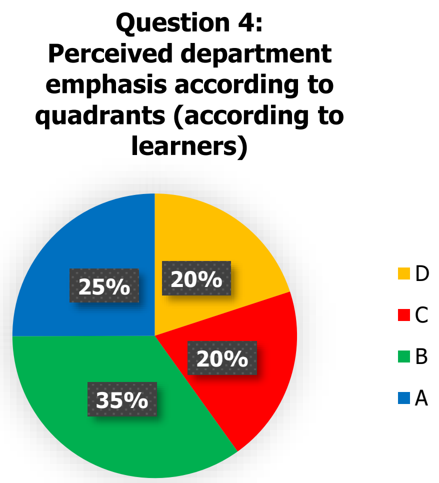


Left brain: 64% Right brain: 36% Cerebral: 54% Limbic: 46%	Left brain: 56% Right brain: 44% Cerebral: 40% Limbic: 60%	Left brain: 60% Right brain: 40% Cerebral: 47% Limbic: 53%

The learner preferences also seem to correlate with the way learners perceive their teachers to emphasise skills and processes in the Mathematics classroom. The learners' perceptions of skills and processes emphasised are more evenly spread amongst the four quadrants than what the teachers themselves deem to view their emphasis in the classroom to be. Teacher themselves perceive their emphasis to be predominantly left-brain. This is indicated in Figure 5.15.

FIGURE 5.15: DEPARTMENT EMPHASIS ACCORDING TO QUADRANT IN COMPARISON TO PERCEIVED DEPARTMENT EMPHASIS ACCORDING TO QUADRANT.





Left brain: 79% Right brain: 21% Cerebral: 59% Limbic: 41%	Left brain: 60% Right brain: 40% Cerebral: 45% Limbic: 55%

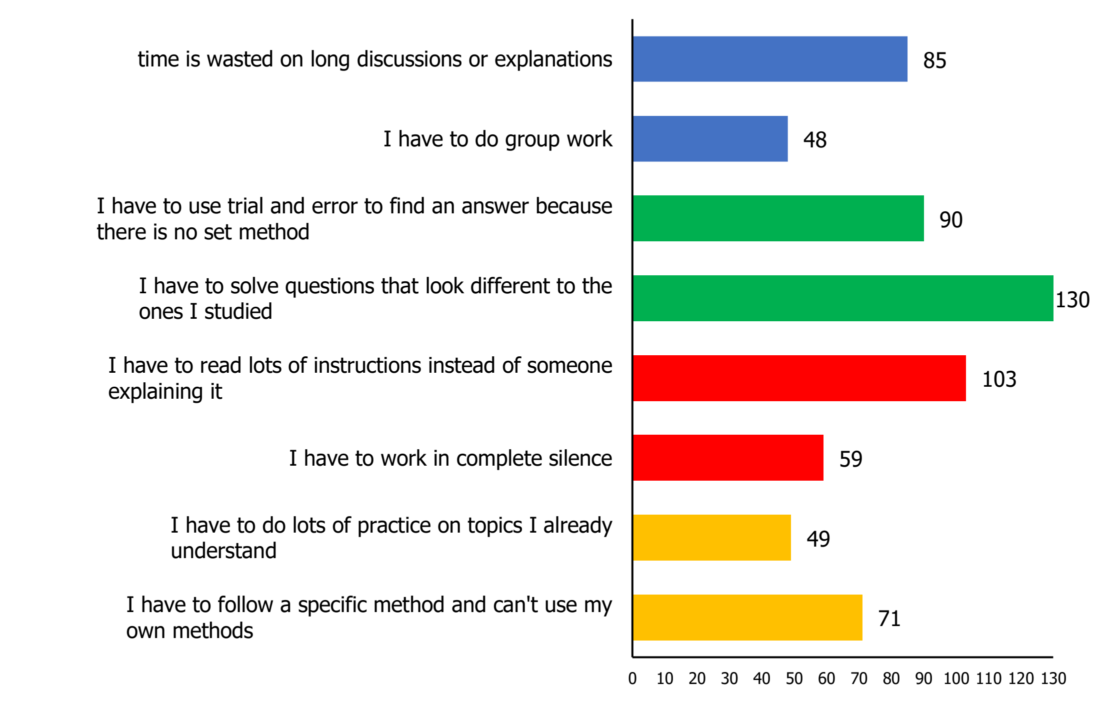
Leonhard Euler could be used as an example to explain why teachers could possibly have a different view of the skills and processes they emphasise in comparison to how learners perceive their emphasis to be. Leonhard Euler has a left-brain (A- and B-quadrant) dominant profile and, according to him, he also encourages left-brain skills and processes. Yet: his view on the nature of Mathematics is fairly Whole Brain® and his teaching philosophy is right-brain (C- and D-quadrant) dominant. It is therefore possible that the teacher participants unknowingly emphasise skills and processes in a more Whole Brain® manner than they realise.

5.4.3 There is security in drill-and-practice

The B-quadrant is also referred to by Herrmann (1990, p. 122) as the "safekeeping" quadrant. Herrmann describes safekeeping as "the protecting and safeguarding aspects of individuals and companies who guard against risks, change or variance in procedure, or anything that may upset a set plan which would generate set results" (Herrmann, 1990, p. 122).

Considering that practice, step-by-step procedures and worked examples are all processes and procedures associated with the B-quadrant, we can assume that there is a certain amount of safety in drill-and-practice in Mathematics. Gladwell's well-known "ten thousand hours of practice" rule in order to "achieve true mastery" supports the claim that with enough practice one is sure to achieve positive results (Gladwell, 2008, p. 40). Yet, the aspect of Mathematics that most learners deem to find the most challenging is when they have to solve questions that look different from the ones they studied. This is indicated in Figure 5.16.

Figure 5.16: Learner preferences according to aversions per quadrant



When learners practise the same type of questions over and over again in order to improve their skills, they are not necessarily developing application or synthesis skills. Learners only preparing for their final examination in this way, could be compared to a sports team practising their skills every day, but only playing one match per season. Although the sports team's fitness and skills could be impeccable, it requires a different skill set to apply their skills in a match, where the demands are much higher. Knowing for example how to pass the ball to another player and knowing which player to pass it to without being versed in the strategies of the opposing team, is challenging. Not only would a player need to become accustomed to making decisions under pressure and making assumptions about the strategies of his or her opponent, but the player also needs to be aware that his or her chosen course of action might not necessarily be successful. In using this analogy of comparing practice and application of skills in Mathematics to that of practice and application of skills in team sports, I hope to show the need for more than mere practice when facilitating and assessing learning in Mathematics. Engaging in Mathematics, like being on the sports field, requires careful analysis (A-quadrant), risk-taking (D-quadrant) and a robustness (C-quadrant) to deal with different possible outcomes.

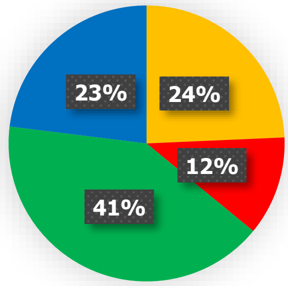
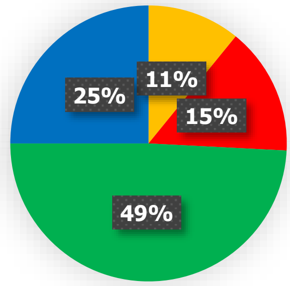
Teachers are managers of their learners' mathematical development. Although there is certainly a need for drill-and-practice, keeping learners safe from challenging questions is denying them the opportunity to grow. Teachers, as team managers, need to find opportunities to develop mathematical 'match' skills of analysis, risk-taking and robustness. As Carl Gauss suggests, failure is an important part of the process of discovery in Mathematics. By devoting selected class time to teaching trial-and-error approaches or giving projects and assignments that challenge learners beyond textbook drill-and-practice activities, teachers can create opportunities for growth.

Figure 5.17 shows what learners deem teachers' key focus to be in Mathematics in comparison to how they prefer to prepare for Mathematics assessments. Although there is alignment between the B-quadrant focus learners perceive their teachers to have and the B-quadrant focus learners have when preparing for Mathematics assessments, the safety provided by practicing the same skill set could potentially debilitate the development of a metacognitive understanding of Mathematics.

These preferences could also be due to a "cultural script", which Stigler and Hiebert (2009, p. 87) explain as a universal view of teaching that people have unknowingly adopted over centuries, regardless of whether they are a teacher or not. This implies that learners have a preconceived view of what they deem to be important to their teacher and how they should respond in turn. As Stigler and Hiebert (2009, p. 87) state: "Playing school is a favorite preschool game", which implies that even preschool children have an understanding of the "cultural script". If learners therefore perceive their teachers to focus on B-quadrant thinking skills, they will follow the "script" in responding in a B-quadrant manner.

One could also argue that by forcing learners to choose merely one method of preparation in the questionnaire, we are not gaining information about learners who use more than one method, but it does give insight into learners' *most preferred* method of preparation. This insight in turn can help teachers to reflect on their actions and possible ways of improvement (Lieberman, 1995).

FIGURE 5.17: WHAT LEARNERS DEEM TEACHERS' FOCUS TO BE IN MATHEMATICS IN COMPARISON TO HOW LEARNERS PREFER TO PREPARE FOR MATHEMATICS ASSESSMENTS

Question 1: **When my teacher talks about Mathematics, they explain it as....**	**Question 3:** **How learners prepare for Mathematics tests**
	
A: logical and analytical process (23%) B: step-by-step instructions to follow (41%) C: an opportunity to share ideas and methods (12%) D: a process of discovery and making connections (24%)	A: go through the homework questions I got wrong to understand where I went wrong and what to watch out for (I like to focus on the details) (25%) B: study examples and step-by-step procedures to solve problems (practice!) (49%) C: study with a friend (or friends) so that we can explain to each other (15%) D: find connections (differences and similarities) between the different topics so that I can distinguish between them (I like to see the bigger picture) (11%)
Left brain: 64% Right brain: 36% Cerebral: 47% Limbic: 53%	Left brain: 74% Right brain: 26% Cerebral: 36% Limbic: 64%

5.4.4 RELFECTIVE PRACTICE NEEDS A ROADMAP

Çimer and Paliç (2012, p. 58) found that unless teachers have "clarity and guidance" on how to critically reflect on their practice, their reflections would be largely superficial and operational rather than critical and interpretative. Yet, in this study, teacher participants were able to give insightful reflections during the innovation. Although the level of education of teacher participants along with a favourable working environment, where professional development is valued, most definitely plays an important role in teacher participants' reflections, I do believe that the following two factors made a significant impact on teacher participants' reflective practice.

1. The HBDI® profiles gave participants insight into their personal identity: who am I and who am I in comparison to those within my community of

practice? The HDBI® therefore sparked personal reflection and also opened reflective conversations with members within the community of practice: Which members have similar profiles? Which members are different? How do my thinking preferences influence my behaviour and attitude towards others? The HBDI® is therefore a roadmap guiding the reflective practice without which the reflective practice would be directionless.

2. Hattie and Yates (2014) have stressed the importance of teachers being aware of their effect on their learners, but obtaining quality feedback from learners that gives insight into how learners perceive their teachers to teach, could be challenging. Herrmann's Whole Brain® theory provides us with a basis from which to design feedback forms on specific approaches according to the four quadrants. When compared with a teacher's HBDI® profile, it can provide valuable feedback on learner perceptions in comparison to a teacher's personal identity. Teachers will therefore not only have insight into who they are, but also into how they are perceived by their learners. This can guide a teacher's reflection even more specifically towards their practice.

5.4.5 Collective and individual professional development

Although teacher participants were eager to discuss their HBDI® profiles with others, their reflective practice on their HBDI® profiles, especially in conjunction with the learner feedback data, was a more personal and private process. According to Solheim, Roland, and Ertesvåg (2018, p. 472) teachers engaging in professional development within communities of practice "understood the usefulness and profitability of collective learning; nevertheless, the individual approach prevailed" where "teachers spent more time reflecting on and thinking about their own practices". From discussions with the teacher participants, it was evident that although the community of practice provided a communal structure and goal for the teaching team, the professional development was a personal experience according to each individual's personal "goals and orientations" (Schoenfeld, 2011, p. 459).

This does not imply that professional development should be left up to teachers in their personal capacity: rather, the collective professional development enables the individual professional development, which in turn strengthens the collective. In their research findings Solheim, Roland, and Ertesvåg (2018, p. 470) found that "when teachers work and learn together, the possibilities for learning appear better."

5.5 Conclusion

In Chapter 2 the advantages of a reflective practice were discussed. This research innovation relies on Hattie and Yates's notion that "those teachers who are students of their own effects are the teachers who are the most influential in raising students' achievement" (Hattie & Yates, 2014, p. 24).

This chapter summarised the main ideas arising from my own reflection as well as those from the teacher participants through the course of the innovation. Reflections reported in this chapter also resulted from collective reflections by the teacher participant group when engaging in conversation about the research innovation and when sharing their personal reflections with each other. Although the innovation itself is limited, the expectation is that the reflective practice will continue beyond the limitation of this innovation. Furthermore, there is an expectancy that the reflective practice discussed in this chapter will lead to a positive influence on learner achievement.

CHAPTER 6

"We are approaching a new age of synthesis. Knowledge cannot be merely a degree or a skill... it demands a broader vision, capabilities in critical thinking and logical deduction without which we cannot have constructive progress."

Ka-shing (2003)

6.1 INTRODUCTION

This research innovation consisted of two interconnected areas of research.

Firstly, Herrmann's Whole Brain® theory was used as the perspective from which to analyse a range of theories applicable to facilitating learning opportunities in Mathematics. The reflection on theories, as discussed in Chapter 2, also supports a Whole Brain® approach to inform practice in the facilitation and assessment of learning in Mathematics. This validates the use of Herrmann's Whole Brain® Theory as the foundation for an integrated theory of practice, in the form of a comprehensive Mathematics-specific Whole Brain® model.

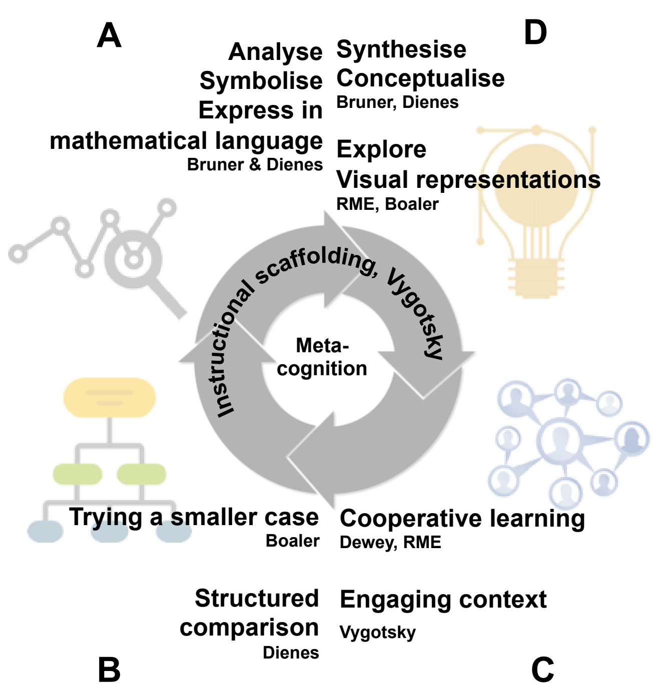
Secondly, using the Herrmann Brain Dominance Instrument® to initiate scholarly reflection within the community of practice produced insights into the teacher participants current practice, their reflection on their practice and the potential for future practice informed by their scholarly reflection. The reflection on how teacher participants facilitate the learning and assessing of Mathematics in terms of Herrmann's Whole Brain® theory was discussed in Chapter 5. This has indicated how the Herrmann Brain Dominance Instrument® can be used to initiate learning and teaching, and collaboration within a community of practice in a Mathematics Department.

Although the teaching practice was informed by Herrmann's Whole Brain® theory, the reflection on the teaching practice brings about new insights which in turn aid a better understanding of Herrmann's Whole Brain® theory. This chapter weaves together the last few strands of the collective reflective practice by looking at the development of the conceptual framework throughout the course of the research innovation. The new conceptual framework is also proposed as an integrated theory of practice for future research.

6.2 AN INTEGRATED THEORY OF PRACTICE

In Chapter 1, a pre-innovation comprehensive Mathematics-specific Whole Brain® model was proposed as both the conceptual framework of the study as well as a model for informing practice. The model, indicated in Figure 6.1, situates existing theories within Herrmann's Whole Brain® model. Although the model contains theory important to informing practice, it lacks guidance into *how* the theories could be applied or what *type of knowledge* could be ascribed to each quadrant:

FIGURE 6.1: PRE-INNOVATION COMPREHENSIVE MATHEMATICS-SPECIFIC WHOLE BRAIN® MODEL



The reflective nature of this research innovation entails a constant reflective process on *how* the theory informs the practice. The theories of both Bloom (1956) and Krathwohl (2002) became a more integral part of the understanding of different knowledge types within Herrmann's Whole Brain® model throughout the course of the research innovation. This together with the approaches set out in the Singapore Mathematics framework (Lim-Teo, 2002), helps to create a better understanding of the concepts, skills, attitudes and processes needed to develop a Whole Brain® metacognitive understanding of Mathematics. The post-innovation comprehensive Mathematics-specific Whole Brain® model aims to integrate and summarise the research of Dewey (Mulcahy, 2007), Bruner (Bruner, 2009; Singer & Moscovici, 2008), Dienes (1963; 1971), Boaler (2008), Bloom (1956), Krathwohl's (2002) as well as the Singapore Mathematics framework (Lim-Teo, 2002).

The post-innovation model, indicated in Figure 6.2, also aims to be a user-friendly representation of concepts, skills, attitudes and processes needed. The interconnectivity between quadrants is shown with a range of arrows pointing towards the centre of the figure indicating that all four quadrants are important in developing a Whole Brain® metacognitive understanding of Mathematics. Whole Brain® metacognitive understanding was therefore indicated in the middle of the post-innovation model in order to indicate that this type of understanding requires concepts, skills, attitudes and processes from all four quadrants. The arrows surrounding Whole Brain® metacognitive understanding, indicate the reflective nature of Whole Brain® metacognition. Herrmann (1990, p. 10) states "that composite whole brain learning groups represent the ultimate teaching configuration" and that there is therefore a need for continuous interaction between quadrants.

FIGURE 6.2: POST-INNOVATION COMPREHENSIVE MATHEMATICS-SPECIFIC WHOLE BRAIN® MODEL

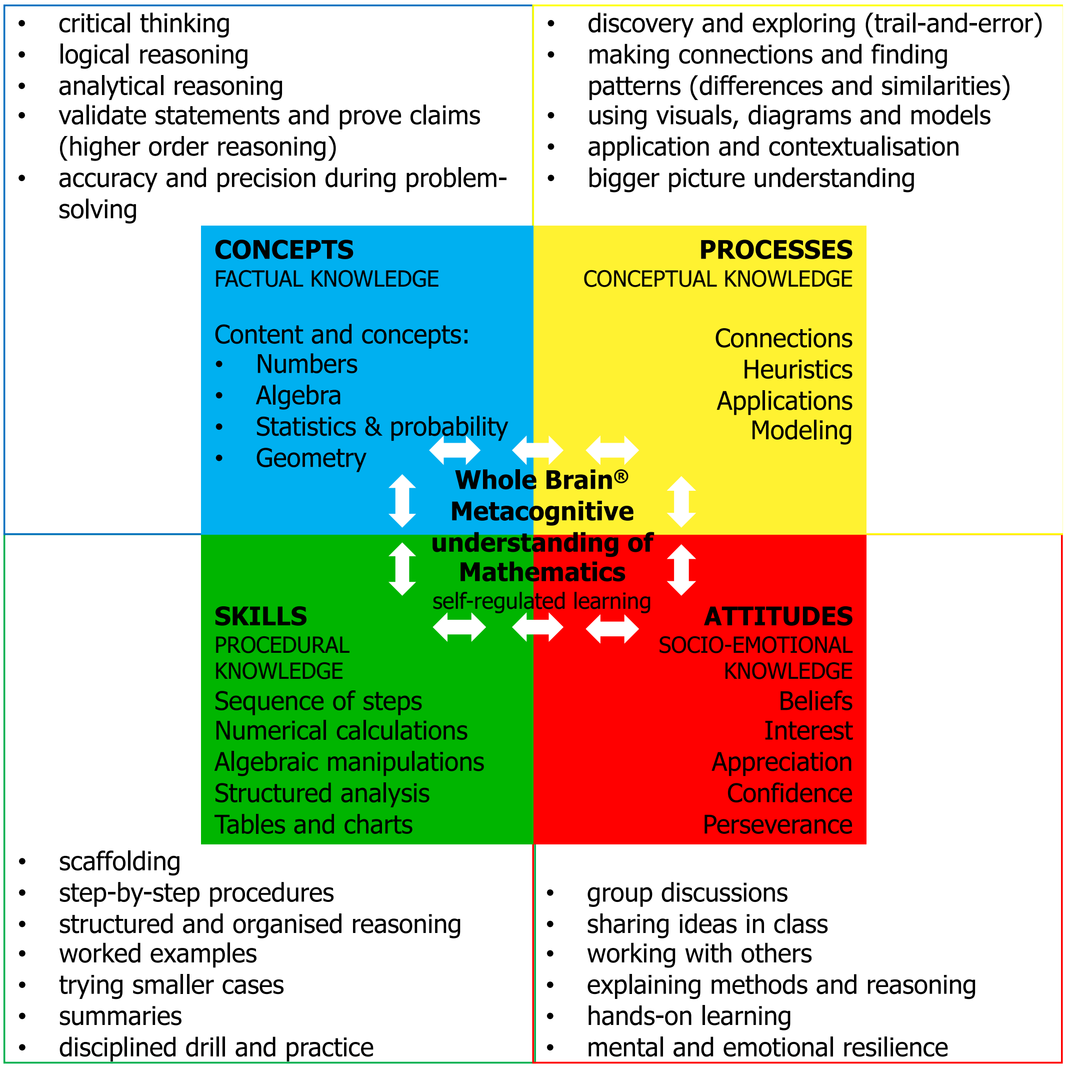


Figure 6.1 lacked reference to Krathwohl's knowledge domains (Krathwohl, 2002) as well as the pentagonal framework for the 1990 Singapore Mathematics curriculum (Lim-Teo, 2002, p. 5). Figure 6.2 incorporates both these theories along with those theories already included in Figure 6.1.

This model in itself is the product of my own Whole Brain® scholarly reflection. Through a process of structured and organised reasoning, I was able to analyse and disseminate the existing literature on pragmatic- and cognitive psychology theories along with theories specific to facilitating learning and assessing in Mathematics. This analysis enabled me to make connections between existing theories and to categorise different approaches according to quadrants within

Herrmann's Whole Brain® model. Through the course of the research innovation, the collective reflective practice that was initiated through discussions with the teacher participants, aided my metacognitive reflection on the theory. This post-innovation model is therefore a product of my synthesis of the theory and my meta-reflection on how the theory informed the practice. One can therefore postulate that the post-innovation comprehensive Mathematics-specific Whole Brain® model is a product of my living theory.

6.3 KEY INSIGHTS FROM THE REFLECTIVE PRACTICE

Through the reflective practice of the teacher participants, certain key insights came to the fore. These concepts serve two purposes. Firstly, it shows the scholarship of learning and teaching in which the teacher participants engaged in and secondly, it adds to the body of knowledge on how the Herrmann Brain Dominance Instrument® impacts on the professional development of a Mathematics teaching team.

- The data concludes that the teacher participant group has a fairly balanced Herrmann Brain Dominance Instrument® team profile. Although this brings a balanced view to the teaching team, it also has the potential to bring about conflict. Members testing with higher C- and D-quadrant profiles expressed that at times they felt stifled by members of the teaching team that had a more conservative A- and B-quadrant focus to teaching.

- It is possible that teachers teach according to their adjective pair score (or stress profile) on the Herrmann Brain Dominance Instrument®, due to a variety of pressures in the working environment, which includes time constraints in having to cover large quantities of curriculum content.

- Learners are not necessarily cognisant of all the thinking modes involved when teachers plan a learning and assessing opportunity. Therefore, learner feedback on a teacher's approach could be skewed towards thinking modes learners perceive to be present in the delivery (and not the planning) of the lesson.

- Thinking modes are not an indicator of personality and therefore not a predictor of how a teacher would teach Mathematics.

- An awareness of Herrmann's Whole Brain® model when reflecting on one's practice has the potential to initiate exploration into lesser preferred quadrants. When a teacher engages in reflective practice, rather than an autopilot approach, it requires greater effort, but has the potential to engage more learners in the process.

- There is no typical profile for a teacher teaching Mathematics. The thinking modes required for encouraging, supporting and inspiring learners require a large quantity of right-brain thinking modes, whilst the quantitative nature of Mathematics itself, requires a large quantity of left-brain thinking modes. Teaching Mathematics therefore requires a Whole Brain® approach. The Herrmann Brain Dominance Instrument® can help facilitate an awareness of how to develop lesser preferred quadrants, regardless of a teacher's profile preferences, in order to adopt a more Whole Brain® approach. This approach is necessary both for supporting different learner preferences and for supporting a Whole Brain® metacognitive understanding of Mathematics.

- Post-graduate studies along with leadership development have the potential for teachers to use their non-dominant thinking modes situationally, as seen in the case of Ada Lovelace and Blaise Pascal. This means that they can complement their preferred thinking modes with their non-dominant thinking modes as the situation requires.

- Any Herrmann Brain Dominance Instrument® descriptor can have both a positive and a negative component to it. This means that a person's strength can also be their weakness. For example: 'emotional' often has a negative connotation, yet emotional support and involvement has quite the opposite connotation. Engaging in reflective practice, as initiated through the Herrmann Brain Dominance Instrument®, can therefore lead to metacognitive self-awareness. This is supported by McTaggart (1994, p. 317) when he states that action research is "a form of self-reflective enquiry undertaken by participants in social situations in order to improve the rationality, justice, coherence and satisfactoriness of (a) their own social practices".

- Self-awareness is important in maintaining a Whole Brain® approach to facilitating learning in Mathematics. An over-focus on any particular thinking mode can create a weakening of thinking modes in other quadrants.

- The movement in education towards integrated project-based learning supports Herrmann's "contextual approach" (Herrmann, 1995, p.6), as well as Dewey's "constructivist approach" (1992, p. 123) to learning. The cooperative teacher working groups needed in setting up an integrated project-based learning opportunity for learners, also lends itself to observing lessons given by teachers outside one's own field of expertise. Exposure to different approaches to teaching also aids a teacher's metacognitive reflective practice.

- Hattie and Yates (2014) stated that feedback is one of the most important aspects in learner achievement. Yet, the data shows that only one of the teacher participants intentionally places emphasis on assessment and homework analysis in order to provide feedback to learners. When learners engage with their own thinking, when analysing their answers to given questions, they have the potential to develop a metacognitive understanding of a topic. Therefore, because of the importance of feedback, this study suggests that analysis should be more purposefully encouraged in a Mathematics classroom.

- Although learners were not formally tested to determine their preferred thinking modes, the learner questionnaire did allow for some indication of learner preferences. These preferences confirmed Herrmann's (1996) findings that a sizable group of learners will test with a balanced Whole Brain® profile.

- Despite a fairly balanced Whole Brain® profile, the data shows that almost 50% of learners prepared for Mathematics assessments using a B-quadrant approach of studying examples and step-by-step procedures as well as drill-and-practice. Over 40% of learners also deemed this approach to be their teacher's key focus in teaching Mathematics. Although the alignment between learners' and teachers' focus shows a shared goal and purpose, the emphasis on B-quadrant thinking, teaching and learning modes, detracts from A-, C- and D-thinking modes. It therefore impedes a Whole Brain® approach to facilitating learning and assessment in Mathematics.

  The B-quadrant, also known as the "safekeeping" quadrant (Herrmann, 1990, p. 122), is an approach to studying Mathematics that consists of clear guidelines, instructions and steps learners can follow in order to obtain predicted outcomes. Unfortunately, the nature of Mathematics is such that problems often also require a synthesised understanding of concepts. Learners who continuously practice skills by memorising steps to solve familiar problems will be unable to confidently explore and analyse unfamiliar problems. Although drill-and-practice is important in helping learners become competent in basic mathematical knowledge and skills, building a mere foundation for a conceptual and metacognitive understanding of Mathematics is not enough.

This study suggests that teachers need to challenge themselves on their current practice. This entails continuous reflection on their practice, the goals they have set for themselves and their learners, as well as the beliefs they have of themselves and their learners. If teachers want their learners to grow beyond a procedural understanding of Mathematics, they will need to provide learners with challenges and opportunities to synthesise their current knowledge structures into a conceptual understanding. Teachers are responsible to help learners become comfortable with a feeling of discomfort when faced with unfamiliar problems in Mathematics. Bruner (Conway, 2007) suggests that this exploration can be done through active inquiry where learners should be encouraged to revert back to basic skills, which Boaler elaborates on by proposing that learners should be "drawing the problem, making a chart with the numbers (and) trying a smaller case" (Boaler, 2008, pp. 185-186). Both Boaler (2008) and Dienes (1971) also advocate that learners should have a firm understanding of basic skills before applying these skills to explore beyond their current understanding and that exploration without a firm understanding of basic skills would lead to limited exploration results. The suggested post-innovation comprehensive Mathematics-specific Whole Brain® Model is therefore suggested to aid teachers in their reflective practice.

- The HBDI® proved to be an effective roadmap in guiding teachers towards reflective practice. Insight into their own thinking preferences allowed for metacognitive reflection. This reflection was further guided specifically towards their teacher practice with the feedback from the learner questionnaires on how learners perceive their teachers to think about their practice. The HBDI® therefore provides teachers with the necessary “clarity and guidance” needed for successful reflective practice (Çimer and Paliç, 2012, p. 58).

- Although each teacher participant’s professional development process was largely individual and personal in nature, it would not have been possible without a collective drive. Linking with the notion of the Randewijk Rope Model, the individual reflective strands need a core theory around which the collective reflective process is strengthened. Herrmann’s Whole Brain® theory along with the HBDI® road map for reflective practice, therefore strengthened the personal professional development of each teacher participant.

6.4 EXTRAPOLATION AND SUGGESTION FOR FUTURE RESEARCH

6.4.1 BUILDING ON THE THEORY

The post-innovation comprehensive Mathematics-specific Whole Brain® model is a product of my personal living theory which could potentially add to the existing body of knowledge of approaches to facilitating learning in Mathematics. The synthesis of knowledge drawn from various educational theories provides a user-friendly summary to both pre- and in-service Mathematics teachers on how to guide learners towards a Whole Brain® metacognitive understanding of Mathematics.

A comprehensive Whole Brain® model specific to other learning areas could also be developed; for example, a comprehensive Physical Science Whole Brain® model. Synthesising subject specific educational theories in terms of Herrmann’s Whole Brain® model serves both as a valuable experience for the individual engaging in the synthesis as well as for those intending to use the product of the synthesis.

6.4.2 Building on the practice

As mentioned in Chapter 1, this research innovation was conducted within an independent school rich in resources, with a strong focus on, and regular time allocation to, professional development. Three of the eight teacher participants were either busy with or held post-graduate qualifications and two of the eight participants were on the senior management team of the school. These factors contributed towards the teacher participant receptiveness to introducing the Herrmann Brain Dominance Instrument® as a professional development tool, as well as their willingness to engage in reflective practice throughout the course of the research innovation. In a school environment where professional development is not as highly valued, teachers might be less receptive.

The challenges of violence and other poor socio-economic circumstances that many South African schools face on a daily basis, could also impact on both teacher and learner feedback should this research innovation be conducted within a South African government school. Yet, the Herrmann Brain Dominance Instrument® has been reported as successful for planning, job design, supervising, teamwork, management training, corporate culture, communication, creativity and career aspiration purposes (Herrmann, 1995) and in this study as a means of initiating reflective practice. Although violence and poor socio-economic circumstances could therefore impact on the results of the study, it would not necessarily detract from the reflective practice. It has the potential to create a sensitivity towards differences and aid communication within a challenging environment. I would therefore like to suggest replicating this research innovation within a more challenging school environment.

Similar to the theory, the research innovation practice can also be extrapolated to focus on a different learning area and the teaching teams within this learning area.

6.5 CONCLUSION

The research innovation was born from a need to know how to teach Mathematics to learners not responding to traditional approaches to teaching Mathematics. Like Herrmann, my own duality (in having an A- and D-quadrant dominance), affected my personal approach both to learning and in later years to teaching Mathematics. Research into facilitating learning in Mathematics has provided teachers with an enormous body of knowledge, but initiating a process of transforming theory into practice seemed to be lacking.

Herrmann's Brain Dominance Instrument® provided me with knowledge about myself. This self-awareness prompted my personal reflective process, both on the theory about my practice and my practice itself. By using Herrmann's Whole Brain® theory as the central fibre to my research innovation, I was able to weave together the theory of my practice, my own reflective practice and collective reflective practice of the teacher participants engaging in the innovation with me.

This chapter showed the comprehensive Mathematics-specific Whole Brain® model as a result of my reflection on the theory applied to my practice, but the model is also proposed as a theory in itself. The comprehensive Mathematics-specific Whole Brain® model is therefore proposed as a guiding framework in the design of learning and assessment opportunities that aims to cater for different learning preferences. In the design and creation of Whole Brain® learning and assessment opportunities using the model, lies the potential for learners to develop a Whole Brain® appreciation and understanding of Mathematics, which in turn could contribute towards a deeper mathematical understanding.

This chapter also summarised the key findings of the teacher participants engaging in the collective reflective practice. Insight into one's own thinking, as initiated through the Herrmann Brain Dominance Instrument®, has shown to be vitally important in developing a meta-cognitive reflective practice. This process was further enhanced by learner feedback which provided teacher participants with a better understanding of how learners perceive their approach to their practice. The Randewijk Rope Model was also designed to indicate how the individual professional development of each teacher participant centres around and is strengthened by the core theory driving the collective practice.

Furthermore, the HBDI® as a professional development tool, has the potential to make teachers not only more aware of their own thinking, but also aware of the differences in their learners' thinking. Schoenfeld (2011, p. 466) states that in order for Mathematics teachers too become highly proficient, professional development needs to focus on ways "to capitalize on the teachers' awareness of the value of examining student thinking." This study proposes that the HBDI® as professional development tool in conjunction with the theory of the comprehensive Mathematics-specific Whole Brain® model, could assist teachers in developing their proficiency.

The expectation is that these findings will not only become the living theory of the teacher participants of this study, but also those engaging in similar research innovations following our journey.

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APPENDIX A

Letter of invitation to teacher participants:

UNIVERSITEIT VAN PRETORIA
UNIVERSITY OF PRETORIA
YUNIBESITHI YA PRETORIA

Faculty of Education

Date:……….. …..

Dear Colleague and potential participant

You are invited to participate in my academic research study.

The purpose of the study is to see whether Herrmann's Whole Brain® theory could benefit the reflective practice of Mathematics teachers in their planning for Whole Brain® learning opportunities and assessments in the senior phase.

Please note the following:

- This is a strictly confidential study and all names will be changed so that you cannot be identified in person based on the answers you give.
- The study aims to fit into our normal professional development program, but I may need to schedule two short individual interviews with you between January and June 2016.
- It might be necessary to photograph or film your classroom activities. You are welcome to volunteer for such a session during a lesson that is convenient to you. It aims to be an opportunity for you to share your initiatives with the rest of the department.
- Your participation in this study is important to me. You may, however, choose not to participate and you may also stop participating at any time without any negative consequences.
- The results of the study will be used for academic purposes only and may be published in an academic journal. I will provide you with a summary of my findings on request.

Please do not hesitate to contact me, or any of my supervisors should you have any queries or concerns.

I trust that this journey we are about to embark on, is as much a process of personal growth and professional development for you, as I hope it to be for me.

Elmarie Meyer (researcher)
emeyer@parklands.co.za

Prof. Pieter du Toit (supervisor)
Pieter.duToit@up.ac.za

Prof. Ansie Harding (co-supervisor)
ansie.harding@up.ac.za

Please sign the form to indicate that:

☑ You have read and understand the information provided above.
☑ You give your consent to participate in the study on a voluntary basis.

________________________ __________________

Participant's signature **Date**

Room 2-63, Aldoel Building
University of Pretoria, Private Bag X20
Hatfield 0028, South Africa
Tel +27 (0)12 420 2817
Fax +27 (0)12 420 5637
Email pieter.dutoit@up.ac.za
www.up.ac.za

Faculty of Education
Fakulteit Opvoedkunde
Lefapha la Thuto

APPENDIX B

Letter of consent to learner participants:

UNIVERSITEIT VAN PRETORIA
UNIVERSITY OF PRETORIA
YUNIBESITHI YA PRETORIA

Faculty of Education

Date:……….. …..

Dear Parklands College Parents and Guardians

I am currently working towards my PhD in Curriculum and Instructional Design and Development at the University of Pretoria. My research looks at the professional development of teachers and how we, as a Mathematics teaching team, can plan learning opportunities that are more sensitive to the different learning and thinking preferences of each learner.

Although my research focuses on the teachers' professional development process, your child will be subjected to the potential altered practice of his or her Mathematics teacher. During the professional development process it might be necessary to photograph the learning process and analyse the methods used by learners in their problem-solving process. Anonymity of all participants will be guaranteed, but should you have any concerns, please do not hesitate to indicate these concerns in the space provided below.

The data gathering process is scheduled to take place in the second semester of 2016. The results of the study will be used for academic purposes only and may be published in an academic journal. I will gladly provide you with a summary of my findings on your request.

Please do not hesitate to contact me, or my supervisors, should you have any questions or comments regarding the study.

I trust that you are as excited as I am about finding ways of making Mathematics more accessible to all our learners.

Yours in education

Elmarie Meyer (researcher)
emeyer@parklands.co.za

Prof. Pieter du Toit (supervisor)
Pieter.duToit@up.ac.za

Prof. Ansie Harding (co-supervisor)
ansie.harding@up.ac.za

Please sign the form to indicate that:

☑ You have read and understand the information provided above.

I hereby $\boxed{\text{give / do not give}}$ permission for my child ______________________________ to be a part of this study.

I have the following concerns:
____

____ ____

Parent name: __________________ Signature: ______________

Date: ________________________

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Faculty of Education
Fakulteit Opvoedkunde
Lefapha la Thuto

APPENDIX C

Herrmann Brain Dominance Instrument® practitioner certification:

HBDI™ Certified
Herrmann Brain Dominance Instrument™

This is to certify that

Walther Meyer

is an

HBDI™ Certified Practitioner

and a member of the

Herrmann International Network

Ann-Louise De Boer
CEO, Herrmann International Africa

Date of Certification: May 5th; 2014

APPENDIX D

Declaration of responsibility by the Herrmann Brain Dominance Instrument® practitioner:

VENTURE FORTH international

Herrmann International

ThinkAdventure® HBDI® intervention

team development ▯ leadership skills ▯ interpersonal relationships

To Whom It May Concern:

I, Walther Martin Meyer, ID 7607215041083, hereby declare that the information from the Herrmann Brain Dominance Instrument® that I will be administering for this project, will only be used for the purpose of the study. All personal information of participants to the study conducted by Mrs Elmarie Meyer, will be kept strictly confidential and will be safely stored on my office premises.

Walther Meyer
+27 82 770 7876 (Managing director)

Cnr Natal & Calcutta Streets (Calcutta Str entrance)
Paarden Eiland
Cape Town, South Africa

P O Box 182 West Coast Village 7433
Cape Town, South Africa

Telephone: +27 21 510 3731
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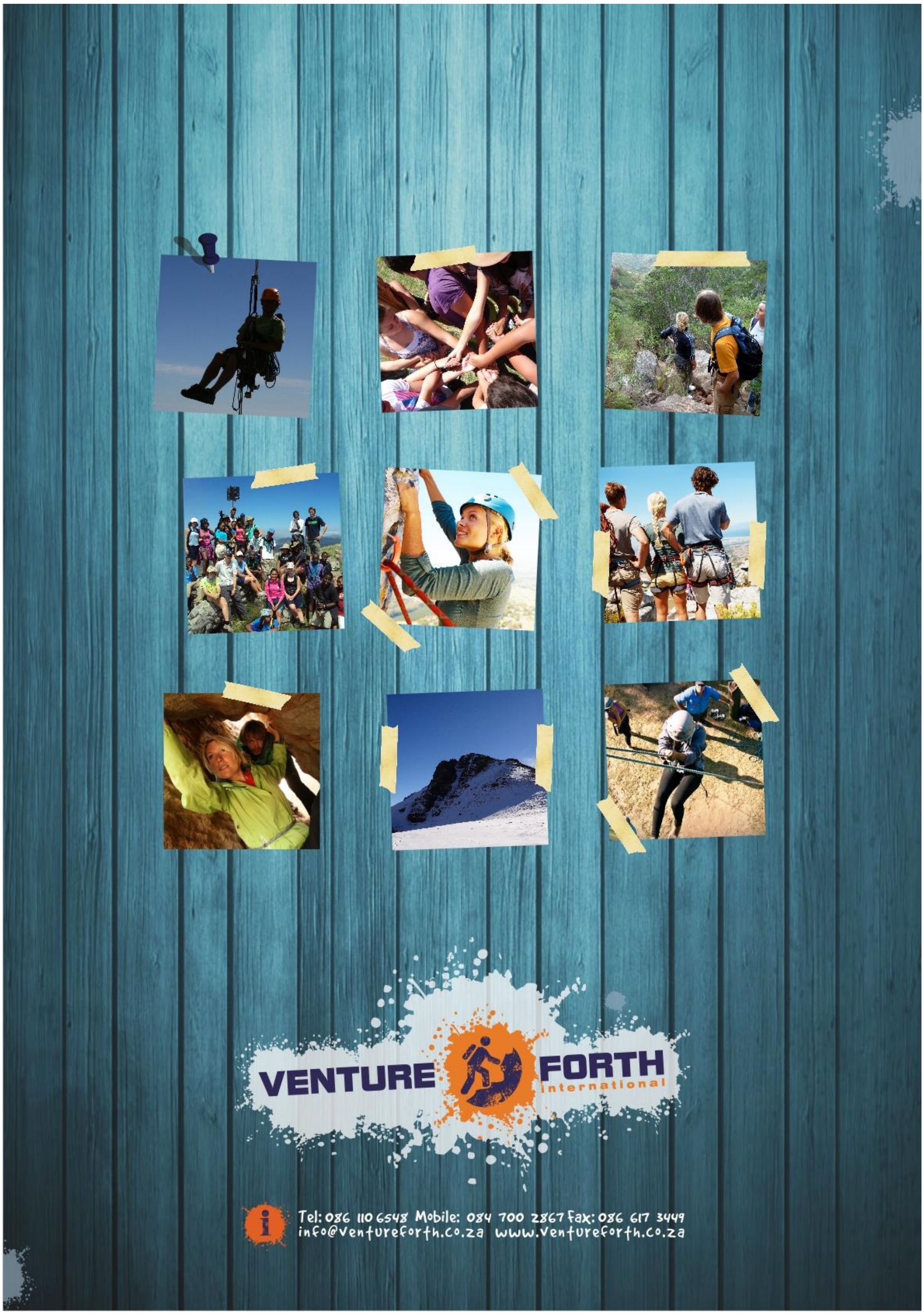
Office mobile: +27 84 700 2867 (24Hr - Emergency)

APPENDIX E

HBDI® profile analysis and ThinkAdventure Proposal



Proposal for:
…… Mathematics Department

Professional development: HBDI® profile analysis and Think Adventure

Proposal date: 23 August 2016
Prepared by: Walther Meyer

Proposed Date: Tuesday 30 August
8 Staff members + Elmarie Meyer (researcher)
Available options: Option 1: Onsite professional development
Option 2: Offsite professional development
Option 3: Longer adventure programmes
Proposed time: 08:00 to 15:00 (if possible)

ThinkAdventure and HBDI®

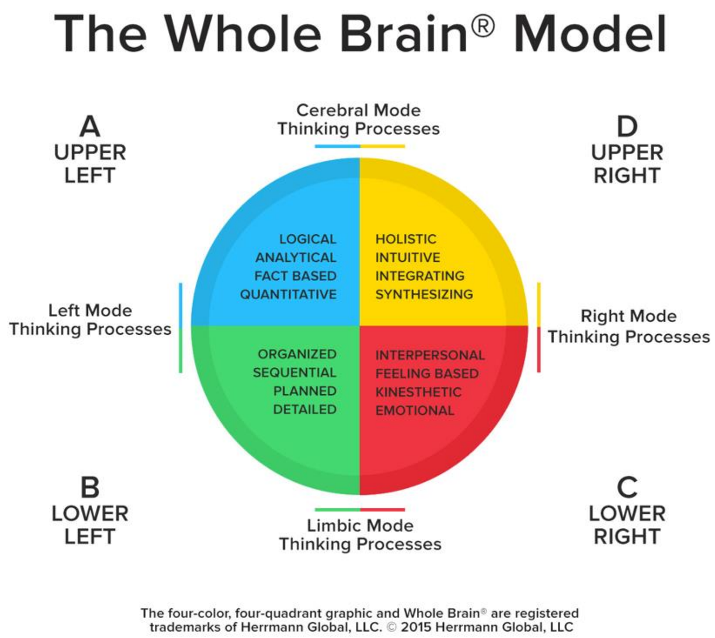
We have all been exposed to various activities and programs marketed as "team building" but very few of these programs have actual measurable results and any real learning outcomes for the participants. As an alternative Venture Forth has developed a customisable, outcomes-based team building program utilising the Hermann Brain Dominance Instrument® (HBDI®) as its foundation.

The program can be designed to suit your requirements ranging from a one day session at your own choice of venue to a multi-day experience at one of our selected venues. You can choose how adventurous and active you want the program to be ranging from the physically easy to extreme mental and physical challenges.
However, regardless of the program you choose the outcomes remain the same. You will learn:

- What the HBDI® is and how to apply it at work and in your life
- How to understand thinking preferences
- How you prefer to think
- How your colleagues, team mates and family members prefer to think
- How to interpret the thinking preferences of others
- How people with different thinking preferences interact
- How to plan according to the thinking preferences of your team
- The value and use of the HBDI® in conflict resolution
- How to apply whole brain thinking in your organisation
- How to apply the HDBI® in team coaching, workshops and education

What are thinking preferences?

Thinking preferences have an impact on virtually everything we do, including communication, decision making, problem solving and managing styles. Understanding your thinking style preferences will give you a new perspective of yourself and people you deal with every day.



What is the HBDI®?

The Herrmann Brain Dominance Instrument® (HBDI®) is the world's leading thinking styles assessment tool. It identifies your preferred approach to emotional, analytical, structural and strategic thinking. It also provides individuals with a significantly increased level of personal understanding.

The HBDI® was developed by Ned Herrmann in the 1970s. Twenty years of research and innovation stand behind the validity of the HBDI®.

Over two-million people worldwide have undergone HBDI® analysis. It is used by over one third of all Fortune 100 companies.

The HBDI® is not just another assessment tool—it picks up where other assessment tools leave off.

Where most assessments end with a single report, the HBDI® offers a valuable range of applications. Identifying your thinking style preferences is only the first step.

How does it work?

The HBDI® identifies and measures the strength of preference for each of the four distinct thinking styles. These correspond to the upper cerebral hemispheres and the lower limbic system of the brain.

The two left side structures combine to represent what is popularly called left brain thinking. The two right side structures combine to represent right brain thinking. The two cerebral structures combine to represent cerebral thinking and the two limbic structures combine to represent limbic thinking.

The HBDI®, through its series of 120 questions, is capable of measuring the degree of preference between each of the four individual thinking structures (quadrants) and each of the four paired structures (modes). This results in a four quadrant profile, which displays the degree of preference for each of the four quadrants of your HBDI® Profile.

Scoring results are free of value judgment and cultural bias. Because it is a self-analysis, most people immediately recognise their results as accurate.

The HBDI® Profile Package includes a full colour profile, accompanying interpretation booklets that explain the profile and scores in detail, and a discussion of the implications that your results have for business, or in this case, teaching and personal life.

The professional development programme will be designed in such a way that activities make apparent the results of the HBDI® profile – both within a personal context and within the communication and collaboration between members of the department. By identifying the thinking preferences and aversions of each member of the department, and of the department as a whole, the professional development aims to start a reflective process aiming to aid communication and collaboration between members of the Mathematics Department.

For this group, we would like to propose an onsite experiences, possibly (and with permission) utilising the pavilion and the pool area. This could allow both for adventure and teambuilding activities, as well opportunities for discussions on implementation of the HBDI® in a classroom and department setting.

Specific ThinkAdventure and HBDI® applications

Individual, group awareness and cohesion

The HBDI® aims to aid individuals in their awareness of their thinking preferences which could increase personal and task orientated effectiveness. Understanding how others think can have a big impact on productivity, collaboration and team effectiveness.

Communication and Conflict resolution

Reflect on your communication with others and how the thinking preferences of your colleagues or learners could influence how they receive your communication. This could potentially lead to reducing conflicts stemming from contrasting communication styles.

Teaching and learning

A better understand of one's thinking, and therefore teaching preferences, could lead to a better understanding of the diverse learning preferences of learners within a classroom. This sensitivity could potentially lead to a more diversified and inclusive approach to teaching.

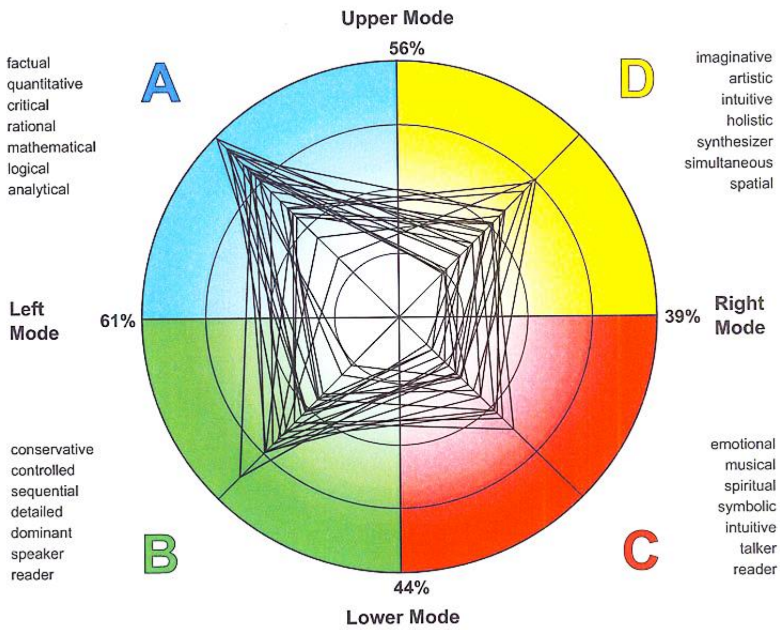
Creativity and innovation

A Whole Brain® approach to innovation can ensure that creative ideas are implemented after thorough analysis and with the necessary sensitivity to ensure buy-in from stakeholders. Once different members of a working group understand their value as part of the innovation process, it could ain in fast-tracking the innovation process.

HBDI® Team Profile

The HBDI® Team Profile is an in-depth analysis of an entire team and the individual members' HBDI® Profiles. The HBDI® Team Profile is a powerful catalyst for discussion and provides an in-depth understanding of the team and its effectiveness.

The HBDI® Team Profile includes a number of reports that are filled with a variety of data sets to explore, compare, and contrast. While each person's thinking preferences are represented, they are all displayed confidentially. The data shows both the preferences of the working group, as well as the areas that are less represented. The quantitative representation often assists in removing the emotion from sensitive areas and gives an opportunity to reflect on the group dynamics objectively.



Quotation

Included:

- Venture Forth facilitator and HBDI® certified practitioner
- Meals will be supplied for:
    - Lunch
    - Tea, coffee and snacks
- HDBI Profiles and facilitation cost be covered by researcher

APPENDIX F

Herrmann Brain Dominance Instrument®:

Ned Herrmann International Africa Holdings (Pty) Ltd * PO Box 12801* Queenswood 0121 * Pretoria * Tel +27 (0)12 807 2194 Fax +27(0)12 807 2194

HBDI

Herrmann Brain Dominance Instrument Thinking Styles Assessment

This 120-question survey form results in a profile of your preferred thinking styles. By understanding your thinking style preferences you can achieve greater appreciation how you learn, make decisions, solve problems, and communicate, and why you do these things—and others—the way you do. The survey measures preferences rather than skills. It is not a test; there are no wrong answers. You will gain the greatest understanding by answering the questions frankly and sincerely

Herrmann International

International telephone number: +27(0)12 807 2194 E-mail: fred@hbdi.co.za
www.hbdi.co.za

INSTRUCTIONS

A profile of your mental preferences will be determined by your responses to the following 120 questions. Answer each question by writing in the appropriate words or numbers, or marking the boxes provided. This is not a test, and there are no right or wrong answers. You are only indicating your preferences. Please respond to questions as authentically as possible, keeping in mind your total self, at work and at home. When you have completed the survey form, confirm that you have answered every question. Then complete the name and address information on the back of the form, and send or fax pages 2 to 5 to Herrmann International Africa at the address on the cover.

Refer to the glossary of terms for clarification of the terms used. Save the glossary page for reference when you receive your profile results.

GLOSSARY OF TERMS

- **Analytic:** Breaking up things or ideas into parts and examining them to see how they fit together.
- **Artistic:** Taking enjoyment from or skillful in painting, drawing, music, or sculpture. Able to coordinate color, design, and texture for pleasing effects.
- **Conceptual:** Able to conceive thoughts and ideas, to generalize abstract ideas from specific instances.
- **Controlled:** Restrained, holding back, in charge of one's emotions.
- **Conservative:** Tending towards maintaining traditional and proven views, conditions, and institutions.
- **Creative:** Having unusual ideas and innovative thoughts. Able to put things together in new and imaginative ways.
- **Critical:** Exercising or involving careful judgement or evaluation, e.g., judging the feasibility of an idea or product.
- **Detailed:** Paying attention to the small items or parts of an idea or project.
- **Dominant:** Ruling or controlling; having strong impact on others.
- **Emotional:** having feelings that are easily stirred, displaying those feelings.
- **Empathetic:** Able to understand how another person feels, and able to communicate that feeling.
- **Extrovert:** More interested in people and things outside of self than internal thoughts and feelings. Quickly and easily exposes thoughts, reactions, feelings, etc. to others.
- **Financial:** Competent in monitoring and handling of quantitative issues related to costs, budgets, and investments.
- **Holistic:** Able to perceive and understand the "big picture" without dwelling on individual elements of an idea, concepts, or situation. Can see the forest as contrasted with the trees.
- **Imaginative:** Able to form mental images of things not immediately available to the senses or never wholly perceived in reality, able to confront and deal with a problem in a new way.
- **Implementation:** Able to carry out an activity and ensure fulfillment by concrete measures and results.
- **Innovating:** Able to introduce new or novel ideas, methods, or devices.
- **Integration:** The ability to combine pieces, parts and elements of ideas, concepts and situations into a unified whole.
- **Intellectual:** Having superior reasoning powers, able to acquire and retain knowledge.
- **Interpersonal:** Easily able to develop and maintain meaningful and pleasant relationships with many different kinds of people.
- **Introvert:** Directed more towards inward reflection and understanding than towards people and things outside of self. Slow to expose reactions, feelings, and thoughts to others.
- **Intuitive:** Knowing something without thinking it out – having instant understanding without need for facts or proof.
- **Logical:** Able to reason deductively from what has gone before.
- **Mathematical:** Perceiving and understanding numbers and being able to manipulate them to a desired end.
- **Metaphorical:** Able to understand and make use of visual and verbal figures of speech to suggest a likeness or an analogy in place of literal descriptions, e.g., "heart of gold."
- **Musical:** Having an interest in or talent for music and/or dance.
- **Organized:** Able to arrange people, concepts, objects, elements, etc. into coherent relationships with each other.
- **Planning:** Formulating methods or means to achieve a desired end in advance of taking actions to implement.
- **Problem solving:** Able to find solutions to difficult problems by reasoning.
- **Quantitative:** Oriented toward numerical relationships; inclined to know or seek exact measures.
- **Rational:** Making choices on the basis of reason as opposed to emotion.
- **Reader:** One who reads often and enjoys it.
- **Rigorous thinking:** Having a thorough, detailed approach to problem- solving.
- **Sequential:** Dealing with things and ideas one after another or in order.
- **Simultaneous:** Able to process more than one type of mental input at a time, e.g. visual, verbal, and musical; able to attend to more than one activity at a time.
- **Spatial:** Able to perceive, understand and manipulate the relative positions of objects in space.
- **Spiritual:** Having to do with spirit or soul as apart from the body or material things.
- **Symbolic:** Able to use and understand objects, marks, and signs as representative of facts and ideas.
- **Synthesizer:** One who unites separate ideas, elements, or concepts into something new.
- **Technical:** Able to understand and apply engineering and scientific knowledge.
- **Teaching/ training:** Able to explain ideas and procedures in a way that people can understand and apply them.
- **Verbal:** Having good speaking skills, clear and effective with words.
- **Writer:** One who communicates clearly with the written word and enjoys it.

BIOGRAPHICAL INFORMATION

Please complete **every** question according to the directions given. Each response, including your answers to questions 1, 2, 3 and 4, provide important data. When directions are not followed or data is incomplete we are unable to process your survey, and must return it to you.

1. Name ____________________________

2. Gender M ☐ F ☐

3. Educational focus or specialist subject(s) ____________________________

4. Occupation or job title ____________________________

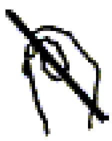
Describe your work (please be as specific as possible) ____________________________

HANDEDNESS

5. Which picture most closely resembles the way you hold a pencil? Mark box A, B, C or D.

A  ☐

B  ☐

C  ☐

D  ☐

What is the strength and direction of your handedness? Mark box A, B, C, D or E.

A	Primary left	**B**	Primary left Some right	**C**	Both hands equal	**D**	Primary right Some left	**E**	Primary right

SCHOOL SUBJECTS

Think back to your performance in the elementary and/or secondary school subjects identified below. Rank order all three subjects on the basis of how well you did: **1 = best; 2 = second best; 3 = third best.**

7____Mathematics **8____Foreign language** **9____Native language or mother tongue**

Please check that no number is duplicated**: The numbers** 1**,** 2**, and** 3 must be used once **and** only once**. Correct if necessary**

WORK ELEMENTS

Rate each of the work elements below according to your strength in that activity, using the following scale**:**

5 = work I do best; 4 = work I do well; 3 = neutral; 2 = work I do less well; 1 = work I do least well.

Enter the appropriate number next to each element. Do not use any number more than four times.

10 ____ Analytical
11 ____ Administrative
12 ____ Conceptualising
13 ____ Expressing Ideas
14 ____ Integration
15 ____ Writing
16 ____ Technical Aspects
17 ____ Implementation
18 ____ Planning
19 ____ Interpersonal Aspects
20 ____ Problem Solving
21 ____ Innovating
22 ____ Teaching/Training
23 ____ Organisation
24 ____ Creative Aspects
25 ____ Financial Aspects

Please tally: Number of: ____5's ____ 4's ____ 3's ____2's ____1's

If there are more than four **for any category, please redistribute.**

KEY DESCRIPTORS

Select eight adjectives, which best describe the way you see yourself. Enter a **2** next to each of your eight selections. Then change one **2** to a **3** for the adjective which best describes you.

26	____ Logical	**35**	____ Emotional	**43**	____ Symbolic
27	____ Creative	**36**	____ Spatial	**44**	____ Dominant
28	____ Musical	**37**	____ Critical	**45**	____ Holistic
29	____ Sequential	**38**	____ Artistic	**46**	____ Intuitive
30	____ Synthesizer	**39**	____ Spiritual	**47**	____ Quantitative
31	____ Verbal	**40**	____ Rational	**48**	____ Reader
32	____ Conservative	**41**	____ Controlled	**49**	____ Simultaneous
33	____ Analytical	**42**	____ Mathematical	**50**	____ Factual
34	____ Detailed				

Please count: seven 2's and one 3? **Correct if necessary.**

HOBBIES

Indicate a maximum of six hobbies you are actively engaged in. **Enter a 3** next to your major hobby, a **2 next** to each primary hobby, and a **1 next** to each secondary hobby. **Enter only one 3**.

51	____ Arts/Crafts	**59**	____ Gardening/Plants	**67**	____ Sewing
52	____ Boating	**60**	____ Golf	**68**	____ Spectator Sports
53	____ Camping/Hiking	**61**	____ Home Improvements	**69**	____ Swimming/Diving
54	____ Cards	**62**	____ Music Listening	**70**	____ Tennis
55	____ Collecting	**63**	____ Music Playing	**71**	____ Travel
56	____ Cooking	**64**	____ Photography	**72**	____ Woodworking
57	____ Creative Writing	**65**	____ Reading	**Other**	____________________
58	____ Fishing	**66**	____ Sailing	**Other**	____________________

Please review**: Only one** 3 **and** no more than six hobbies**. Correct if necessary.**

ENERGY LEVEL

73. Thinking about your energy level or "drive," select the one that best represents you. Mark box A, B**, or** C**.**

A ____Day person **B ____Day/night person equally** **C ____Night person**

MOTION SICKNESS

74. Have you ever experienced motion sickness (nausea, vomiting) in response to vehicular motion (while in a car, boat, plane, bus, train, amusement ride)? Check boxes A, B, C, or D to indicate the number of times.

A ____None **B ____1-2** **C ____3-10** **D ____More than 10**

75. Can you read while traveling in a car without stomach awareness, nausea, or vomiting?

A ____Yes **B ____ No**

ADJECTIVE PAIRS

For each paired item **below, check the word or phrase, which is more descriptive of you. Mark box** A **or** B **for** each **pair, even if the choice is a difficult one.** Do not omit any pairs**.**

76	____Conservative	Empathetic____	88	____Imaginative	Sequential____
77	____Analyst	Synthesizer____	89	____Original	Reliable____
78	____Quantitative	Musical____	90	____Creative	Logical____
79	____Problem-solver	Planner____	91	____Controlled	Emotional____
80	____Controlled	Creative____	92	____Musical	Detailed____
81	____Original	Emotional____	93	____Simultaneous	Empathetic____
82	____Feeling	Thinking____	94	____Communicator	Conceptualise____
83	____Interpersonal	Organiser____	95	____Technical things	People-oriented____
84	____Spiritual	Creative____	96	____Well-organised	Logical____
85	____Detailed	Holistic____	97	____Rigorous Thinking	Metaphorical Thinking ____
86	____Originate Ideas	Test and Prove Ideas____	98	____Like Things Planned	Like Things Mathematical____
87	____Warm, Friendly	Analytical____	99	____Technical	Dominant ____

Please review**: Did you mark one and only one of each pair? Correct if necessary.**

INTROVERSION / EXTROVERSION

100. Mark one box to place yourself on this scale from introvert to extrovert:

Introvert								**Extrovert**

TWENTY QUESTIONS

Respond to each statement by marking the box in the appropriate column	**Strongly agree**	**Agree**	**In between**	**Disagree**	**Strongly disagree**
101 I feel that a step-by-step method is best for solving problems.					
102 Daydreaming has provided the impetus for the solution of many of my more important problems.					
103 I like people who are most sure of their conclusions.					
104 I would rather be known as a reliable than an imaginative person.					
105 I often get my best ideas when doing nothing in particular.					
106 I rely on hunches and the feeling of "rightness" or "wrongness" when moving toward the solution to a problem					
107 I sometimes get a kick out of breaking the rules and doing things I'm not supposed to do.					
108 Much of what is most important in life cannot be expressed in words.					
109 I'm basically more competitive with others than self competitive					
110 I would enjoy spending an entire day "alone with my thoughts."					
111 I dislike things being uncertain and unpredictable.					
112 I prefer to work with others in a team effort rather than solo.					
113 It is important for me to have a place for everything and everything in its place.					
114 Unusual ideas and daring concepts interest and intrigue me.					

Please review to make sure you have answered all 120 questions.

	FORM

You must provide an address and indicate the method of payment in order to receive your HBDI results. Please print.

Date ___________________

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Division	
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APPENDIX G

How my teacher teaches Mathematics

Your Mathematics teachers would like to know what you think about their teaching. Try and be as truthful as possible in your answers. This is about YOUR perception and how YOU study, therefore there are no right or wrong answers. It is completely anonymous and will help your teacher to get a better understanding of how you perceive their teaching.

My Mathematics teacher is (or was) ____________________

1. When my teacher talks about Mathematics, they explain it as....
*(Tick the **ONE** option that you think BEST describes your teacher's view of Mathematics.)*

☐ a logical and analytical process

☐ an opportunity to share mathematical ideas and methods

☐ a process of discovery and making connections

☐ step-by-step instructions to follow

2. My teacher places a lot of emphasis on....
*(Tick the **THREE** options that you think best describes your teacher.)*

☐ critical thinking

☐ logical reasoning

☐ problem-solving

☐ trial and error

☐ looking for patterns (making connections)

☐ using drawings / diagrams to solve problems

☐ step by step procedures

☐ looking at examples

☐ structuring my work

☐ sharing ideas in class

☐ working with others

☐ having to explain my methods / thinking

3. When I prepare for a Mathematics test I like to...
*(There is no right or wrong answer here. We all study in a different way. Tick the **ONE** option that you prefer the MOST.)*

- ☐ study examples and step-by-step procedures to solve problems (practice!)
- ☐ study with a friend (or friends) so that we can explain to each other
- ☐ go through the homework questions I got wrong to understand where I went wrong and what to watch out for (I like to focus on the details)
- ☐ find connections (differences and similarities) between the different topics so that I can distinguish between them (I like to see the bigger picture)

4. I think it would help my learning if my teacher could also focus on...
*(Choose a **MAXIMUM OF THREE** options that you would like your teacher to also focus on in order to help you learn. In other words, things that they are NOT currently focusing on.)*

- ☐ critical thinking
- ☐ logical reasoning
- ☐ problem-solving
- ☐ trial and error
- ☐ looking for patterns (making connections)
- ☐ using drawings / diagrams to solve problems
- ☐ step by step procedures
- ☐ looking at examples
- ☐ structuring my work
- ☐ sharing ideas in class
- ☐ working with others
- ☐ having to explain my methods / thinking

5. It really motivates me to learn when...
*(Tick the **TWO** options that explain what motivates YOU when doing Mathematics)*

- ☐ I can explore new mathematical concepts without having to follow a specific method
- ☐ I can see how different concepts are linked and can be used to solve a problem
- ☐ I can share my ideas and work with a friend
- ☐ I can have an opportunity to build and draw mathematical shapes or play with Maths apps
- ☐ I have clear guidelines that help me organise my work
- ☐ I have examples to look at and lots of activities to practice what I have learnt
- ☐ I can use logic to find solutions
- ☐ I can break a difficult question down into smaller parts to be solved

6. I really struggle when...
*(Tick the **TWO** options that explain what makes it difficult for YOU to do Mathematics)*

- ☐ I have to follow a specific method and can't use my own methods
- ☐ I have to do lots of practice on topics I already understand
- ☐ I have to work in complete silence
- ☐ I have to read lots of instructions instead of someone explaining it
- ☐ I have to solve questions that look different to the ones I studied
- ☐ I have to use trial and error to find an answer because there is no set method
- ☐ I have to do group work
- ☐ time is wasted on long discussions or explanations

7. Write a short sentence (or sentences) on the one thing that your teacher does that really helps you to understand and learn Mathematics.

____

____

APPENDIX H

My perception on Mathematics Education

Please complete the 5 questions below. There are no right or wrong answers. It is important that you choose the option or options that are most in line with your perception on Mathematics education.

1. The way I teach Mathematics was mostly influenced by ...

   Mark only one block

   ☐ the way I was taught at school

   ☐ pedagogy / didactics courses I took at tertiary level

   ☐ professional development

   ☐ I received whilst teaching

   ☐ a mixture of the above

2. I consider Mathematics to be a(n) ....

   (Choose the ONE option that you MOST agree with.) Mark only one block.

   ☐ procedural problem-solving

   ☐ exact science

   ☐ human activity

   ☐ continuous process of discovery

3. I consider Mathematics to be a subject that …

   (Choose THREE options that MOST expresses your personal view about Mathematics education.)

   - ☐ relies on subject matter expertise
   - ☐ is about practical application
   - ☐ is an opportunity to challenge and motivate learners
   - ☐ requires active participation during the learning experience
   - ☐ is about being organized and consistent
   - ☐ allow for intuition and educated guessing
   - ☐ is a process of discovery and exploring new ideas
   - ☐ seeks to validate statements and proof claims
   - ☐ is about practicing and evaluating ideas
   - ☐ is an opportunity to collaborate and share ideas
   - ☐ requires a conceptual (bigger picture) understanding
   - ☐ places emphasis on accuracy and precision during problem-solving

4. I like to encourage …. in solving problems in Mathematics

   (Choose THREE options that MOST expresses your personal view on problem-solving in Mathematics.)

   - ☐ group discussions
   - ☐ pattern recognition
   - ☐ brainstorming
   - ☐ higher order reasoning
   - ☐ sharing ideas
   - ☐ using examples
   - ☐ creativity
   - ☐ organisation of thoughts
   - ☐ step by step procedures
   - ☐ activate participation (hands on learning)
   - ☐ critical thinking
   - ☐ logical reasoning

5. My teaching philosophy: Please include an idea or quote that has been inspirational to your teaching career as Mathematics teacher