Journal of Sustainability Science and Management
Volume 17 Number 9, September 2022: 148-161
eISSN: 2672-7226

THE IMPACT OF NEUROSCIENCE LITERACY ON SUSTAINABILITY OF THE STUDENTS' MATHEMATICS LEARNING ENVIRONMENT

MOHAMAD ARIFFIN ABU BAKAR* AND AHMAD TERMIMI AB GHANI

Faculty of Ocean Engineering Technology and Informatics, Universiti Malaysia Terengganu, 21030 Kuala Nerus, Terengganu, Malaysia.

**Corresponding author: mohamadariffin6299@gmail.com*
Submitted final draft: 22 May 2022 *Accepted: 16 July 2022* http://doi.org/10.46754/jssm.2022.09.010

Abstract: Learning mathematics is strongly related to brain function. Neuroscience research has defined how different areas of the brain will mechanise and respond to the complex process of learning mathematics. This interrelationship requires practical details and clarification. However, a lack of neuroscience information and literacy inhibits efforts to improve the mathematics learning environment. Therefore, this study aims to determine the impact of neuroscience literacy on the mathematics learning environment of students. A systematic literature review was conducted using the PRISMA strategy, with the input of keywords into databases such as Scopus, ScienceDirect, Google Scholar, Pubmed and Web of Science, to search for the best articles on the subject. The year of publication, objective, content, results and dense discussions were analysed. The results suggest that several aspects of neuroscience literacy like principles, mechanisms and practices, are deemed important and may bring a positive impact in learning mathematics. The attributes affect cognition, psychology and behaviour in shaping and sustaining the students' mathematics learning environment based on personal, social, organisational and physical components or virtual spaces. As a result, neuroscience should be considered as an alternative to transforming and improving the outcome of mathematics learning among students.

Keywords: Neuroscience, neuroscience literacy, neuroscience's impact, mathematics learning, learning environment, sustainability.
Abbreviations:
AGES: Attention, generation, emotion and spacing
RAD: Reticular activating system (RAS), Affective filter in the amygdala and dopamine

Introduction

Mathematics learning is used to assess a country's educational quality in international initiatives, such as TIMSS and PISA (Karyotaki & Drigas, 2016; Leo & Muis, 2020). Compared with other subjects, mathematics is considered to hold on its own. Therefore, any learning concerns or problems in the subject must be given special attention. Solutions are very much needed, especially when integrating new knowledge and discoveries. The development of neuroscience knowledge has resulted in a synergy of biological science and learning psychology, resulting in the emergence of new concepts (Nouri, 2016). The integration of neuroscience and mathematics learning is regarded as extremely important and should be studied (Kuhl *et al.,* 2020). The frequently brought-up issue is whether neuroscience can address existing problems in the mathematics learning environment (De Smedt *et al.,* 2011). The main discussion among academics, professionals, practitioners and those involved in the field over the last two decades has been related to problems in the learning environment (De Smedt *et al.*, 2011; Amran *et al.*, 2018). The issues are linked to two major factors: The internal or self-factor of students such as motivation (Amran *et al.,* 2018), cognitive processes (Srimaharaj *et al.*, 2018; Fathiazar *et al.*, 2020), metacognitive skill sets (Cherrier *et al.,* 2020) and the ability to solve mathematical problems (Clark, Hudnall & Pérez-González, 2020) and external factors like physical, material, tools, curriculum and learning approaches (Otoo *et al*., 2018).

The rapid development of new technologies may help enhance the study of educational neuroscience (Nouri, 2016). It includes research on theories, models and implications at policy level, strategic planning, curriculum and syllabuses as well as classroom practices (De Smedt *et al.,* 2011). Many studies have been conducted to resolve questions on neuroscience intervention in the mathematics learning environment (Nouri, 2016; Amran *et al.*, 2018) which aim to fill the gap, establish correlations and test the significance between attributes in the two topics (Matta, 2020). The relationship between learning environment and neuroscience has been noticed for a long time (Kuhl *et al.*, 2020; Clark, Hudnall & Gonzalez, 2020). However, few studies only explain the situation as a source of information. Educators who are directly involved in the learning environment may be perplexed and unaware of the relationship between neuroscience and the learning environment (Dubinsky, 2010; Tan & Amiel, 2019; Kuhl *et al.*, 2020). Just several educators are involved in neuroscience research and education (Hohnen & Murphy, 2016; Kuhl *et al.*, 2020; Amran & Bakar, 2020). This is because clinical studies are becoming more aggressive and prominent, and have even been accompanied by the use of technology (Nouri, 2016). Neuroscience studies such as electroencephalography (EEG), positron emission tomography (PET) and functional magnetic resonance imaging (fMRI) have demonstrated the ability of neuroscience to provide a way to solve learning problems such as autism spectrum disorder (ASD), dyslexia, anxiety and numerical literacy issues with the help of computer technology (Nouri, 2016; Alpar & Hoeve, 2019).

These issues will be aggravated if educators are not exposed to neuroscience knowledge, are unaware of the benefits, do not explore the effectiveness of using its practices in the classroom and do not take advantage of the opportunities available. This study will conduct a systematic assessment and collect literature to explain the impact of neuroscience literacy on the students' mathematics learning environment. The main components that form the foundation of literacy will be dissected and the impact on students' mathematics learning will be discussed in-depth.

Conceptual Framework

Neuroscience is a multidisciplinary field that is rapidly evolving (Dorantes-González & Balsa-Yepes, 2020). It describes how a specific part of the brain shapes knowledge, behaviour, thought processes and learning (Willis, 2008; Amran *et al.*, 2019). Many neuroscience research focus on the brain's overall performance in the thought process including the rate, limit and potential of thought until the formation of permanent knowledge, attitudes, values and behaviours (Firmanto *et al.,* 2018). Educational Neuroscience (EN), Mind, Brain and Education (MBE), neuropedagogy and other theories have revealed an understanding of neuroscience's potential in explaining learning abilities and how students shape their learning environment (Patten, 2011; Nouri, 2016; Amran *et al.,* 2019). According to the Learning Environment Model, personal, social, organisational, physical and virtual spaces are components of the learning environment (Gruppen & Fogarasi, 2021). External and internal factors such as the physical classroom, learning resources, curriculum, motivation, interest, enjoyment, emotion, attention, cognitive process, memory and learning experience all have an impact on these components (Ochsner, 2000; White, 2012; Hohnen & Murphy, 2016; Otoo *et al.*, 2018; Alpar & Hoeve, 2019). These factors will shape learning management and regulation where they are closely related to neuroscience concepts and mechanisms that occur in various sections of the brain (Hohnen & Murphy, 2016). As a result, it can be concluded that a solid understanding and literacy of neuroscience can contribute to a more conducive student learning environment.

The AGES model (Davachi *et al.*, 2010) and RAD Learning concept (Willis, 2008) explore how neuroscience may influence the learning environment. The former model (which stands for Attention, Generation, Emotion and Spacing) explains how people cope with a learning situation and shape their self and social environment (Davachi *et al.*, 2010; Davis *et al.*, 2014). The latter concept which comprises three neuroscience mechanisms namely the Reticular activating system (RAS), Affective filter in the amygdala and Dopamine, ensures that learning occurs optimally through self-efficacy and also contact with the environment (Willis, 2008). Previous research has explained the role of neuroscience in shaping students' learning environments. According to Molenberghs *et al.* (2011), Kuhl *et al.* (2020), Clark, Hudnall and Gonzalez (2020) and Barokah, Budiyono and Saputro (2020), neuroscience has an impact on student motivation, metacognition and mathematical problem-solving. There is a link between the learning environment and neuroscience literacy, and they both influence one another (Hohnen & Murphy, 2016). As a result of the lack of studies to implement the concepts, approaches and applications of neuroscience in the mathematics learning environment, there is a need to clarify the relationship and effects between the two constructs as depicted in Figure 1.

It is important to know the interaction between neuroscience literacy and student learning environment. This study takes this initiative to describe aspects or dimensions in the relationship and collision of neuroscience with the mathematics learning environment. Next, it is necessary to find out the impact on students, which is to determine the positive impact on mathematics learning. Two research questions will be the focus of this systematic literature review namely:

i. What are the aspects of neuroscience literacy that influence students' mathematics learning environment?
ii. What is the impact of neuroscience literacy on students' mathematics learning environment?

Methodology

This study starts with a search for articles and journals containing the following keywords: "neurosciences education", "neuroscience learning", "educational neurosciences", "neurosciences-based learning", "brain and education" and "brain-based learning" in Google Scholar, Scopus, ScienceDirect, Pubmed and Web of Science. The subject to focus on was mathematics or its related learning. Relevant journals were chosen by first reviewing the abstract and if it met the criteria, the contents would be explored in considerable detail. Literature, data, findings, results and discussion were based on the methodology of Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) proposed by Moher *et al.* (2009). A total of 17 articles were selected after going through the identification, screening, eligibility and inclusion criteria. Some articles did not mention mathematics learning in their titles or abstracts but they were chosen because they were somewhat relevant and their concerns were discussed. Table 1 depicts an analysis of the aspects discussed concerning themes involving neuroscience knowledge that influenced the student mathematics learning environment.

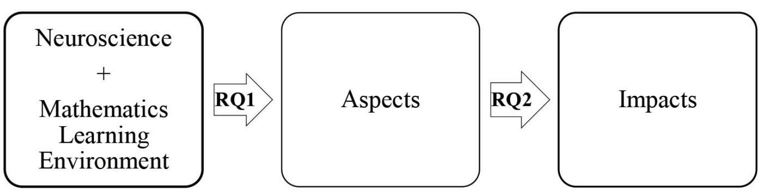

Figure 1: The conceptual framework of the study

Table 1: Analysis of aspects discussed in neurosciences related to the mathematics learning environment

Authors	Objectives	Aspects Discussed	Descriptions
(1) Pluck *et al.* (2020)	i. To assess for neurobehavioral traits and intelligence, and correlate to grade point average (GPA) data	i. Neurobehavioral traits ii. Intelligence	i. Neurobehavioral traits are individual self-disciplines such as perception, way of thinking and self-management ii. Intelligence is an individual's tendency and ability in cognitive coordination
(2) Grospietsch and Mayer (2019)	i. To demonstrate the knowledge of neuroscience literacy among pre-service sciences teachers	i. Neuromyths	i. Neuromyths are scientific misconceptions regarding the potential and function of the brain, the brain profile, learning and memory
(3) De Smedt *et al.* (2011)	i. To discuss the cognitive dimension and its correlation with neuroscience knowledge	i. Cognition	i. Cognitive neuroscience is an important aspect to describe the learning process and level of thinking such as analysis and reasoning
(4) Susac and Braeutigam (2014)	i. To discuss brain region activation and functions in elements of mathematics education	i. Brain regions	i. A specific part of the brain has an executive function that is related to behaviour, cognitive processes and psychology
(5) Cherrier *et al.* (2020)	i. To analyse the impact of brain knowledge and metacognition on the academic performance of students based on the NeuroStratE intervention programme	i. Metacognition	i. Metacognition is the knowledge of personal cognitive processes, self-regulation and own monitoring during learning
(6) Martín-Lobo *et al*. (2018)	i. To analyse, relate and compare learning strategies and academic performance of students from a neuropsychological perspective	i. Neuropsychology	i. Refer to motivational and metacognitive matters that force students to plan, manage and individually take control of their learning process
(7) Clark, Hudnall and Pérez-González (2020)	i. To examine the neural responses in children when exposed to a new, unfamiliar mathematics concept	i. Brain region activation	i. Activation and functional connectivity of brain regions depends on learning and individual cognitive activity

(8) Kuhl *et al*. (2020)	i. To show that there are significant links between the rate of neuroplastic change of cortical surface anatomy and children's early mathematical abilities	i. Neuroplasticity	i. Neural reorganisation processes include the change in thickness and folding of brain anatomy
(9) Serpati and Loughan (2012)	i. To quantitatively identify what teachers regard as beneficial in neuroeducation ii. To explore teachers' experiences and viewpoints on how neuroscience may assist their teaching and learning experience	i. Neuroeducation ii. Brain structure	i. Understanding of the brain for educational programme development ii. Neuroscience knowledge is essential to effectively serve the needs of educators
(10) Hohnen and Murphy (2016)	i. To bring together several convergent and complementary ideas in neuroscience to create a model outlining the optimal learning environment for a child in a classroom	i. Neurosciences knowledge ii. Brain development	i. Understanding of students' learning and its relationship with brain regions ii. Information and facts about brain development and brain region functioning
(11) Srimaharaj *et al.* (2018)	i. To propose the method to define the learning state of each student via brain cognitive performance identification during mathematics learning	i. Cognitive performance	i. Refering to student's ability to pay attention, how they focus during learning and thinking skills related to learning tasks and time
(12) Fathiazar *et al.* (2020)	i. To assess the efficacy of an educational neuroscience-based curriculum in improving academic achievement in elementary students with a mathematical learning disorder	i. Cognitive neuroscience	i. Source of information for educational thinking and practice ii. Psychological foundations of behaviour and mind iii. New insights into neural mechanisms iv. Underlying learning, memory, growth, thinking, excitement and motivation

(13) Mareschal (2016)	i. Discussing behavioural and neuroimaging evidence with children suggests that improving inhibitory control may be beneficial	i. Inhibitory control	i. Knowledge about how the brain controls the many competing beliefs that hold in the mind ii. The need for children to inhibit pre-existing beliefs or superficial perceptions to engage in acquiring and applying new and counterintuitive knowledge
(14) Adiastuty *et al.* (2020)	i. To survey the creative thinking patterns in mathematics learning viewed from the gender of vocational high school students	i. Creativity	i. About cognitive processes and how the brain processes work
(15) Bartoszeck and Bartoszeck (2012)	i. To survey teachers on how neuroscience can improve teaching and learning	i. Neuroscience literacy	i. Information about the teacher's belief to refer to neuroscience contribute to the teaching and learning, how the finding effectively to the improvement of educational practices
(16) Amran and Bakar (2020)	i. To investigate how student's emotion affect their learning of mathematics and their memory	i. Emotion learning	i. Information about how emotion influences and stimulates students' cognitive processes in learning
(17) Aisha Mahmood *et al.* (2012)	i. Analysing disparities in mathematical thinking, skills, abilities, processes and achievements through the lens of cultural neuroscience	i. Cultural neuroscience	i. How does cultural psychology influence multi-level thinking processes and styles like emotion, perception and analysis?

Several terms from the analysis table could be summarised as basic components in understanding neuroscience literacy. These terms which are very relevant to education or more specifically, the mathematics learning environment could be referred as:

i. Principles of neuroscience, knowledge of what neuroscience is the brain structure, including parts and their basic functions. The knowledge provided accurate information about which parts of the learning process were effectively involved, such as perception, beliefs, motivation, attention, thinking process and memory. Knowledge of psychology and behaviour that resulted in effective learning was included.

ii. Mechanisms of neuroscience are the actual process of learning in the brain, including the specific activation, plasticity and connectivity of regions as well as the role of the synapse, dopamine and the amygdala. The effects of mechanisms on the deep learning process, such as metacognition, insight, problem-solving and memory regulation. Knowing about these mechanisms could help to improve understanding of the brain's full potential and dispel myths.

iii. The practice of neuroscience, an application of neuroscience knowledge to individual development such as learning, thinking, behaviour, management and so on. Indeed, neuroscience could be used as a method, framework, strategy, model and instrument in shaping the learning environment.

Table 2: Meta-analysis of the impact of neuroscience literacy on student mathematics learning environment

Component of Learning Environment	**Aspects of Neuroscience**	**Impact on the Students**	**References**
Personal	Principles	i. Aware of self-potential ii. Avoid misconceptions about self-efficacy (myth) iii. Form a mathematical belief system iv. Able to avoid "math anxiety"	De Smedt *et al.* (2011), Mareschal (2016), Martín-Lobo *et al.* (2018), Grospietsch and Mayer (2019), Cherrier *et al.* (2020), Amran and Bakar (2020)
	Mechanisms	i. Self-determination ii. Know how to sustain motivation, attention and intention iii. Make students alert to learning aims iv. Can manage time and is alert to affective self-learning time v. Know a more effective way of thinking according to the order of thinking vi. Build deep learning by knowing the mechanisms of self-learning	De Smedt *et al.* (2011), Susac and Braeutigam (2014), Hohnen and Murphy (2016), Mareschal (2016), Grospietsch and Mayer (2019), Cherrier *et al.* (2020), Clark, Hudnall and Pérez-González (2020), Kuhl *et al.* (2020), Adiastuty *et al.* (2020)
	Practice	i. Know how to improve learning memory ii. Plan and monitor learning and engagement iii. Always sensitive to personal health and brain abilities iv. Improve mathematical problem-solving skills v. Practise creative mathematical problem-solving methods vi. Can manage learning resources	De Smedt *et al.* (2011), Susac and Braeutigam (2014), Hohnen and Murphy (2016), Srimaharaj *et al.* (2018), Pluck *et al.* (2020), Cherrier *et al.* (2020), Adiastuty *et al.* (2020)

Social	Principles	i. Take advantage of peer intelligence, which is the level of common brain ability ii. Able to reduce math anxiety	Susac and Braeutigam (2014), Martín-Lobo *et al.* (2018), Clark, Hudnall and Pérez-González (2020)
	Mechanisms	i. Help and guide each other ii. Improve self-learning monitoring skills iii. Practise metacognitive discussion to enhance understanding	De Smedt *et al.* (2011), Mareschal (2016), Srimaharaj *et al.* (2018), Amran and Bakar (2020), Cherrier *et al.* (2020), Kuhl *et al.* (2020), Fathiazar *et al.* (2020), Adiastuty *et al.* (2020)
	Practice	i. Being active and interacting with others ii. Improve social skills with cooperative and collaborative thinking iii. Solve mathematical problems by learning together (peer tutoring)	Serpati and Loughan (2012), Bartoszeck and Bartoszeck (2012), Aisha Mahmood *et al.* (2012), Hohnen and Murphy (2016), Martín-Lobo *et al.* (2018), Pluck *et al.* (2020), Cherrier *et al.* (2020), Amran and Bakar (2020)
Organizational	Principles	i. Comprehensive mathematics syllabus based on students' age and brain development ii. Optimise learning capacity with "sensitive periods" related to brain anatomy and their functions	De Smedt *et al.* (2011), Serpati and Loughan (2012), Aisha Mahmood *et al.* (2012), Susac and Braeutigam (2014), Srimaharaj *et al.* (2018), Clark, Hudnall and Pérez-González (2020), Fathiazar *et al.* (2020)
	Mechanisms	i. Improve cognitive enhancement using technological tools ii. Using optimal learning periods in line with neuroscience mechanisms ii. Using tools to support students in their decision-making process	De Smedt *et al.* (2011), Bartoszeck and Bartoszeck (2012), Susac and Braeutigam (2014), Hohnen and Murphy (2016), Martín-Lobo *et al.* (2018), Kuhl *et al.* (2020)
	Practice	i. Diversify delivery strategies that can improve thinking skills ii. Creating classroom climate and the student behaviour	Serpati and Loughan (2012), Aisha Mahmood *et al.* (2012), Pluck *et al.* (2020), Cherrier *et al.* (2020), Fathiazar *et al.* (2020)

Physical and virtual spaces	Principles	i. Customise learning spaces and manage self-directed learning orientations	Martín-Lobo *et al.* (2018), Cherrier *et al.* (2020)
	Mechanisms	i. Build a learning environment that can increase motivation, belief and fun ii. Maintain positive emotions, excitement	Susac and Braeutigam (2014), Martin-Lobo *et al.* (2018), Srimaharaj *et al.* (2018), Amran and Bakar (2020), Kuhl *et al.* (2020)
	Practice	i. Diversify learning spaces that are conducive and lead to thinking and inquiry activities ii. Take advantage of learning resources	Serpati and Loughan (2012), Bartoszeck and Bartoszeck (2012), Aisha Mahmood *et al.* (2012), Grospietsch and Mayer (2019), Cherrier *et al.* (2020), Fathiazar *et al.* (2020)

Results and Discussion

This systematic literature review included 17 articles that were both qualified and sufficient to be discussed. The research questions below would be the focus of the discussion.

RQ1: What are the aspects of neuroscience literacy that influenced students' mathematics learning environment?

Based on the review and revelation, it an interaction could be deduced between neuroscience and the mathematics learning environment. As neuroscience is vast, there were numerous terms used in different fields and branches of its research. Thus, to facilitate an understanding of neuroscience literacy, this study had summed up the relationship between neuroscience and mathematics learning in three aspects. Furthermore, it could explain how neuroscience literacy affected the students' mathematics learning environment. Based on the Learning Environment Model (Gruppen & Fogarasi, 2021), Table 2 states an interpretation of aspects of neuroscience literacy that affected the mathematics learning environment.

Internal and external factors could work together to create a positive and effective mathematics learning environment. Personal, social, organisational, and physical and virtual spaces as discussed by Gruppen and Fogarasi (2021) were internal and external factors that could ensure a conducive learning environment. These elements could bring positive and effective impact on students' cognitive, psychological and behavioural learning outcomes (Martín-Lobo *et al.*, 2018; Pluck *et al.*, 2020; Cherrier *et al.*, 2020). According to De Smedt *et al.* (2011), Srimaharaj *et al.* (2018), Amran and Bakar (2020) and Adiastuty *et al.* (2020), some aspects of neuroscience were also the drivers of cognitive, psychological and behavioural elements in mathematics learning. This overlap implied that neuroscience constructs and the learning environment both influence the cognitive, psychological and behavioural aspects of learning. In short, aspects of neuroscience were interconnected and mutually influential in the learning of mathematics.

This demonstrated that neuroscience knowledge should be thoroughly understood, and neuroscience practices should be executed in a mathematics learning environment (De Smedt *et al.*, 2011; Serpati & Loughan, 2012; Hohnen & Murphy, 2016). Accordingly, the findings of this study could reveal how the proposed components of neuroscience literacy such as principles, mechanisms and practise could act as connecting lines and influence students' mathematics learning. A rigorous understanding of the structure, anatomy, parts, mechanisms and functions of the brain, as well as its adaptation and implementation would provide a clear image of how mathematical learning occurs. The relationship between neuroscience and mathematics learning had been described as a very complex system (De Smedt *et al.*, 2011; Clark, Hudnall & Pérez-González, 2020) but when the dimensions of the learning environment were specifically sectioned, it provided simpler and clearer answers and descriptions of the relationship. According to De Smedt *et al.* (2011), Bartoszeck and Bartoszeck (2012) and Grospietsch and Mayer (2019), faults in the delivery of neuroscience literacy would give rise to misconception, unwillingness to pay attention and feeling of irrelevance, particularly among those involved in learning. As a result, the aspects of neuroscience literacy proposed were an appropriate effort in providing understanding and enhancing the mathematics learning environment.

RQ2: What is the impact of neuroscience literacy on students' mathematics learning environment?

The main issue in mathematics learning involved internal and external factors related to students' cognitive, psychological and behavioural elements (De Smedt *et al.*, 2011; Martín-Lobo *et al.*, 2018; Pluck *et al.*, 2020). Internal factors included motivation, perception, belief, cognitive, metacognitive sets, thinking skills, memory and problem-solving ability (Mareschal, 2016; Cherrier *et al.*, 2020; Adiastuty *et al.*, 2020; Fathiazar *et al.*, 2020; Amran & Bakar, 2020). The external factors comprised learning resources, syllabus, curriculum, delivery and physical learning activities, and learning methods (Bartoszeck & Bartoszeck, 2012; Aisha Mahmood *et al.*, 2012; Hohnen & Murphy, 2016; Cherrier *et al.*, 2020). These factors influenced and could leave an impact on the mathematics learning environment of students.

According to Table 2, a better comprehension of neuroscience literacy might assist in the specialised treatment of a mathematics learning environment. The meta-analysis table mentioned above could provide information to students and mathematics educators in particular, to help them solve problems in teaching and learning. Serpati and Loughan (2012), Susac and Braeutigam (2014), Hohnen and Murphy (2016) and Clark, Hudnall and Pérez-González (2020) stated that knowledge of brain structure, anatomy, function and mechanisms specific to learning needs might shape students' positive self-esteem, increase their confidence and reduce anxiety in learning mathematics. This effect had the potential to create an effective learning environment. Students would feel a sense of belonging and ownership in their learning. Personal factors such as self-determination, goal setting, motivation, efficacy, self-regulation and thinking skills could be improved when students were exposed to neuroscience literacy as discussed by De Smedt *et al.* (2011), Susac and Braeutigam (2014), Grospietsch and Mayer (2019), Cherrier *et al.* (2020), Clark, Hudnall and Pérez-González (2020) and Kuhl *et al.* (2020). Mathematics educators could use strategies to stimulate student interest and motivation such as providing induction sets based on neuroscience mechanisms, memory regulation, metacognition or amygdala activation (Willis, 2008; Davachi *et al.,* 2010; Amran & Bakar, 2020). These include teaching with infographic methods, storytelling and relating the topics to daily situations.

Furthermore, neuroscience literacy could help students learn mathematics effectively. Based on students' brain development, plasticity abilities, memory and thought processes, educators could provide resources, content, materials and interesting delivery methods. De Smedt *et al.* (2011), Susac and Braeutigam (2014), Hohnen and Murphy (2016), Srimaharaj *et al*. (2018), Pluck *et al.* (2020), Cherrier *et al*. (2020) and Adiastuty *et al.* (2020) had explained how executive brain function was formed when content and delivery methods were centred on student brain activity. This impact would result in in-depth learning that corresponded to the RAD concept proposed by Willis (2008). Learning resources and materials should be provided following neuroscience processes or regulations. Mathematics tasks should be coordinated with students' brain and memory activities and not directly burdened with questions of a critical and creative nature (Adiastuty *et al*., 2020). This was to ensure that motivation continued to be built and students did not experience sudden cognitive load (Willis, 2008).

Organisational and classroom settings based on neuroscience literacy might also have a significant impact on mathematics learning. Syllabus and learning materials that were appropriate and effective for brain development could also influence outcomes (Willis, 2008; Cherrier *et al.*, 2020). In this context, Mahmood *et al.* (2012), Amran and Bakar (2020), Cherrier *et al.* (2020) and Fathiazar *et al.* (2020) reported that technological aid could increase the impact on students. In this context, the current curriculum might be in need of constant review to suit the level of brain maturity. The integration of current technologies was also highly encouraged as students were more inclined to use technological gadgets such as tablets and smartphones. Improvements in classroom settings, strategies and learning resources based on neuroscience practice could improve scaffolding, networking, and collaboration while also influencing aspects of social thinking and learning culture (Mahmood *et al.*, 2012). Computerised strategies with futuristic learning applications could drive motivation, interest and enjoyment in students. For example, the use of infographic textbooks and digital materials could further stimulate the students' memory and thinking regulation.

Furthermore, as reported by Mahmood *et al.* (2012), Mareschal (2016), Srimaharaj *et al.* (2018) and Fathiazar *et al.* (2020), the inclusion of neuroscience practices into the mathematics learning environment had potential to improve critical thinking, questioning, reasoning and computational skills. Students could logically process their learning, which would form a direct effect on emotion, attention, generation and spacing when they use neuroscience mechanisms to coordinate their thinking. They could logically identify weaknesses and strengths, and errors and inaccuracies to solve problems (De Smedt *et al.*, 2011; Srimaharaj *et al.*, 2018). Solving complex mathematical problems would be easier and implemented independently if the students' thinking coordination was systematic, managed, critical and creative.

Limitations and Recommendations

To ensure that this effort was sustainable, the study's weaknesses and limitations were also discussed. The first and most essential limitation was the article selection. Not all articles were chosen in this study because of a set of criteria that had to be followed and the selection was calculated sufficiently when it reached saturation, where triggers could be implemented by testing the constructed concepts. However, there would be a gap in the quality and accuracy of the selected articles because there were more appropriate and accurate ones to highlight. As a result, it was recommended that future studies with refined and careful selection be conducted to support the findings of this study. Although mathematics learning was presented as an interplay of the present study, the findings could be applied to other subjects and learning areas. This would open more space for studies and discussions, and encourage possibilities for specialised knowledge to develop.

In short, aspects such as knowledge contribution should be defined as the direction of future research, i.e., exploring the principles, mechanisms and practises in neuroscience to translate them into learning elements such as cognition, metacognition, intrinsic and extrinsic motivational elements, emotions and achievements. Alternatively, future studies could explore thinking skills such as creativity, critical, reasoning and so on. Methodologies could also be varied to improve the consistency of theory and applications in neuroscience such as addressing the lack of empirical, evidence-based, theoretical, design and developmental studies.

Conclusion

This study explained the impact of neuroscience literacy on the learning environment in general, and mathematics in particular. Based on the findings, it was possible to conclude that neuroscience knowledge played a significant role in ensuring the effectiveness of learning. Educators and stakeholders should be invited to develop knowledge and make neuroscience the foundation of educational transformation. These findings could pave the way for positive perception of neuroscience literacy, as well as a path to change the educational setting.

Acknowledgements

This research was funded by Fundamental Research Grant Scheme (FRGS), Ministry of Higher Education Malaysia FRGS/1/2022/STG06/UMT/02/4 (Grant No. 59722) and Universiti Malaysia Terengganu.

References

Adiastuty, N., Waluya, S. B., Rochmad & Aminah, N. (2020). Neuroscience study: Gender and mathematical creative thinking skills in vocational high school students. *Journal of Physics: Conference Series*, *1613*(2020), 1-7. doi:10.1088/1742-6596/1613/1/012056

Aisha Mahmood, Mohd Fauzi Othman & Yudariah Mohammad Yusof. (2012). A conceptual framework for mathematical ability analysis through the lens of cultural neuroscience. *Procedia-Social and Behavioral Sciences*, *56*(2012), 175-182.

Ali Nouri. (2016). Exploring the nature and meaning of theory in the field of neuroeducation studies. *International Journal of Educational and Pedagogical Sciences*, *10*(8), 2743-2746.

Ali Salim Rashid Alghafria & Hairul Nizam Ismail. (2011). The effects of neuroscience- and non-neuroscience-based thinking strategies on primary school students' thinking. *Procedia Social and Behavioral Sciences*, *15*(2011), 3291-3298.

Alpar, G., & Hoeve, M. V. (2019). Towards Growth-Mindset Mathematics Teaching in the Netherlands. In C. M. Stracke (Ed.), LINQ, *EPiC Series in Education Science*, *2*, 1-17.

Alvi, E., Mursaleen, H., & Batool, Z. (2016). Beliefs, processes and difficulties associated with mathematical problem solving of Grade 9 students. *PJERE*, *1*(1), 85-110.

Amran, M. S., & Bakar, A. Y. A. (2020). We feel, therefore we memorize: Understanding emotions in learning mathematics using neuroscience research perspectives. *Universal Journal of Educational Research*, *8*(11B), 5943-5950. DOI: 10.13189/ujer.2020.082229

Amran, M. S., Rahman, S., Surat, S., & Abu Bakar, A. Y. (2019). Connecting neuroscience and education: Insight from neuroscience findings for better instructional learning. *Journal for the Education of Gifted Young Scientists*, *7*(2), 341-352. http://dx.doi.org/10.17478/jegys.559933

Ari Firmanto, Imanuel Hitipeuw, Marthen Pali & Fattah Hanurawan. (2019). Learning style based teaching to enhance student metacognition skills (Review of Neuroscience Learning Theory). *Advances in Social Science, Education and Humanities Research*, *304*, 467-472.

Barokah, I., Budiyono & Saputro, D. R. S. (2020). Mathematics module based on problem-based learning to improve students' metacognition. *Journal of Physics: Conference Series*, *1613*(2020), 1-10.

Bartoszeck, A. B., & Bartoszeck, F. K. (2012). How in-service teachers perceive neuroscience as connected to education: An exploratory study. *European Journal of Educational Research*, *1*(4), 301-319. DOI: 10.12973/eu-jer.1.4.301.

Cherrier, S., Le Roux, P. Y., Gerard, F. M., Wattelez, G., & Galy, O. (2020). Impact of a neuroscience intervention (NeuroStratE) on the school performance of high school students: Academic achievement, self-knowledge and autonomy through a metacognitive approach. *Trends in Neuroscience and Education*, *18*(2020), 1-10. https://doi.org/10.1016/j.tine.2020.100125

Clark, C. A. C., Hudnall, R. H., & Pérez-González, S. (2020). Children's neural responses to a novel mathematics concept. *Trends in Neuroscience and Education*, *20*(2020), 1-9. https://doi.org/10.1016/j.tine.2020.100128

Corrado Matta. (2020). Neuroscience and educational practice: A critical assessment from the perspective of philosophy of science. *Educational Philosophy and Theory*, (2020), 1-15. https://doi.org/10.1080/00131857.2020.1773801

Davachi, L., Kiefer, T., Rock, D., & Rock, L. (2010). Learning that lasts through AGES: Maximizing the effectiveness of learning initiatives. *Neuroleadership Journal*, *3*, 53-63.

Davis, J., Balda, M., Rock, D., McGinniss, P., & Davachi, L. (2014). The science of making learning stick: An update to the ages model. *Neuroleadership Journal*, *5*, 1-15.

De Smedt, B., Daniel Ansari, Grabner, R. H., Hannula-Sormunen, M., Schneider, M., & Verschaffel, L. (2011). Cognitive neuroscience meets mathematics education: It takes two to Tango. *Educational Research Review*, *6*(2011), 232-237. http://doi.org/10.1016/j.edurev.2011.10.002

Dorantes-González, D. J., & Balsa-Yepes, A. (2020). A neuroscience-based learning technique: Framework and application to STEM. *International Journal of Educational and Pedagogical Sciences*, *14*(3), 197-200.

Dubinsky, J. M. (2010). Neuroscience education for prekindergarten-12 teachers. *The Journal of Neuroscience*, *30*(24), 8057-8060.

Fathiazar, E., Mani, A., Adib, Y., & Sharifi, Z. (2020). Effectiveness of an educational neuroscience-based curriculum to improve academic achievement of elementary students with mathematics learning disabilities. *Research and Development in Medical Education*, *9*(1), 18-18.

Fleming, S. M., Huijgen, J., & Dolan, R. J. (2012). Prefrontal contributions to metacognition in perceptual decision making. *The Journal of Neuroscience*, *32*(18), 6117-6125.

Grospietsch, F., & Mayer, J. (2019). Pre-service science teachers' neuroscience literacy: Neuromyths and a professional understanding of learning and memory. *Frontiers in Human Neuroscience*, *13*(20), 1-16. DOI: 10.3389/fnhum.2019.00020

Gruppen, L. D., & Fogarasi, M. C. (2021). Considerations on conducting research on wellness in the context of the learning environment. *Global Advances in Health and Medicine*, *10*, 1-9. https://doi.org/10.1177/2164956121989708

Hohnen, B., & Murphy, T. (2016). The optimum context for learning; Drawing on neuroscience to inform best practice in the classroom. *Educational & Child Psychology*, *33*(1), 75-90.

Karyotaki, M., & Drigas, A. (2016). Latest trends in problem solving assessment. *International Journal of Recent Contribution from Engineering*, *Science & IT*, *4*(2), 1-10. http://dx.doi.org/10.3991/ijes.v4i2.5800

Kuhl, U., Friederici, A. D., Legascreen consortium & Skeide, M. A. (2020). Early cortical surface plasticity relates to basic mathematical learning. *NeuroImage*, *204*(2020), 1-9. https://doi.org/10.1016/j.neuroimage.2019.116235

Leo, I. D., & Muis, K. R. (2020). Confused, now what? A Cognitive-Emotional Strategy Training (CEST) intervention for elementary students during mathematics problem solving. *Contemporary Educational Psychology*, *62*(2020), 101879. https://doi.org/10.1016/j.cedpsych.2020.101879

Mareschal. (2016). The neuroscience of conceptual learning in science and mathematics. *Current Opinion in Behavioral Sciences*, *10*, 114-118.

Martín-Lobo, P., Martínez-Álvarez, I., Muelas, Á., Pradas, S., & Magreñán, A. (2018). A study of 16 years old student learning strategies from a neuropsychological perspective: An intervention proposal. *Trends in Neuroscience and Education*, *11*, 1-8.

Michelle Tan, Y. S., & Amiel, J. J. (2019). Teachers learning to apply neuroscience to classroom instruction: Case of professional development in British Columbia. *Professional Development in Education*. https://doi.org/10.1080/19415257.2019.1689522

Molenberghs, P., Trautwein, F. M., Bockler, A., Singer, T., & Kanske, P. (2016). Neural correlates of metacognitive ability and of feeling confident: A large-scale fMRI study. *Social Cognitive and Affective Neuroscience*, *2016*, 1942-1951. DOI: 10.1093/scan/nsw093.

Ochsner, K. N. (2000). Are affective events richly recollected or simply familiar? The experience and process of recognizing feelings past. *Journal of Experimental Psychology: General*, *129*(2), 242-261. DOI: 10.1037//0096-3445.129.2.242

Otoo, D., Iddrisu, W. A., Kessie, J. A., & Larbi, E. (2018). Structural model of students' interest and self-motivation to learning mathematics. *Education Research International*, *2018*, 1-10. https://doi.org/10.1155/2018/9417109

Patten, K. E. (2011). The somatic appraisal model of affect: Paradigm for educational neuroscience and neuropedagogy. *Educational Philosophy and Theory*, *43*(1), 87-97.

Pluck, G., Bravo Mancero, P., Ortiz Encalada, P. A., Urquizo Alcivar, A. M., Maldonado Gavilanez, C. E., & Chacon, P. (2020). Differential associations of neurobehavioral traits and cognitive ability to academic achievement in higher education. *Trends in Neuroscience and Education*, *18*, 1-11.

Serpati, L., & Loughan, A. R. (2012). Teacher perceptions of neuroeducation: A mixed methods survey of teachers in the United States. *Mind, Brain, and Education*, *6*(3), 174-176.

Srimaharaj, W., Chaising, S., Temdee, P., Chaisricharoen, R., & Sittiprapaporn, P. (2018). Brain cognitive performance identification for student learning in classroom. *The 6th Global Wireless Summit (GWS-2018)*, 102-106.

Susac, A., & S. Braeutigam (2014). A case for neuroscience in mathematics education. *Frontiers in Human Neuroscience*, *8*, 1-3.

White, A. L. (2012). What does brain research say about teaching and learning mathematics? *Southeast Asian Mathematics Education Journal*, *2*(2), 75-87.

Willis, J. (2008). *How your child learns best: Brain-friendly strategies you can use to ignite your child's learning and increase school* success. USA: Sourcebooks, Inc.