Planning mathematical modelling tasks from neurobiological data and principles

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Abstract

*The background of the article is the discourse on the application of neuroscience principles, protocols and tools to education. In this paper, we discuss how theory from neuroscience was used to plan learning tasks in mathematical modelling environments. It prompts the question, "*How should we structure mathematical modelling lessons if we can pinpoint the functional and structural vulnerabilities, and the subsequent lack of neural integration, in an individual's brain?*" The article aims to illustrate via a case study how educators can use neurobiological data to plan mathematical modelling tasks for middle school students with disabilities who are performing at a very early level in mathematics. The original research (Scott-Wilson, 2014) was conducted in Central Australia with a classroom of students with disabilities (SWD) participating in mathematical modelling tasks. The intervention consisted of replacing their typical and more traditional instructivist-oriented mathematical lessons with mathematical modelling tasks for one month. The tasks were designed specifically for the SWD using data from their psycho-educational profile and their neurobiological data. The former was kept in their school records and the latter, showing the structural and functional vulnerabilities of the brain, was obtained through a clinical brain mapping assessment conducted by a trained professional. The primary research methodology was design-based research (DBR). DBR was used to plan, implement and evaluate the effectiveness and suitability of the modelling tasks for the SWD. The secondary research methodology was a case study analysis. This was used to record the progress, and specific barriers to learning, that emerged while working through the DBR cycles. The education philosophy of the researcher-teacher is based on the Christian curriculum-approach by Harro Van Brummelen (1988).*

The outcomes suggest that neurobiological data are useful in designing mathematical modelling tasks that will support students with multiple barriers to learning. Future research on a much larger sample is needed to support the discourse on the meaning of current neuroscience and its application and relevance to the field of teaching and learning.

Abstrak

*Die akademiese gesprek oor die toepassing van neurologiese beginsels, protokolle en werktuie wat gerig is op opvoeding, met die doel die beplanning van leergerigte take in wiskundige modelleringomgewings, vorm die agtergrond van hierdie artikel. Dit vra die vraag: "*Hoe moet ons wiskundige modelleringslesse struktureer sodat ons presies kan vasstel waar die funksionele en strukturele swakplekke en die gevolglike gebrek aan neurologiese integrasie in 'n individu se brein is?*" Die doel van die artikel is om in 'n gevallestudie te illustreer hoe opvoeders neurobiologiese data kan gebruik om wiskundige modelleringstake vir middelskool leerders met leergebreke, wat slegs in staat is om op 'n baie vroeë wiskundige vlak te funksioneer, te beplan. Die oorspronklike navorsing (Scott-Wilson, 2014) was uitgevoer in Sentraal-Australië in 'n klaskamer met leerders met leergebreke (LMG) – 'n reeks van wiskundige modelleringslesse is gebruik. Die onderwyssessie het bestaan uit die vervanging van hul tipiese en meer tradisionele-onderrig gerigte wiskundelesse met 'n reeks wiskundige modelleringstake wat oor 'n maand gestrek het. Die take was spesifiek ontwikkel vir LMG leerders waartydens die data van hul psigo-opvoedkundige profiele wat in die skool se rekords te vinde was, gebruik is. Hierby is data gevoeg wat uit kritiese assessering tydens die sessie verkry is. Die primêre navorsingsmetodologie was die ontwerpgebaseerde navorsingsbenadering (OGNB) wat die effektiwiteit en geskiktheid van die beplanning, implementering en evaluering van die modelleringstake vir die LMGs bepaal het. Die sekondêre navorsingsmetodologie was gevallestudie analises om die vordering, en spesifiek die leergrensversperrings wat gedurende die implementering van die leertrajek ontstaan het toe deur siklusse van OGNB gewerk is, te ondersoek. Die opvoedingsfilosofie van die navorser-onderwyser is gebaseer op die christelike kurrikulumbenadering soos beskryf deur Harro Van Brummelen (1988).*

Die uitkomste van die studie suggereer dat die neurologiese data baie handig en geskik is in die ontwerp van modelleringstake waartydens leerders met gestremdhede wat veelvuldige leerversperrings beleef, in hierdie proses versterk kan word. Verdere navorsing op 'n groter skaal is nodig om die akademiese gesprek in huidige neuro-wetenskap in sy toepassings en relevansie vir die veld van (wiskundige) onderrig en leer, te ondersteun.

Keywords: mathematical modelling, neurobiological data, design-based research, Christian curriculum approach

Kernwoorde: wiskundige modellering, neurobiologiese data, ontwerp-gebaseerde navorsing, leerders met gestremdhede, christelike kurrikulumbenadering

1. Introduction

Historically neuroscientists worked in their space and educators in theirs. This allowed for a one-way approach where educators heard about the latest neuroscience and applied it directly to their classroom context, often resulting in misapplication. Mayer (2017) reminds us that a direct applicational link between neuroscience and classroom practice is likely untenable, even when filtered through educational psychology.

Beuchamp and Beuchamp (2013:49) suggest that neurobiology may become more useful to educators if they engineer a boundary crossing between the two disciplines. A boundary crossing is where consideration is given to a situation in one context with the intent of a movement or transfer to a new context, while embracing the challenge of negotiating the differences between the two contexts to generate new solutions. For the reliable transfer of knowledge across disciplines, they foresee a breaking of the tradition where researchers from different disciplines work in their silos, to a more bold and integrated approach between the two fields. This metaphorical, but intentionally engineered, bridge between the disciplines of education and neuroscience may help to secure more viable applications of neuroscience knowledge in the classroom.

Similarly, Mayer (2017) and De Smedt, Ansari, Grabner, Hannula, Schneider & Verschaffel (2010:99) argue that the metaphor of a two-way street between education and neuroscience is important for mathematical education, particularly when development is atypical and behavioural methods cannot elucidate a deep enough level of description. These authors state that in moving forward it is critical for educational researchers to study functional and structural brain changes to enhance remedial intervention in students with learning difficulties. Moreover, they strongly urge educators to become familiar with neuro-imaging data generated by functional magnetic resonance imaging (fMRI) techniques and related tools.

If a boundary crossing is necessary for education to benefit from neuroscience, how is it accomplished? Beuchamp and Beuchamp (2013:49) believe that this proverbial crossing is achievable by:

- educators and neuroscientists attending multidisciplinary conferences to learn each other’s language, metaphors, and philosophies;
- asking research questions and building research designs that sit in the boundary space;
- using boundary objects such as tools, documents, protocols, or other facilitating artefacts across settings.

In a nutshell, research and/or researchers from education, psychology and neurobiology must be present in the same space. Moreover, the intention of their interactions should be the collaborative transfer of neuroscience data and knowledge across the silo boundaries into education. This transference should make application of these concepts viable in the classroom.

2. Definitions of key concepts

Educators are not always familiar with neuroscience language. In the following section, we define some of the neuroscience concepts and other key concepts related to this study.

2.1 The brain-mind dyad

The first Cognitive Revolution occurred in the 1950 and 1960s. With the unsealing of the black box, the mind, came the mandate of developing an increasingly robust understanding of how the brain-mind dyad works and its inferred applications for teaching and learning. According to Sing and Sing (2011:1), the brain-mind dyad refers to how the brain as a physical organ, can give rise to the mind and explain the conscious. In this connection, the brain is understood as the structural correlate of the mind, and the mind as the functional correlate of the brain. For learners to learn, they need to consciously incorporate information from the external, and the internal environment with the consciousness. Consequently, if the structure of the brain is vulnerable, the function of the brain will be compromised. Thus, the flow and neural integration of information between the external and internal environments and the consciousness will be impacted and impede the learning of mathematical concepts.

Similarly, Siegel (2017:3) contributes to the long-standing discussion on the brain-mind divide. He distinguishes between the brain as an organ with electro-chemical energy flow through it to accomplish its tasks, and the mind as “an embodied and relational process that regulates the flow of energy and information”. In layman’s terms, the brain is an organ powered by electro-chemical energy, and the mind is our ability to build relationships and work with information. Psychiatry and neuropsychology are fields which extensively study the correlation between the responses of the mind and the functional integrity of the brain structures. How does one translate this theory for educational purposes?

2.2 Functional Magnetic Resonance Imaging (fMRI)

fMRI is considered a sophisticated neuroscience method that examines changes in glucose utilisation or blood flow from which researchers infer neural activity (Whitten, 2012). Both the increase and decrease in neural activity in specific regions are measures and recorded as an image. The images provide insights using functional and structural comparisons of neural activity between those with neurotypical development and where neurobehavioral disorders are present. These neurobehavioral disorders may be cognitive, behavioural and/or psychiatric conditions (Whitten, 2012). Comparisons of physiological responses can also occur within specific subgroups of neurotypical subjects. fMRI measures physiological responses during specific cognitive tasks; these findings can be correlated to the behavioural outcomes of these tasks. In both cases, fMRI produces physiological measures relevant to behaviour and mental processes, thereby helping us understand the brain-mind dyad.

2.3 Students with disabilities

This study (Scott-Wilson, 2014) focused on students with disabilities who met the criteria of a diagnosed cognitive impairment, low adaptive functioning in several areas, and who needed an individual educational adjustment plan and intensive support to access the curriculum. The study cohort also consisted of students with structural and functional vulnerabilities across multiple brain regions.

2.4 Mathematical modelling

Mathematical modelling, in the context of this study, meant that learners were given a contextualised problem and were asked to devise a solution in the form of a model. There was no teaching beforehand of concepts and procedures, followed by practice. Rather, students worked in small groups in a collaborative manner and created solutions. Their solutions combined their implicit knowledge drives with knowledge gained from group discussions, and their own and others' reflections as they progressed through cycles of creating, implementing, and evaluating mathematical ideas (Blomhøj & Jensen, 2003; Doerr & Pratt, 2008). During these cycles, students' solutions were represented as models. Lehrer and Schauble (2010:9) articulate these models as "analogies in which objects and relations in one system, the model system, are used as stand-ins to represent, predict, and elaborate those in the natural world".

3. The Conceptual Frameworks of the Study

The study blended a Christian perspective with a neurobiological model as a basis for designing mathematical modelling tasks for SWD.

3.1 The Christian perspective of the study

According to Van Brummelen (1988), Christian educators are guided by their adoption of broad curricular goals and Kingdom-principles when designing lessons. Van Brummelen's key argument is that a Christian teacher's first commitment is to the Kingdom principle of discipleship. Therefore, all knowledge should be presented with a clear connection to biblical values and never in isolation from it.

Van Brummelen further argues that the application of this philosophy in a classroom setting results in purposeful integrations that bridge existing dichotomies found in pedagogy. In emphasising procedural skills (knowledge-how) separate from moral values, he alludes to the split between the teaching and learning of concepts (knowledge-that) and those of rich contexts (requiring problem-solving and creativity). The typical approach in textbooks to new mathematical concepts illustrates this; students are introduced to concepts via a step-by-step procedure, devoid of a context requiring problem-solving, creativity and/or a personal response, and divorced from any values. In contrast, Van Brummelen (1988:113-134) argues that the embedding of Scriptural dispositions in all forms of knowledge, will integrate rather than separate elements of pedagogy, such as knowledge with values.

Van Brummelen's guidelines cannot be followed in its full directive in a public-school setting, where the mission of overt discipleship is not allowed. However, Van Brummelen's (1988:115) message for teachers that, "Jesus expects you and your fellow teachers to choose and design and adapt curriculum with care", can be readily incorporated in any school setting.

Another Kingdom principle relevant to this study is the question of partial redemption and how this is achieved. Every book in the Bible contains a clear message of redemption. Yet the outworking of this redemption may only be partial in this world, until the arrival of the new Heavens and new Earth, where the redemption would be in full. The question then is, “How do we redeem, even if only in part, disrupted neurobiology that impacts directly on the learning of mathematics?”

3.2 The neurobiological perspective of the study

A significant part of the conceptual framework of the study is the philosophy of the Neuro-Sequential Model of Therapeutics (NMT). According to this model, the brain consists of different systems that are connected and interacting with one another (Perry & Hambrick, 2008). It identifies four main anatomically distinct regions which are the brainstem, diencephalon, limbic system, and cortex.

The lowest part of the brain, the brainstem, connects the spinal cord to most other parts of the brain. Situated above the brainstem is the limbic system, which is made up of various structures, and above and surrounding the limbic system is the cortex. The diencephalon is the anterior region of the limbic system; it contains the thalamus and hypothalamus.

Standring (2015) explains how the abovementioned parts of the brain work. Different parts form systems within the brain, and mediate different final functions. For example, the cortex mediates voluntary movement and thinking while the brainstem/midbrain mediates states of arousal. The hypothalamus and the pituitary gland form the link between the neural system and the endocrine systems. The pituitary gland synthesizes the hormones oxytocin, serotonin and endorphin which relate to feelings of trust and bonding, feelings of well-being and appetite, and feelings of pleasure and stress relief respectively. The substantia nigra in the brainstem, synthesises the hormone dopamine, which increases motivation and concentration. Most sensory information from the skin and muscles, passes through the brainstem first. The limbic system, and particularly the thalamus, acts as a doorkeeper for almost all incoming sensory information. It is here that important stimuli are identified and allowed through to the cortex. Sensory stimuli, for example someone saying your name, which has important embedded meaning due to experience is more readily allowed through. While background noise, such as the hum of an air-conditioner, is filtered out and not allowed to rise to the consciousness.

A key idea of the NMT model (Perry & Hambrick, 2008; Perry, 2009) is that the brain is organised sequentially in a specific hierarchy. During development, the brain organises from the bottom to the top, meaning that the lower parts of the brain develop earliest. The brain's development is influenced by neuro-signals. The monoamine neural systems are systems of neuro-signals functioning in response to specific hormones. Monoamine neural systems project throughout all brain regions from the bottom up and communicate across multiple regions simultaneously to provide an organising and orchestrating role. On the other hand, when these neuro-systems in the brain are compromised, such as by trauma and/or developmental delays, and they become abnormally organised, they lead to dysregulation across regions.

3.2.1 A clinical tool providing a brain map

Perry and his associates (Perry & Hambrick, 2008; Perry, 2009) created a clinical assessment tool which makes the brain-related neurobiology of an individual visible. Perry's (2013) team gives examples of how the data produced by the tool links directly to fMRI scans.

The tool requires stakeholders to complete a questionnaire. The response items on the questionnaire relate to functions mediated by the different brain structures and include references to the student's pulse rate, sleeping patterns, eating patterns, relationships, impulse control, symbolic cognition and so on. In the context of this study, various stakeholders met to complete the questionnaire. These included the school nurse, the foster carers of the learner, the teacher and teacher aide. Data was also taken from the latest psychological assessment. Once the information was inputted into the NMT online system, a visual heuristic was produced showing vulnerable areas as a representation of how the individual's brain is organised (MacKinnon, 2012). The tool provides a visual heuristic describing the current structural and functional strengths and vulnerabilities of the student's brain. It also generates an estimation of the functioning of the student across the following broad domains and compares these to age-typical peers and to mature adults respectively. These terms are defined in the report generated by the tool.

- Sensory integration – the ability of the brain to integrate, process, store and act on sensory information. This sensory information originates both from outside the body, through the senses, and inside the body, from various systems (e.g. metabolic system).

- Self-regulation – Functions that modulate and regulate other key systems. These include bottom-up somatosensory regulation, top-down cerebral modulation and dissociation.
- Relational functioning – the complex set of relationship related functions such as bonding, attachment and empathy.
- Cognitive functioning – the myriad of functions related to complex sensory processing. These include language, perspective taking, speech, reading, future planning, moral reasoning and similar cognitive capacities.

3.3 The modelling perspective of the study

As indicated above, modelling fits well with the holistic learning environment encouraged by Van Brummelen and Siegel. Typically, teachers and researchers of mathematics are slow to expose students with complex disabilities to mathematical modelling tasks and for good reason. Modelling proverbially strikes where students with disabilities are the most vulnerable. It requires skill sets and dispositions that SWD seem to be lacking. Lehrer and Schauble (2010:10) state that "… one cannot investigate the development of a phenomenon, if the conditions [required] for its development are absent".

Learners with dysregulation in any of the four regions, experience some difficulty meeting the demands of modelling tasks. Firstly, model representations require written assumptions and lengthier formulations, more sophisticated verbal explanations, complex data organisations, justifications, generalisations and negotiations. When the upper areas of the brain map show disruption, the learner will experience deficits in their reasoning, abstract thinking, and communication skills (Perry, 2009). The conditions required for successful development are compromised, so how can we help these learners meet the integration demanded by modelling in the upper brain regions?

Secondly, data from learners with disrupted neural integration in the mid-regions of the brain suggests that such learners tend to have poor relational skills. Poor relational skills hinder positive collaborative work in group settings. Again, this is a challenge that cuts straight to the heart of modelling. English and Watters (2005) affirm that modelling is a social sharing process which allows learners to work collaboratively to plan, monitor, communicate and optimise results in response to feedback and group scrutiny. What do educators do when we know that our learners lack the necessary social skills to meet these requirements?

Another aspect to bear in mind is Siegel's (2012) argument that when the flow of information in a domain is vulnerable due to poor integration, learners will appear chaotic or rigid, or both, in aspects of their classroom and learning behaviour. To indicate their inability to meet the cognitive demands of the modelling task at that given point in time, these learners either "freeze" and/or become poorly behaved and may resort to flight/fight behaviours. Thus, learners with dysregulation across all four levels of the brain will not be ready for modelling activities in their purer form. Consequently, there is very little research into mathematical modelling for students with disabilities. This study contends that the traditional question for educators and researchers on whether students with disabilities should be exposed to modelling, must shift to how students with disabilities should be exposed to modelling to overcome some of the challenges listed above.

A way forward in answering this question is to consider the key principles from the field of modelling and that of child and adolescent psychiatry. Once identified, these principles should then be carefully blended in a lesson plan for use in a research and teaching, specifically designed for boundary crossing purposes.

In light of this, the challenge for educators is to engage in a multidisciplinary approach drawing on these principles from psychiatry and adapting and designing mathematical modelling lessons using these principles as boundary crossing tools.

3.4 Principles from neuroscience translated into modelling

It is suggested that a plausible transfer between activities in child and adolescent psychiatry and those in mathematical modelling is bridged in the Principle of Construction identified by Lesh, Cramer, Doerr, Post and Zawojewski (2003). According to these authors, the Principle of Construction is concerned with the types of data structures students use to represent their solutions. This means educators can allow for learners to present their solutions or models in a variety of modes.

Moreover, in adapting the lesson design developmentally, students may only need to produce precursors to modelling tasks, instead of more sophisticated and mature products. Lehrer and Schauble (2010) explain that students would construct the precursory models around their actual experiences of the activities and could draw on a wide range of representations in the construction of their models. They indicate that the precursors to the model often take the shape of drawings, physical replicas, sculptures and simulations. To maintain a balance between mathematical and neuro-developmental goals, precursors allow for representations of concepts expressed in movement, play and art-based activities. The idea of play as a tool to develop abstract, decontextualised, decentralised, and generalised representative thinking in learners is not new. Paradigm-shifting theorists such as Piaget (1962) and Vygotsky (1967) have long since familiarised educators with the cognitive benefits of play. Moreover, as these precursors to a model focus on a small part of essentials of the model, while ignoring many other relevant factors, they allow students to produce more simplistic or rudimentary products.

To summarise, the Principle of Construction in modelling allows for rudimentary precursors before more sophisticated models as outcomes for students. These can be represented in a very wide range of modes or activities.

3.5 The integration of the Christian, Neurobiological and Modelling Perspectives

Perry and his team have created a clinical assessment tool which makes the brain-related neurobiology of a student visible. It was initially created to understand the way the brain processes stimuli in children who have experienced trauma at a very young age. The emergence of this clinical tool means that a form of neurobiological data is now accessible to educators for planning purposes. This clinical tool shows both the structure and function of an individual's brain and matches data from fMRI scans, (Perry & Hambrick, 2008; Perry, 2009; Perry, 2013). This links to Van Brummelen's exhortation, as educators could use the brain map data as a key component in helping us plan, design and adapt our lesson objectives for students with diverse needs. Mayer (2017), however, reminded us that neuroscience data should not be directly applied to an educational setting. Consequently, this study engaged in crossing a boundary between neuroscience and education using the data from the brain-mapping tool.

An additional step was the consideration of the redemption principle. The redemption principle draws on the work of Siegel (2017). Siegel's work progressively challenges thinking beyond the revolutionary idea of learning as changes to neural plasticity of the 1990s. He urges professionals in the field to consider neural integration as a necessary mechanism to facilitate the growth of the mind. A healthy mind that can excel in school and the workplace is an integrated mind. Siegel (2012:334) states that, "In this view,

… educational measures would be aimed toward promoting integration – in the body and brain, in relationships, and in the regulatory functions of the embodied and relational mind.”

In other words, where there are indications of disruption and dysregulation of the neurobiology, the redemption principle encompasses the need to aid learning by helping the neural system integrate across several dimensions including the brain with the body (skin-to-skull), the lower regions of the brain with the upper regions (information coming through the senses with abstract thinking), and the individual with their peers relationally. Mathematical modelling optimises conditions for neural integration. It has a strong emphasis on learning through relationships. It requires that learners use information from their senses and internal logic to formulate and optimise solutions. Modelling also utilises precursors that can be expressed through multiple formats including somatosensory schemata, thereby optimising conditions for neural integration.

At the same time, modelling meets Christian ideals. Van Brummelen, for instance, advises using learning contexts that allow for critical thinking in a real-life setting. These contexts should be driven by life values or moral dispositions embedded in both knowledge-that and knowledge-how activities. They should, furthermore, require problem-solving, creativity and personal responses. The underlying aims of mathematical modelling fit well with Van Brummelen’s ideal of a learning context. Modelling requires the careful design of materials, supporting the integration of information with values, and thereby bridges some of paradoxes inherent in education.

Through Perry’s clinical tool and the application of its principles to modelling, Van Brummelen’s ideal of careful design of materials can be extended to include the needs of SWD. Furthermore, it is a resource that educators can use to meet the goal of restoration highlighted by Siegel; with a specific focus on redeeming the neural system. However, application of this information must first be filtered through a boundary crossing research design into the context of education.

4. Principles from NMT

De Nooyer and Lingard (2016) studied NMT principles in a child and adolescent day programme and an inpatient unit in Australia. They discuss specific examples of how to match activities to at-risk brain regions using NMT principles.

4.1 Brain map indicating low-level disruption

NMT principle: According to the philosophy of the clinical tool and the recommendations contained in the report generated for each client, when the lower parts of the brain map show vulnerability, learners will typically present as struggling with self-control, impulsivity, reactivity and attention deficit challenges (Perry, 2009). The approach (Perry, 2009; MacKinnon, 2012; De Nooyer & Lingard, 2016) suggests that educators use somatosensory activities which are enjoyable to the learner and that have repetitive rhythm associated with them to help the student regulate while learning. Examples of such activities are deep breathing routines, music, and movement such as swimming, walking, cycling, drumming and table tennis. The selected activities will need to stimulate the tactile, proprioceptive and vestibular areas. In designing the activities, it is valuable to consult with occupational therapists on the learners' sensory profile and needs.

Link to curricular design: The principle utilised in mental health is that activities embedded in sensory-motor schema helps the learners stay engaged in the activities and promotes sensory integration. Transferring this principle to education requires that the model construction activities be embedded into a sensory-motor schema. When learners with lower level dysregulation are constructing models, we should allow them to move their bodies in rhythm, and/or to use sensory objects with which to represent their solution. This allows for somatosensory self-regulation connecting the skin to skull. They may for example, need to create a physical object of the model using body movements and real objects.

Principle for lesson planning: Plan a lesson where the precursor is demonstrated by the student in a somatosensory form/activity such as exercise, and one which intentionally introduces neural integration between the body and the brain.

4.2 Brain map indicating mid-level disruption

NMT principle: Moving upwards from the lower brain regions, when the limbic system shows atypical development, the learner will find emotional regulation and social dynamics harder to negotiate (Siegel, 2012). From this data, educators can predict that the sharing of ideas and information between the learner and other learners will likely become problematic. There is a significant number of principles of psychology embedded in how dysregulation in the limbic area should be approached in learning environments. The main objective when intervening in the limbic area is to begin to create states of emotional regulation that will help learners progressively enter the positive shared experiences and the collaborative relationships needed by modelling over time. From a psychiatric perspective, techniques commonly found in play and arts-related therapies are particularly useful in strengthening vulnerabilities in this domain (Perry, 2009).

Link to curricular design: The recommendation section of the report indicates that learners with vulnerabilities in this area benefit when activities are embedded in play scenarios, or use a form of art including drawing, painting, paper designs, or sculpturing. The challenge for educators is to find a game or simulation that will allow the play to appear age-appropriate during the process of model construction.

Principle for lesson planning: If the data in the limbic area depict high levels of vulnerability and dysregulation, the neurological principle is to develop the functional ability of students to work in groups. To this end the report recommendations indicate that learners with disruptions at this level may need to work in parallel to their peers while constructing their models, before engaging in a dyadic relationship with an adult or a more mature peer, and finally progressing to small group work. Neuro-integration takes the form of an increased capacity for relational dynamics and sharing of information as learners begin to develop the capacity to connect with others.

4.3 Brain map indicating higher-level disruption

NMT principle: In the philosophy of this neurobiological approach, after relationship dynamics have been taken into account, a verbal and insight-oriented approach can be adopted to work with the cortex areas of the brain (Perry, 2009). Therapeutic examples would be cognitive behavioural therapy, narrative work and/or drama activities.

Link to curricular design: As the higher levels of the brain are responsible for abstractions, when the brain map shows these are vulnerable and not yet fully integrated with lower levels, these higher cortical functions are essentially “off-line” at that given point in development. Consequently, learners with higher level disruptions are very unlikely to manage activities where abstractions are presented in representational forms such as formulas and written and verbal narratives. The report uses the measure of a cortical modulation ratio to determine whether students will be able to benefit from verbal-insight or “talk” approaches.

Principle for lesson planning: If the cortical areas are stable, learners can engage for lengthier periods in traditional middle school activities such as reading and writing tasks, including journaling, or more sophisticated communication and reasoning tasks such as debating. However, when these areas are vulnerable, learners will only be able to sustain these types of activities for very short periods.

According to the NMT philosophy, the design of lessons should follow a bottom-up approach meaning that lesson planning has to start with the lowest part of the brain map where undeveloped functions are visible, and from there move sequentially up the brain map as improvements are seen (Perry, 2009). Moreover, care must be taken to ensure that the lesson plans are relational (safe), relevant (developmentally matched), repetitive (patterned), rewarding (pleasurable), rhythmic (resonant with neural patterns), and respectful of the child, family and culture (Perry 2009;2013).

Table 1.1 provides a summary of the main principles from child and adolescent psychiatry (Perry, 2009) and Siegel (2012).

Table 1.1: The principles and associated examples from child and adolescent psychiatry as interventions for disruptions across certain sections of the brain map

<table>
<tr><td colspan="3">Step 1: Brain map as a clinical assessment tool provides:</td></tr>
<tr><td>Heuristic visual of functional and organisational structure of individual’s brain</td><td colspan="2">Information on sensory-integration, self-regulation, relationships and cognitive capacity</td></tr>
<tr><td colspan="3">Step 2: Principles suggested by the NMT philosophy to strengthen vulnerable regions of the brain:</td></tr>
<tr><td>Lower regions</td><td>Mid-regions</td><td>Upper regions</td></tr>
<tr><td>Use movement in the form of repetitive and patterned somatosensory activities:
• Rhythmic breathing exercises
• Walking, running
• Ball sports
• Drumming
• Swinging
• Trampoline Jumping</td><td>Use art-based activities and play-based activities
Start with parallel play,
Progress to dyadic relationships with adults and more mature peers.
Last, move into small group work</td><td>Use verbal and insightful approaches such as
• Journaling
• Storytelling
• Drama or theatre
• Talk therapies</td></tr>
</table>

Step 3: Areas to focus integration:		
Connecting skin to skull (body-brain)	Connecting individual to peers (relationships)	Connecting upper and lower areas of brain

5. Research method and design

In this section the components of the research design and its implementation will be discussed in more detail.

5.1 Study design

The primary orientation of the study was design-based research (DBR). The objectives were to design mathematical modelling tasks appropriate for and accessible to students with disabilities using the principles of neurobiology and data from a boundary crossing tool. Lessons were designed with the whole class in mind and the modelling tasks were incorporated in the classroom mathematics lessons for one month. We evaluated the learners' responses to the tasks, adjusting from reflections, and drawing out generalised principles for future design.

The second method was a case study analysis of certain learners and their responses to the modelling activities designed for them. This article reports on one case study which analysed a student's response to the activities planned from neurological data.

5.2 The setting

The setting took place in remote Australia in a public middle school for learners from mostly lower socio-economic households. A special needs unit consisting, at the time, of six classes occupied a wing of the school. These classes were small, ranging from five to ten learners. Each class had one teacher and one teacher aide. The activities were prepared for the whole class and six of the eight learners participated in the research side of the classroom intervention.

5.3 Study participant

In this study, Charlie's data was evaluated. Although placed in first year at middle school, his developmental data positioned him at an early childhood, very low-primary school level. Charlie is a 12-year-old male who has an ongoing history of concerns regarding his limited attention span and challenging behaviours, and his inability to stay on-task in classroom situations.

Support history indicates that at the age of three, Charlie was removed from his mother and placed with his grandmother, before being moved into the foster care system. He received occupational therapy at the time. A paediatrician diagnosed him with Foetal Alcohol Syndrome when he was five years old. At age seven, he received speech intervention and a cognitive assessment was conducted. The cognitive assessment indicated borderline impaired working memory and cognitive ability of a low average capacity. At the time of the study, he was being fostered by a local family and arrangements allowed for monthly visits to see his mother and grandmother.

At age 11, before moving from primary to middle school, he was reassessed by a psychologist. Documentation showed that he had issues with behaviour, including an attention span of no longer than 30 seconds, scribbling and destroying work when frustrated, overreacting to typical classroom situations such as someone accidentally knocking him, being paranoid about people talking "about him" when they are not, constantly tapping and singing, absconding from home and school, and self-harming. At that time clinical features of foetal alcohol syndrome (microcephaly, smooth philtrum, and short palpebral fissures) were confirmed. Additional diagnoses of the inattentive type of ADHD and oppositional defiant conduct disorder were given. For the most part, Charlie's characteristics are congruent with a description of the typical profile of learners with foetal alcohol syndrome disorder (FASD). FASD has a very strong effect in the cognitive domain including overall intellectual functioning, attention, working memory, executive skills, speed of processing, inhibitory control and academic skills (Nuñez, Roussotte & Sowell, 2011).

His latest primary report, before moving to middle school, indicated that Charlie had an incomplete knowledge and understanding of the Year 6 mathematical content and very limited competence in using skills and related processes. It was noted that he needed explicitly structured lessons and support, constant reassurance and encouragement. His report further indicated that he had made minimal progress in his year level, that he did not attend to tasks quickly or independently, and that he needed teacher direction to start. It was also observed that he was still developing his group work skills. He was working on strategies to calm himself down. It was noted that he had a negative attitude towards mathematics, resulting in unfinished work. He fared better in practical tasks and discussion than in writing tasks. Charlie was selected for this study as he met the criteria of a student with disabilities who had a diagnosed cognitive impairment, low adaptive functioning in several areas, and who needed an individual educational adjustment plan and intensive support to access the curriculum.

Moreover, his brain map data showed dysregulation across all four areas of the brain, due to experiencing trauma at a very young age.

Below in Figure 1.1. is the generated map of Charlie's brain structure and functions at the time of the study. Red indicates underdeveloped areas, yellow indicates developing areas, and green shows well-developed areas. The cell at the bottom right of the Functional Item Key is labelled CV (1). Its position in the Functional Item Key and its white colour indicates that it is located in the very lowest level of the brain called the brain stem. The label CV (1) can be decoded by referring to the list in the top left of Figure 1.1. Under the heading of Brain Stem the first item in the numbered list is Cardiovascular/ANS meaning that it relates to the functioning of the cardiovascular area and the autonomic nervous system. Time 1 refers to this being the first test conducted on the participant. The goal is to conduct several tests over time to see if the neurological system of the participant is stabilising through interventions. The score listed underneath Time 1 in the same row as Cardiovascular/ANS indicates how the participant scored for this category. Typical refers to how a candidate of the same age with a well matured and structurally and functionally stable neurobiological system would score. In the case CV(1) there is a match between the participants score and that of the neurotypical ideal in so far as both are scored as 12.

Given the data in Figure 1.1, Charlie had disruptions across all four of the major brain areas, his cortex being the most vulnerable. For example, he has ongoing difficulties with attention (brain stem area), with sleeping at night (cerebellum), with self-regulating his behaviours and emotional state, with language (cortex), and with doing academic work such as maths (frontal cortex).

The graph in Figure 1.2 shows Charlie's progress across four key developmental domains, namely sensory integration, self-regulation, relational and cognitive functionality compared to age-typical peers and with mature adults. For example, cognitively Charlie is functioning similar to a typical learner half his age, meaning he functions on par with a typical 6- to 7-year-old. Relationally, he had the social skills of a 5- to 6-year-old child, and he had the sensory integration capacity of a 7- to 8-year-old learner.

	Brainstem	Time 1	Typical
1	Cardiovascular/ANS	12	12
2	Autonomic Regulation	12	12
3	Temperature regulation/Metabolism	8	12
4	Extraocular Eye Movements	6	12
5	Suck/Swallow/Gag	12	12
6	Attention/Tracking	3	12
	DE/Cerebellum		
7	Feeding/Appetite	7	12
8	Sleep	5	12
9	Fine Motor Skills	10	12
10	Coordination/Large Motor Functioning	10	11
11	Dissociative Continuum	7	11
12	Arousal Continuum	3	11
13	Neuroendocrine/Hypothalamic	10	11
14	Primary Sensory Integration	11	12
	Limbic		
15	Reward	8	12
16	Affect Regulation/Mood	7	11
17	Attunement/Empathy	7	11
18	Psychosexual	9	10
19	Relational/Attachment	7	11
20	Short-term memory/Learning	11	12
	Cortex		
21	Somato/Motorsensory Integration	11	12
22	Sense Time/Delay Gratification	5	10
23	Communication Expressive/Receptive	6	12
24	Self Awareness/Self Image	3	10
25	Speech/Articulation	9	12
26	Concrete Cognition	7	11
	Frontal Cortex		
27	Non-verbal Cognition	4	10
28	Modulate Reactivity/Impulsivity	6	10
29	Math/Symbolic Cognition	3	10
30	Reading/Verbal	4	10
31	Abstract/Reflective Cognition	3	10
32	Values/Beliefs	4	10
	Total	230	358

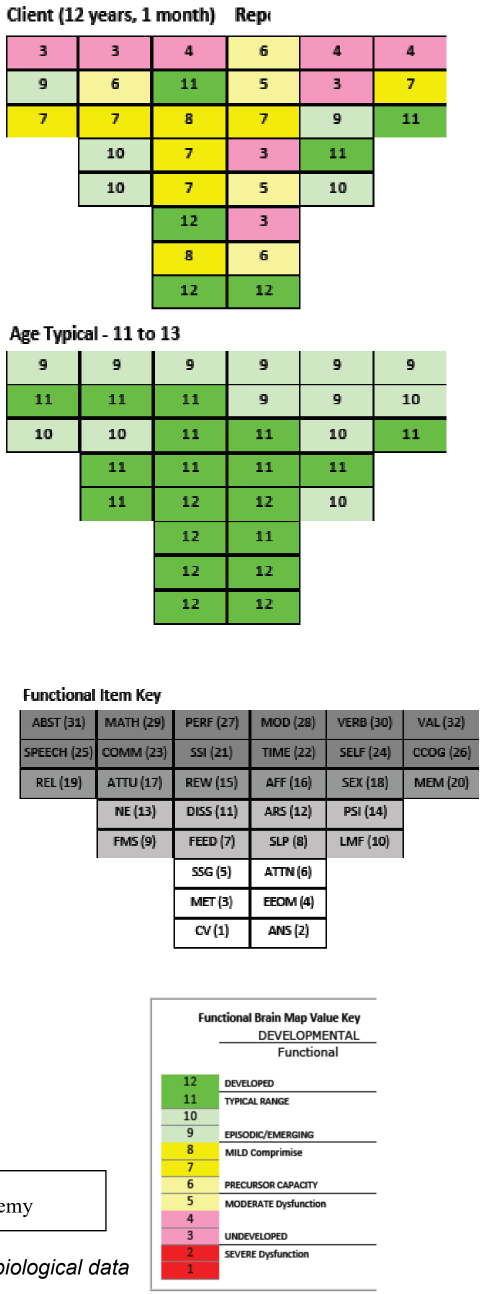

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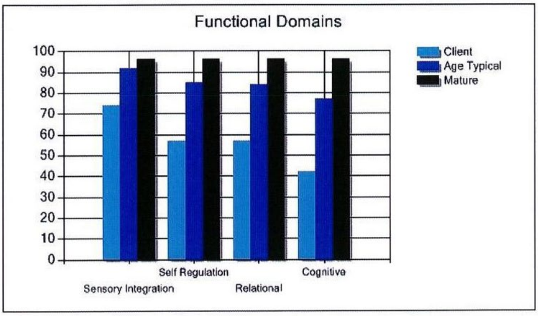
Figure 1.1: Functional brain map: Charlie's neurobiological data



Functional Domains Values

	Client Age	Age Typical	Mature	% Age Typical
Sensory Integration	74	92	96	80.43
Self Regulation	57	85	96	67.06
Relational	57	84	96	67.86
Cognitive	42	77	96	54.55
Cortical Modulation Ratio	1.43	7.00	24.00	20.50

Figure 1.2 Charlie's functional status in comparison to age-typical peers and mature adults

5.4 Data collection

In the context of the larger study, data was collected from existing school records, including school reports and assessments from therapists, school-wide data programmes, work samples in class and video and voice recordings during the actual lessons. The researcher was also the teacher of the class, enabling data collection through observation during activities. All observations were guided by a framework of questions. These looked for evidence to support or dismiss the notion that SWD could learn mathematical concepts through carefully designed developmentally and age-appropriate modelling activities using the cross-boundary tool of a brain map.

5.5 Intervention

5.5.1 Curricular design: Planning lessons using NMT principles

Given the nature of design-based research, the data was used to plan suitable mathematical modelling tasks for Charlie.

Since Charlie's cognitive capacity matched that of a 6-year-old, the tasks were differentiated to include a range of descriptor-levels between Foundation to Year 3 from the national curriculum under the strands of location, transformation and shape. Given that it was a special needs unit, the other learners in the group also matched this grouping level for mathematical concepts.

The broad curricular goals for this unit of work, were fourfold:

- Students had to demonstrate that they could give and follow directions
- Students had to demonstrate an understanding of clockwise and anticlockwise turns
- Students could recognise and draw 3D shapes
- Students had to demonstrate that they could use a grid reference system

Linking with NMT principles the lessons were designed to accommodate all four areas of the brain. As per the recommendations of his report, for the lower areas of the brain, the modelling tasks were designed to provide precursors in the form of rhythmic somatosensory movement. For the limbic system, the activities had to be play or art based. Subsequently, the modelling tasks were designed to make room for play and art orientated activities that could take place in parallel mode and/or in a small group context. For the cortex system reading, writing and talking activities were incorporated.

The task designed to meet the outcome of giving and following of directions was a scavenger hunt. Learners were placed in two teams. Each team hid Easter eggs in a location of their choice in the schoolyard. They then wrote and planted directional clues across the school that would guide the other team to the hidden eggs. Teams were in competition to see which team could find the hidden location of the eggs first, each team using the directional clues of the other team.

The planning of the hunt and the writing out of directional clues drew on the higher levels of the brain. Working in teams and competing in a Scavenger hunt race drew on the middle level of the brain (play-based). Running around the school to find and interpret directions to the Easter eggs drew on the lower level of the brain (somatosensory based).

For the outcome of being able to give and follow rotations involving clockwise and anticlockwise turns, students were divided into pairs of two. Each pair was given a combination lock designed out of cardboard. The unlocking of each of the rotators at the back was visible as you turned the dial in different directions. This allowed learners to work out which sequence of turns would unlock the latch. The combination was veneered as a bomb, and pairs were informed that they represented a bomb squad team who had 20 minutes to defuse the bomb by unlocking the hatch. A timer in the form of an explosive was put on the whiteboard as a countdown. Learners were asked to defuse the bomb and record the code before the bomb detonated.

Again, the turning of the dial clockwise and anticlockwise and watching the rotors at the back unlock was somatosensory in form and aimed to integrate the functioning of lower areas of the brain. Working as a pair pretending to be a member of a bomb squad was play-based and aimed to integrate limbic system function. Systematically recording and checking the instructions that would unlock the latch to defuse the bomb required cognitive skills processed by the higher levels of the brain.

To learn how to recognise 3D shapes and their attributes, learners were assigned to their original teams to construct a model of the school using foam blocks. Thereafter, they were shown the school from Google Earth and explored the idea of a "top view" of the school. Next, learners worked individually on dot paper or on their iPads in a sketching programme with dot paper to produce a top view of the school. All top view drawings were enlarged with the photocopier machine and placed on the white board. The learners then worked in teams preparing and debating which top view was the most accurate representation of the school.

The somatosensory principle was incorporated by building a model using 3D blocks. The drawing, on the iPads of the school from a top view, aimed to integrate the limbic system as it was more art-based. The debate on which top view drawing was the most accurate representation of the school required integration of the functioning of the cortex.

For the curricular outcome of being able to follow directions using a grid reference system, each team was given a copy of the top view drawing nominated by the team that "won the debate". Teams then had to design a grid reference as an overlay and mark a location of their choice on the grid reference. Each team provided the other team with their grid reference and location directions. Thereafter the teams were given an opportunity to learn how to fly a remote helicopter, before flying the helicopter to the allocated grid references across the school grounds.

The somatosensory aspect was controlling the remote helicopter as it flew across the school. The play-based principle was learning to fly the helicopter together. The higher-level tasks were planning a grid reference system and allocating directions to a specific location on the school grounds using the coordinates of the invented system.

A summary of how the principles of the NMT model (Perry, 2009) were adapted to curricular design are shown in Table 1.2 below.

Table 1.2: Showing how the modelling tasks were adapted to include the principles of neurobiology in respect to the different regions of the brain

Lower Brain Regions	**Mid-regions**	**Upper regions**
Movement in the form of repetitive and patterned somatosensory activities, such as walking, running and turning a dial	Play and art-based activities May need to start with parallel play activities working towards small group work over a period of time	Verbal and other insightful therapies • Journaling • Storytelling • Drama or theatre • Talk therapies
Adaptation to the mathematical modelling activities to embed the neurobiological principles		
Task designed: Set up and participate in a treasure hunt competing in teams. Learner activity: Each team had to hide the treasure, and then develop a set of directional clues for the other team to find the treasure. The teams swopped these "clues" and then tried to and find where the other team had hidden their treasure by following the directions around the school. Task designed: Defuse a "bomb'. Learner activity: Defuse a bomb by working out the rotation of a combination lock – repetitive movement of turning clockwise and anti-clockwise and recording the "solution".	Building a 3D representation of the school with foam blocks. Drawing a top view using software. Fly a remote helicopter to the given coordinates.	Writing down the directions for the other team to follow to the treasure. Recording the instructions for the other team to open the combination lock. Designing a grid and providing coordinates to the team. Debating which design showed the best representation of the school from a top view.

5.5.2 Predictions based on Charlie's brain map

Charlie's data showed that the lowest point of vulnerability was his brain stem and cerebellum areas. The recommendations in Charlie's report indicated he would have a readiness to engage in all activities that evoked sensory-motor schemata for example, reading directions while running and searching for Easter eggs, and physically turning a dial to work out the difference between clockwise and anti-clockwise. Charlie had well-coordinated large muscle movement which made him agile, and his previous school reports mentioned that he was good at sport and enjoyed sporting activities.

The next area of the brain, journeying upwards along the brain map, is the limbic area. According to the NMT model, a robust limbic system helps a learner to deal with relationships and social-emotional challenges. Charlie's limbic area appeared relatively stable, but not fully so, considering that he had the social capacity of a child aged 5 years and 6 months. This was partly supported by his last school report which stated that he enjoyed interacting with his peers, but that he was not ready for the fuller dimensions of group work. As per the report recommendations, he would oscillate between parallel activities and some form of collaboration, without entering into full collaboration with his peers.

It was important to consider that the disruption in Charlie's frontal cortex area was rather severe and his cortical modulation ratio (ability to benefit from verbal-insightful approaches) still at an infancy level. Using the principles of the NMT framework (Perry, 2009) smaller amounts of higher order activities were included into his learning activities until the lower regions of the brain became more stable. The set mathematical tasks involving the higher order aspects included planning and recording the directions to the Easter eggs in writing, recording the instructions of how to defuse the bomb through a series of sequential turns, and participating in the debate on the best top view design(s) from amongst the class efforts. It was predicted, due to the significant upper disruption shown in his brain map, that there would be very little neuro-integration in this part of the brain. Consequently, his behaviour would become rigid or chaotic should he be expected to engage in these types of activities for extended periods of time.

As Perry, Pollard, Blakley, Baker and Vigilante (1995) state, though the neuro-developmental framework is designed to work from the bottom up, top down functioning is also possible. We thus include higher cognitive functioning activities in Charlie's lesson plans to provide him with the opportunity to develop these skills. Even some interaction with tasks at these higher levels is considered development. The neuro-developmental framework allows us, as teachers, more in-depth understanding of the avoidance of these tasks. The acting out is not just poor behaviour, these tasks stretch Charlie's ability. As such his endocrine system signals a threat, and he needs to respond to this threat. Freeze, fight or flight are the most common responses. Avoidance, flight, is more socially acceptable than throwing a tantrum, fight. Removing all such tasks from Charlie's realm would, however, deprive him of the opportunity to interact with them and develop a new response to the perceived threat. Careful planning using the neuro-developmental framework, however, allows interaction with the same material at lower brain function levels. Ensuring that Charlie has interacted with the tasks at these lower levels, maximises the likelihood of success at the higher levels. Once this is achieved, it acts as a motivator in further tasks. There is no motivator like success to alter his view of his ability to perform in tasks requiring integration of higher cognitive function.

5.5.3 Results

Charlie's response to the neurological principles embedded in the design were monitored during the study. The mathematical tasks were implemented in the normal class timetable for mathematics lessons for the duration of one month. Charlie's levels of engagement and learning behaviour were digitally recorded in both an audio and video format for analysis. As was predicted by his brain map, Charlie's responses showed that he was able to engage in and sustain activities which were modified to align with the lower and mid-brain structures.

To illustrate, he participated enthusiastically in activities that drew on the skin-to-skull, or the body-mind connections. Charlie participated in the scavenger hunt running around the school and interpreting directional clues to find the Easter eggs. He "defused the bomb" by turning the rotors clockwise and anticlockwise until the latch was released. Likewise, Charlie built a model of the school with blocks, participated in drawing a top view of the school, and flying a helicopter to grid references. During these activities Charlie was engaged and self-regulated, and no behavioural problems were noted.

Furthermore, evidence showed that he was also able to interact positively with other team members for short periods of time during these activities, but not to the full extent and manner required by modelling. For example, when learners had to work in pairs to defuse the bomb, Charlie did not participate much with his partner. A while into the lesson, he left his partner, took the bomb, and went to sit on the couch by himself, contemplating how to unlock the latch by turning the dials. His main contributions to the group were in a help-giving capacity, for example, when certain students could not find the app with the dot paper, or did not know how to fly the remote helicopter, he would make an offer to his peers to “show them how to do it”. For the most part, his approach to group work was social in nature (chatting together while building a model of the school), rather than academic. During the building with the blocks, for example, he would make it known to the group that he was building a section of the school and he proceeded to do so in parallel to the others. He loved to draw with the iPad, sitting on a beanbag in class, completely absorbed in the activity for an entire lesson.

Results from monitoring Charlie’s behaviour during the one-month trial also showed the activities in which he did not successfully participate. As predicted by the brain map these were largely activities which draw on the upper areas of the brain. Charlie preferred not to write down any directional clues for the Easter hunt (he would express a few directions verbally), nor for the combination of the locks regarding the direction of the turns and the degrees of rotation required (for example, half a turn clockwise). Only with adult prompting, was he able to write a little.

While his classmates were involved in these activities, his own behaviour became chaotic. For example, as his classmates were trying to write down and test the code for the bomb, Charlie would try to distract them by introducing a pretend sword fight with his ruler. When he was reprimanded, he deliberately left the class for a while. Similarly, while his classmates were debating which drawing of the top view was the most accurate, he lost interest after a few minutes and ventured to the fish tank in the class, making a rod from his ruler and trying to catch the fish. He chose which drawing he liked between different options, but he would not enter a debate or a justification of his choice against the rival choices of other learners. Table 1.3 provides a summary of Charlie’s responses to the tasks designed using the principles of child and adolescent psychiatry.

Table 1.3: Charlie's responds to tasks designed for the lower, middle or upper areas of the brain using the NMT principles

Neurobiological principles for each of the brain levels		
Lower Brain Regions	**Mid-regions**	**Upper regions**
Use movement in the form of repetitive and patterned somatosensory activities or exercise	Use play and art-based activities May start with parallel play then move into a dyadic relationship with adults and more mature peers, before engaging in group activities in a fuller capacity	Use verbal and insightful teaching/therapeutic approaches such as journaling, storytelling, drama or theatre, and talk therapies
Adaptations build into the lesson planning designs		
Running across the school grounds, turning a dial, building a model out of blocks, controlling a remote helicopter	Play-based: A scavenger hunt competition, pretending to defuse a bomb, flying a remote helicopter across the school grounds, building with blocks Art-based: Drawing on dot paper or using an iPad app with dot paper	Planning a scavenger hunt, recording directional clues Systematically recording the sequence of turns to defuse a bomb Debating which top view drawing represented the school most accurately
Charlie's responses to these activities		
Full engagement Presented as enthusiastic and motivated Able to self-regulate for the duration of the activity	Full engaged in play activities and art activities, but mostly in a parallel mode. Occasional cross-over into a group dynamic to offer help to peers, or to chat socially Not able to "interthink" with a group yet	Very limited engagement Required adult prompting Displayed rigid or chaotic behaviour Ran out of the classroom, initiated a sword fight with a ruler, tried to catch the fish in the fish tank

As predicted by the neurological principles, Charlie participated fully in the activities of the lower regions and in the activities suggested for the midbrain regions. However, he was not participating fully yet in the interpersonal or interthink learning dynamics required by modelling, preferring parallel activities with occasional cross-over into the group to offer help or to chat socially. On the other hand, he displayed a range of negative behaviours when expected to engage in any activities which demanded input from the higher-order regions such as writing and debating. Consequently, his behaviour problems increased markedly during these activities.

6. Discussion

The brain map is a clinical tool which informs lesson design in the context of boundary crossing between neuroscience and education. Given that modelling tasks can be difficult to plan and orchestrate, the role of the brain map is to help the educator proactively put in place learning conditions that would be most supportive of the individual. Since the brain map provides an approximation of the developmental status of certain key areas at a given point in time, it helps to establish the strengths and vulnerabilities of learners, thereby feeding into careful lesson planning and adaptations. This supports the role of the Christian educator in ensuring education begins discipleship, training up a child in the direction they should go (Proverbs 22.6, New King James Version), recognising their strengths and the giftings they possess and allowing opportunities for these gifting to be used.

Under the previous heading, it was illustrated how the data could be used in practice. It answered the research question of how we should structure mathematical modelling lessons if we could pinpoint the functional and structural vulnerabilities, and the subsequent lack of neural integration, in an individual's brain. The example being used was the planning of mathematical modelling tasks for students with developmental delays. Charlie's reaction to the interventions supports the neurobiological idea that he will learn more effectively when the activities are designed in line with the needs of the lower and midbrain levels, where the first signs of vulnerabilities have emerged. In other words, somatosensory, play-based and art techniques, were more relevant and accessible to Charlie than tasks which demanded extended periods of higher cortical function such as reading, writing and debating. If a learner has disruptions in the lower regions, they will engage more readily with learning activities that involve movement and sensory experiences, than sitting down with a worksheet. The understanding of Charlie's responses in the light of his personal history aligns with Jesus' example interacting with those he met with compassion. Jesus also utilised an often less direct route leading and prompting the crowds to a deeper understanding with parables and stories (Matthew 13, New King James Version). The approach to modelling leads and prompts Charlie towards a fuller understanding.

One could argue that in terms of higher cortex demands, Charlie quickly became rigid and refused to comply, or became chaotic (leaving the classroom, trying to catch fish or initiate imaginary sword fights). These behaviours align with Siegel's (2012) prediction of negative behavioural characteristics when demands are made to the mind in areas that have a poor flow of information through them.

The implication of this study is that through a tool of neuroscience a visual heuristic of an individual's brain structure and function are available to educators, which can be used to inform lesson planning and delivery. This clinical tool has significant implication for students who are chronologically at a certain age, but developmentally well-below the functioning of their peers. Essentially, it supports educators in making a range of predictions around the propensity of the learner to engage in set tasks at a given point in time. For example, the brain map allows us to gauge the level of the neurobiological resources that are available to individual learners for becoming engaged in modelling tasks. The data also helps us to plan the forms of engagement that will aid the construction of the model during the modelling activity, and the type of data structures or representations that will best support long-term development. This allows us to utilise the principle of partial redemption, leading the individual into more fullness of function and life.

The recommendations from the study is that modelling tasks should be introduced to learners with significant developmental delays and become a part of their learning repertoire. The expectation is that these modelling tasks take the form of precursors to more sophisticated models, and that the mode of construction or representation of the model are informed by and matches a learner's neurobiological data. As the brain, through appropriate intervention over time, begins to stabilise and integrate, learners will grow in their ability to produce more sophisticated representations of concepts. This requires a long-term commitment to modelling and very carefully planned lesson activities to support development and change through integration.

The key implication of the study is to argue that we do not use such forms of neurobiological data as confirmation to suspend modelling activities with SWD, but that we should use it in the input phase of our lesson planning to guide and inform our design of modelling activities.

7. Conclusion

Neuroscience, neurobiology, neuroplasticity, neural integration – what are the immediate applications of these fields to education? As demonstrated in the case study, the use of neurobiological data to plan mathematical modelling tasks for SWD in a boundary crossing space can contribute to more successful engagement from learners and realistic learning outcomes and expectations around model representations from educators. Thereby helping educators develop learning contexts that are driven by life values or moral dispositions embedded in both knowledge-that and knowledge-how activities, that require problem-solving, creativity and personal responses. Educators have a starting point, and learners have an engagement point, when modelling construction expectations and modes match neurobiological data. It can also provide practitioners with a viable theoretical and conceptual framework for understanding the unique experiences of SWD and their classroom challenges in terms of learning and behaviour. There is a rationale for further research and for the results of studies like this to have application beyond SWD for all children and classrooms. This is an exciting moment for educators to contribute to the dialogue of planning and conducting learning interventions which optimise the integration of neuro-systems and strengthen the higher-order functioning skills needed for increasingly sophisticated mathematical modelling. It is also an opportunity for educators to demonstrate the Christian values of designing curricular outcomes with care and sensitivity to meet the developmental needs of the students. Furthermore, it highlights both the usefulness of neuroscience tools and principles in practical classroom application and begins to address neuro-integration within the context of modelling classroom. Thus, both the fields of neuroscience and education are enhanced, showing that benefits can occur as part of a two-way street. However, the integrating of the principles of Christian curriculum design, neuroscience and mathematical modelling remains a challenge.

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