THE DEVELOPMENT OF A TECHNOLOGY-ENHANCED, BRAIN-BASED FRAMEWORK FOR SCIENCE EDUCATION: A SOUTH AFRICAN CASE STUDY

by

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I dedicate this study to my God and give Him all the honour! He gave me the strength to be resilient. He encouraged me, through Philippians 4:13: “I can do all things through Christ, who strengthened me.” He constantly reminded me to take only one step at a time.

Thank you, Lord, for Your unending mercy and grace. It was not through my power, wisdom and endurance that I achieved this. Your grace is enough.

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LIST OF ACRONYMS AND ABBREVIATIONS

3D	Three-dimensional
4D-TPACK	Four Dimensions of TPACK (Framework)
APS	Admission Point Score
AR	Augmented Reality
CHE	Council on Higher Education
DHET	Department of Higher Education and Training
ERN	Error-related Negativity
ERP	Event-related Potential
FET	Further Education and Training
ICT	Information and Communication Technology
LMS	Learning Management System
MBE	Mind-brain Education
MOOC	Massive Open Online Course
MSLQ	Motivated Strategies of Learning Questionnaire
NSFAS	National Student Financial Aid Scheme
OECD	Organisation for Economic Cooperation and Development
SAMR	Substitution, Augmentation, Modification, Redefinition
SDT	Self-determination Theory
SRS	Student Response System
STEM	Science, Technology, Engineering and Mathematics
TBBaSK	Technology-enhanced, Brain-based Science Knowledge (Framework for science education)
TIMSS	Trends in International Mathematics and Science Study
TPACK	Technological, Pedagogical Content Knowledge (Framework)
TPASK	Technological Pedagogical Science Knowledge (Framework)
TUT	Tshwane University of Technology
UDL	Universal Design for Learning
VR	Virtual Reality

THE DEVELOPMENT OF A TECHNOLOGY-ENHANCED, BRAIN-BASED FRAMEWORK FOR SCIENCE EDUCATION: A SOUTH AFRICAN CASE STUDY

ABSTRACT

This study suggests a teaching framework to enhance the intrinsic motivation, mindset and science performance of undergraduate university students from disadvantaged socioeconomic backgrounds in South Africa.

The Technology-enhanced, Brain-based and Science Knowledge (TBBaSK) Framework for science education is based on the Technological Pedagogical Content Knowledge (TPACK) Framework. However, it integrates elements, tenets and principles of brain-based learning (BBL) to assist lecturers in their planning and presentation of science lectures. It contributes to research on technological, pedagogical and content knowledge by adhering to the call to consider educational contexts and real-life classroom applications and develop metacognition in teaching and learning approaches. Furthermore, it reacts to recommendations from studies on brain-based learning to provide more support in science classrooms. The application of this framework includes brain-based learning principles and applications such as mindfulness techniques, the impact of mind moves as brain exercises, an understanding of mindset, multisensory teaching and the development of metacognition. These techniques are integrated with technology in science education, as described by the TPACK Framework.

The TBBaSK Framework was applied using a case study strategy at the Tshwane University of Technology (TUT), a university of technology in South Africa. An experiment was conducted over six Saturdays, focusing on Fluids from the first-year Physics curriculum to determine the framework’s influence on mindset, motivation and science performance. Both qualitative and quantitative data were collected during the experiment. The mindset and motivation of both a control group and an experimental group were measured before and after the intervention using standardised tests. Science performance was measured before and after assessment.

The combination of the qualitative and quantitative results shows that implementing the components of the TBBaSK Framework positively influenced motivation, mindset and science performance. Qualitative results showed that 91.3% of the participants of the experimental group felt more self-motivated, believed they could kindle a growth mindset and felt optimistic that the intervention had helped them understand science better.

Keywords: TPACK, brain-based learning (BBL), intrinsic motivation, mindset, technology, multisensory education, science performance,

CHAPTER 1: INTRODUCTION

“The capacity to learn is a gift, the ability to learn is a skill, and the willingness to learn is a choice.” – Brain Herbert (Pheiffer, 2018:80–83)

1.1 INTRODUCTORY REMARKS

This thesis describes research to constitute a technology-enhanced, brain-based framework for science education. This is done in reaction to the urgent need for improved science education.

The poor performance of science students is a global problem. Freeman et al. (2014) cited the President’s Council of Advisors on Science and Technology from the USA, which called for 33% more students to complete their bachelor’s degrees in science, technology and mathematics. There is an increasing demand for students in science-related professions. The cost of not fixing this problem is enormous to the economy (Reddy et al., 2016). The resolution of this issue in the USA remains pending, as indicated by Yik et al. (2022) in the *International Journal of STEM Education*. The Trends in International Mathematics and Science Study (TIMSS) states that South Africa is no exception (Mullis et al., 2020).

According to the TIMSS, South Africa's science performance in schools is highlighted as an issue, consistent with findings elsewhere (Mullis et al., 2020).

1.2 DEFINITIONS

A multisensory approach to education involves engaging multiple senses in learning by using multiple activities to enhance understanding, memory retention and overall learning outcomes (Schachl, 2013).

The mind is a set of operations carried out by our brain (Kandel, 2012).

Mindset is a person’s established attitudes, convictions and assumptions that influence how they see and understand the world. It is a way of thinking that affects how people approach various challenges and opportunities in life (Myers et al., 2016).

A fixed mindset (entity belief) involves people with a fixed mindset thinking that their intelligence and skills are fixed characteristics. They frequently give up easily when presented with problems to preserve their self-esteem, feel intimidated by others’ achievements, and avoid challenges to preserve their self-worth (Blackwell et al., 2007; Dweck, 1999, 2007).

A growth mindset (**incremental belief)** involves people with a growth mindset who think that their skills can be improved through hard work, perseverance and education. They like challenges, view setbacks as chances to improve, and are motivated by others' achievements (Dweck, 1999).

Brain-based learning, also known as neuroeducation, educational neuroscience or mind-brain education, involves applying knowledge about the brain and its functioning to inform teaching and learning strategies. It is based on understanding that how the brain learns can help optimise educational practices and enhance student outcomes (Caine & Caine, 1990).

Intrinsic motivation involves people who are intrinsically motivated being drawn to the action for its own sake, and experiencing joy, fulfilment or a sense of flow. The task or activity is intrinsically pleasant, fascinating or rewarding (Deci & Ryan, 1985).

Science performance involves students' knowledge, comprehension and application of scientific concepts, principles and procedures frequently being assessed as indicators of science performance (Fitzakerley et al., 2013).

Technology-enhanced education refers to the integration of various technological tools, resources and methods into the teaching and learning process to enhance the quality and effectiveness of education (Ng, 2018).

TPACK (Technological Pedagogical Content Knowledge) is a teaching framework that enables educators to comprehend how educational technology, instructional strategies and learning objectives interact in a particular learning environment (Koehler et al., 2013).

TBBaSK (Technology-enhanced, Brain-based Science Knowledge) (an outcome of this thesis) is a teaching framework that aims to change mindset, intrinsic motivation and science performance.

1.3 THE STATE OF SCIENCE EDUCATION

Excellent science education is crucial for promoting economic prosperity all over the world. According to the evidence that is currently available, economic growth and scientific achievement are positively correlated (Baker et al., 2002; Hanushek et al., 2008). Poor facilities and ineffective teachers have frequently been blamed for low academic achievement in science in underdeveloped nations (Reddy et al., 2016). This is also true for South Africa, where the legacy of the apartheid government can still be seen in the educational disparities 29 years later (Van der Berg & Gustafsson, 2019). The successful completion of higher education is crucial to South Africa's higher education sector (CHE, 2017). Statistics from the Department of Higher Education and Training (DHET)'s 2017 report on higher education in contact universities confirms that there are significant challenges and disparities in graduation rates in the higher education sector in South Africa (DHET, 2017). Less than 30% of students can complete their degrees within the expected or prescribed time frame, suggesting that many students face delays or obstacles in their academic progress.

The data suggests that most students take longer than six years to complete their higher education qualifications. This extended timeline can indicate various challenges faced by students during their academic journey. It highlights a concerning dropout rate, with one-third of students not completing their degree programmes. This is a significant issue in higher education, as many students are not achieving their educational goals. Despite increasing racial equality, significant inequalities still persist. Addressing these disparities is crucial for creating a more equitable and inclusive higher education environment.

Statistics from the DHET's 2020 report (DHET, 2020) shows that the average graduation rate for undergraduate certificate and diploma programmes in public higher education institutions in 2019 was 20.8%. The number of students in major fields of study in science, technology, engineering and mathematics (STEM), who graduated from public higher education institutions in 2019, was 64 636 out of 221 942. This means that approximately 29% of students in major STEM fields successfully graduated in 2019.

South Africa has a low rate of people with tertiary qualifications. Among all the Organisation for Economic Cooperation and Development (OECD) partner countries, only 7% of adults in South Africa have a tertiary education. Younger adults have an equally low tertiary attainment rate: just 6% of 25- to 34-year-olds have a tertiary education. Unfortunately, it is well below the 38% average of all members, the lowest across all OECD partner countries (OECD, 2021).

Socioeconomic status directly impacts academic achievement for children from underprivileged backgrounds who are experiencing resistance to receiving a quality education (Van der Berg & Gustafsson, 2019). Another obstacle that keeps many children out of early childhood education in South Africa is the country's high unemployment rate. According to scientific accomplishments reported by TIMSS 2015 (Mullis et al., 2020), the top five ranked countries were Singapore (597), Japan (571), Chinese Taipei (569), the

Republic of Korea (556) and Slovenia (551). The bottom five nations were Saudi Arabia (396), Morocco (393), Botswana (392), Egypt (371) and South Africa (358) (Mzekandaba, 2016).

The influential early childhood development programme in Singapore is directly responsible for the success story of science education in that country (Reddy et al., 2016). There is optimism that the Schooling 2025 Action Plan will help South Africa solve this issue (Reddy et al., 2016). This programme, launched by the South African government, intends to improve all aspects of primary education, including hiring teachers, student registration, school funding, and literacy and numeracy foundations (Murugan, 2010).

The literature suggests several causes for students' poor academic performance, particularly in science. Children's educational and academic success depends on their parents' involvement (Tan et al., 2020). Another significant factor for students underperforming in science, according to lecturers, is the absence of the support of their parents and mentors (Bonne & Johnston, 2016; Seaton, 2018). Additionally, English language competency and students' attitudes towards science are factors in underachievement (Tan et al., 2020).There are 11 official languages in South Africa. It might be difficult since English is not most South African students' first language. According to Dempster and Reddy (2007), this language barrier can have a negative impact on academic performance. The diverse demographic backgrounds of South African students can significantly impact their academic achievement (Van der Berg & Gustafsson, 2019). An urgent solution to this problem is needed.

1.4 ALTERNATIVE TEACHING APPROACHES

As it is not necessarily easy to change the state of science education, as mentioned above, an alternative approach is needed (Raja & Nagasubramani, 2018). One potential alternative is changing the teaching methods and moving away from conventional educational approaches.

Conventional or traditional teaching places lecturers at the centre of the learning process, explaining new knowledge to students, who are expected to listen passively and absorb the information (Lathan, 2018). While these teaching methods are often used due to time constraints and the need to cover the syllabus within a specific time frame, the statement acknowledges that there is room for improvement in certain areas. This teaching method often involves students memorising and reciting material, which does not develop critical thinking and problem-solving skills.

After revising previous work, new knowledge is explained to the students on the board. Students are supposed to listen and take it in (Lathan, 2018). It is not that this way of lecturing is necessarily wrong, but there is undoubtedly room for improvement in specific areas.

Alternative methods promote active student engagement, critical thinking, problem-solving and decision-making skills, providing a more effective and meaningful learning experience. By implementing these strategies into their lesson plans, teachers may foster an atmosphere that promotes deeper learning and gets students ready for difficulties in the real world (see Chapter 2.10).

Some of the alternative teaching approaches are based on brain-based learning. Kaur (2023) argues that brain-based learning, as a pedagogy, should inform educational practices by insights from brain science to create more effective and engaging learning experiences. Hinton and Fischer (2008) advocate for strong alliances between brain sciences and education. Brain-based learning minimises conventional lecture-style teaching, favouring practical methods that engage students' brains. This might include incorporating exercise breaks and implementing a multisensory approach, to name but a few.

Several researchers are working on brain-based learning principles and applications. For example, the work of Tokuhama-Espinosa (2014, 2018, 2019, 2021) on mind-brain education (MBE). In addition, Caine and Caine (1990, 1991), Caine et al. (2005) and Jensen (2005, 2008) did research on brain-based learning.

Dweck (1999, 2006, 2018) is still researching the importance of mindset. By using brainology, she focuses on students' beliefs about their intelligence and learning abilities. It emphasises the idea of a growth mindset, where individuals believe that their abilities and intelligence can be developed through effort and learning. Brainology provides resources and interventions to help students adopt this growth mindset and overcome fixed mindset beliefs.

According to research by Whitman and Kelleher (2016), students' intrinsic motivation will increase if given challenges in their area of interest. The likelihood that their knowledge and abilities will be entrenched in their long-term memory is considerably higher. According to Whitman and Kelleher (2016), using technology in the classroom can boost students' intrinsic motivation. Khaloufi and Laabidi (2017) acknowledged the importance of technology, especially in the wake of the COVID-19 pandemic. The issue still persists, despite extensive studies on poor performance in science. It is still unclear how to increase students' interest in the subject (Freeman et al., 2014; Spencer, 2019).

1.5 BRAIN-BASED LEARNING IN SCIENCE EDUCATION

Several quantitative experimental studies on brain-based learning done in secondary schools found a positive outcome on science performance (Achor & Gbadamosi, 2020; Lagoudakis et al., 2022; Ozden & Gultekin, 2008; Saleh & Subramaniam, 2019; Sani et al., 2019). Al-Tarawneh et al. (2021), Al-Balushi and Al-Balushi (2018), Alanazi (2020), Riskiningtyas and Wangid (2019), Saleh and Subramaniam (2019) and Wijayanti et al. (2021) agreed on this statement. See Chapter 2.11 for a detailed discussion.

Recommendations from a systematic review of the use of brain-based learning in science teaching in the school by Bada and Jita (2022) are as follows:

- Brain-based learning should be further used for instruction because its effectiveness has been objectively ascertained in the literature through appropriate research methods.
- The integration of brain-based learning should be further encouraged in other science subjects such as Chemistry and Physics, where integration is currently low.
- Efforts should be made to improve the integration of brain-based learning across all levels of education.
- Different constructs of brain-based learning should be encouraged to improve its integration in the science classroom.

1.6 TECHNOLOGY-ENHANCED SCIENCE EDUCATION

Incorporating technology into science education can enhance students' engagement, critical thinking and problem-solving skills. However, it is crucial to balance technology use and hands-on experiences, and ensure equitable access to technology for all students. The use of technology in science education is discussed in more detail in Chapter 2.9.

The Technological Pedagogical Content Knowledge (TPACK) Framework

The Technological Pedagogical Content Knowledge (TPACK) Framework is widely used in education to guide educators in planning, designing and delivering lessons that effectively integrate technological, pedagogical and content knowledge. It encourages a holistic approach to teaching that considers the unique context of each learning environment and helps educators make informed decisions about when and how to use technology in their instruction. The TPACK Framework is widely used for the training of science teachers (Chang et al., 2014; Hechter, 2012; McCrory, 2014; Mugot & Fajardo, 2021; Sheffield et al., 2015; Trautmann & MaKinster, 2010). Jimoyiannis (2010) developed the Technological, Pedagogical Science Knowledge (TPASK) Framework, and Thohir et al. (2022) developed the 4D-TPACK Framework for science teachers. These are explained in more detail in Chapter 3.2.4.

Although the TPACK Framework was exclusively developed for teachers to be equipped in the interaction between technological, pedagogical and content knowledge, the researcher of this study considers this to apply to university lecturers as well. Several qualitative studies confirmed the positive impact of the TPACK Framework on educators (Chang et al., 2014; Hechter, 2012; Jimoyiannis, 2010; McCrory, 2014; Mugot & Fajardo, 2021; Niess, 2005; Rodríguez-Becerra et al., 2020; Sheffield et al., 2015; Thohir et al., 2022; Trautmann & MaKinster, 2010). See Chapter 3.2.4 for a more detailed discussion.

The theoretically sound TPACK Framework has to be improved in light of previous research findings and criticism. Cox (2008) points out a lack of clarity around the boundaries between the different constructs within the TPACK Framework. Categorising cases that fall between the defined constructs is complex and can hinder effectively applying the framework in practice.

Angeli and Valanides (2009) agreed that the TPACK Framework requires additional clarity to fully understand the complex interactions between technological, pedagogical and content knowledge. This highlights the need for ongoing research and development to refine the framework and ensure that it is grounded in sound pedagogical principles (Voogt et al., 2013).

Jimoyiannis (2010) highlighted the importance of considering classroom environments and educational contexts from the perspective of integrating technology into science education. He requested inputs on the perception and adoption of the TPASK Framework by science teachers, real-life classroom applications, developing metacognition in teaching and learning approaches, and their impact on students.

1.7 PROBLEM STATEMENT

The poor performance of science students is a global problem. This holds for secondary and tertiary education (Baik et al., 2019; Pinxten et al., 2019). This is also the case in South Africa. The Tshwane University of Technology (TUT) is committed to providing access to higher education for students from underprivileged backgrounds through National Student Financial Aid Scheme (NSFAS) bursaries. The restriction that the combined household income should not exceed R350 000 per year demonstrates the need for students from low-income and working-class families to pursue their academic aspirations.

The cost of not addressing the poor performance problem is enormous to the economy of countries, especially developing countries such as South Africa. Although the reasons for the poor performance are vast, one way of addressing the problem is through alternative teaching approaches.

Brain-based learning is considered a pedagogy that may improve many teaching approaches and techniques (Bada & Jita, 2022). In addition, the TPACK Framework for professional teacher development has been adjusted for science education (Jimoyiannis, 2010; Thohir et al., 2022). However, the TPACK model has to be improved in light of previous research findings and criticism (see section 1.6). Jimoyiannis (2010) requested inputs on the perception and adoption of the TPACK Framework by science teachers, real-life classroom applications, and developing metacognition in teaching and learning approaches to measure the impact on students.

Although several quantitative experimental studies on brain-based leaning done in secondary schools found a positive outcome on science performance, specific recommendations from a systematic review of brain-based learning in science education by Bada and Jita (2022) were outlined in section 1.5. Despite the potential of brain-based learning, it is not well used in science education, and its specific constructs need further development in the science education environment.

The researcher of this study adhered to these calls and decided to combine brain-based learning with the TPACK Framework in a proposed technology-enhanced, brain-based framework for science education. This framework provides components and guidelines for lecturers implementing brain-based learning and technology-enhanced education in the science classroom. In this way, this research study wants to assist in alleviating the problem of underperformance in science.

1.8 RESEARCH QUESTIONS

This study aims to develop a framework (the technology-enhanced, brain-based framework for science education) to enhance undergraduate students' intrinsic motivation, mindset and science performance.

The following research question addresses the purpose of this study:

Main research question:
What constitutes a technology-enhanced brain-based framework for science education (the TBBaSK Framework)?

The sub-research questions that help to solve the main research question are:
RQ 1: What is the effect of using technology in science understanding?
RQ 2: What is the effect of brain-based learning on science understanding?
RQ 3: What is the effect of intrinsic motivation on science performance?
RQ 4: What is the effect of mindset on science performance?
RQ 5: What is the effect of implementing the TBBaSK Framework on mindset, intrinsic motivation and science performance?

1.9 RESEARCH AIMS AND OBJECTIVES

The aims and objectives to resolve the problem are given below in more detail.

Research objective	Research question	Addressed in
To determine the influence of technology on science understanding	(1) What is the effect of using technology in science understanding?	Chapters 2.8, 2.9
To explore the influence of brain-based learning on science understanding	(2) What is the effect of brain-based learning on science understanding?	Chapters 2.11, 2.12
To determine the effect of intrinsic motivation on science understanding	(3) What is the effect of intrinsic motivation on science performance?	Chapters 2.6, 2.7
To determine the effect of mindset on science understanding	(4) What is the effect of mindset on science performance?	Chapters 2.4, 2.5
To investigate the effect of the TBBaSK Framework on mindset, intrinsic motivation and science performance	(5) What is the effect of implementing the TBBaSK Framework on mindset, intrinsic motivation and science performance?	Chapters 6, 7

1.10 RESEARCH DESIGN

This section outlines the research design and methodology used in this study: The approach adopted is to undertake a case-study research project to deliver a teaching framework to enhance science performance. Adopting pragmatism as a philosophical stance, the researcher reviewed the literature on the reasons for weak academic performance in science education and other pedagogies. This led to a suggestion for a solution by creating the TBBaSK Framework. The researcher intervened with a sample group to test the framework by choosing a difficult part of the curriculum and different data-collection instruments in the mixed-method study.

The following phases were executed in this research design (Figure 1.1).

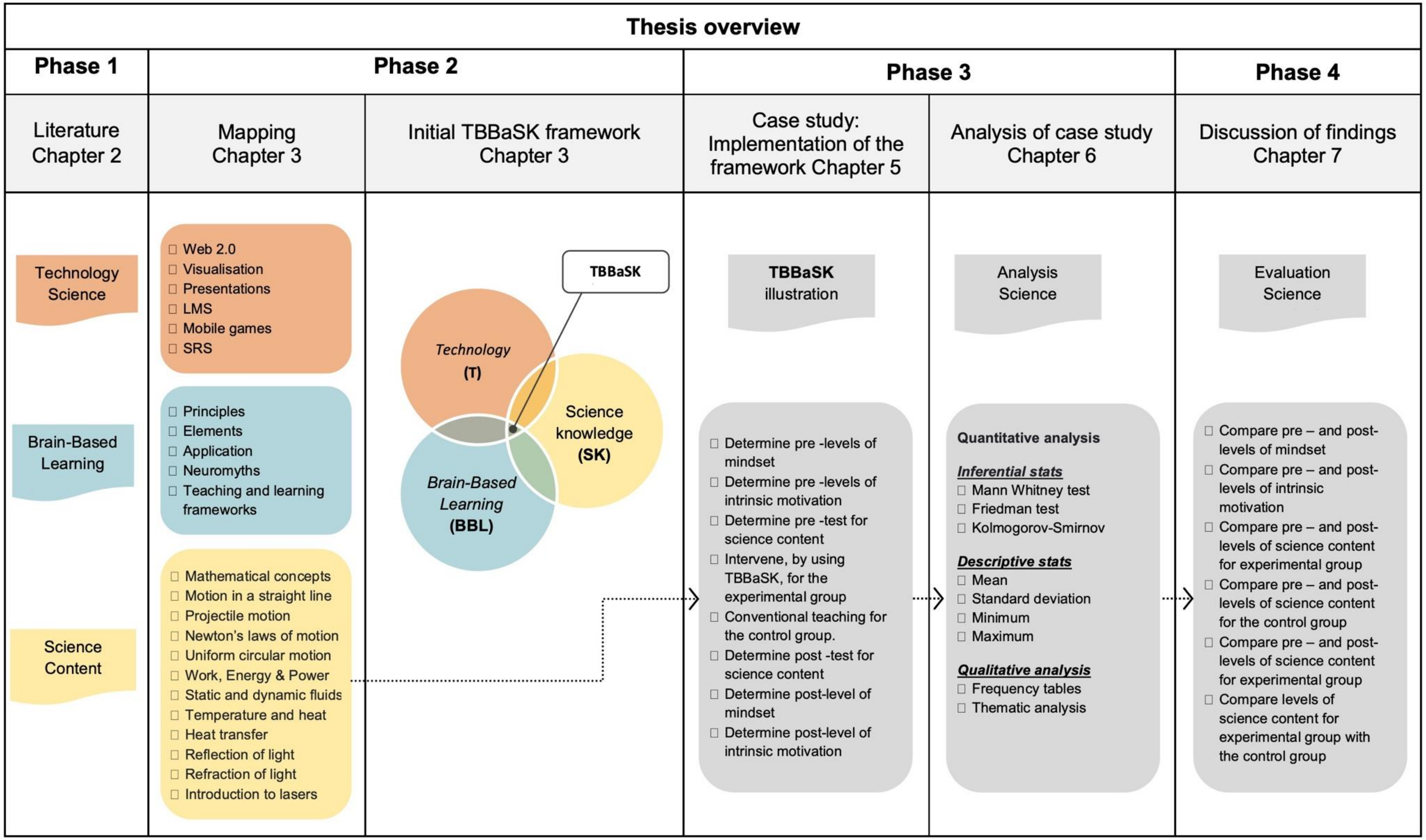


Figure 1.1: Overview of the thesis

Phase 1. Literature review. Existing literature on the variables involved in this research study and their relations are discussed (Chapter 2)

Phase 2. Mapping and development of the framework (Chapter 3)

Phase 3. The implementation and analysis of the framework (Chapter 5)

Analysis of the case study (Chapter 6)

Phase 4. The discussion and interpretation of the findings (Chapter 7)

Table 1.1 summarises the research design followed in this study.

Table 1.1: The research design

Research design		
Research philosophy	Pragmatism	
Research method	Mixed methods	
Research strategy	Case study	
Data collection	Pre- and post-tests	Questionnaires

1.11 CONTRIBUTION

- To provide a comprehensive overview of the TPACK model, its complexities and its importance to science education. This is accomplished by illuminating TPACK as an evocative model for the proficient requirement of science educators by incorporating brain-based learning.
- To improve university science performance for previously disadvantaged students, specifically in poor socioeconomic environments. This goal intends to assist science lecturers to gain a deeper understanding of TPACK and how to apply it effectively in their lectures at university level.
- To improve science lecturers' capacity to adopt TPACK and equip them to apply efficient brain-based learning activities. A complete understanding of TPACK will enable teachers to improve and apply their technological, pedagogical and content expertise in science education.
- To implement brain-based activities such as mind moves and mindfulness techniques, specifically within the science classroom. This indicates a need for more studies to explore the potential benefits and challenges of integrating these practices into science education.

- To increase understanding of the influence of brain-based learning on mindset: The researcher found a gap in understanding how brain-based learning specifically influences mindset (Chapter 2.12.2). This suggests a need for further research to explore the relationship between brain-based learning approaches and mindset development in educational settings based on the well-known TPACK Framework. Using this framework in lecturing, students will not get bored in class, but will engage with the content in a limited time. Preparation for the lecturer may be a constraint, but as time passes, it will become easier. Lecturers should be committed to making a positive contribution.

The purpose of this study is to develop a framework (the TBBaSK Framework) to enhance undergraduate students' intrinsic motivation, mindset and science performance.

1.12 ASSUMPTIONS AND LIMITATIONS

It is assumed that the lecturer has experience working with technology to add other information to the need for specific knowledge. It is believed that the students exposed to the study are computer literate because they are doing a course in computer literacy.

Although the findings are encouraging, the following significant limitations are mentioned:

- The study should be replicated at other universities to guarantee that the results are generalisable.
- The number of students participating in the study was limited due to their willingness to attend Saturday classes.
- The duration of the intervention was only six Saturdays.

1.13 SUMMARY

This chapter introduces the problem of poor science performance at the undergraduate level at a university of technology in South Africa. It is shown that this is not only limited to developing contexts, but is a global problem. To alleviate the problem, the researcher suggests creating a teaching framework for science education called the Technology-enhanced, Brain-based and Science Knowledge (TBBaSK) Framework. Apart from providing a teaching framework for science lecturers, it also addresses shortcomings in the TPACK Framework and brain-based learning research in science education. It is argued that such a framework may affect mindset, motivation and science performance. An overview is given of how this research was conducted. There is continued interest in science achievements from multiple sectors, and this area may be relevant to practitioners in science professions.

The literature review required to carry out this investigation is covered in the following chapter.

CHAPTER 2: LITERATURE REVIEW

2.1 INTRODUCTION

This chapter centres on the integration of diverse concepts that are crucial for the research undertaken in this study. Utilising Google Scholar, a comprehensive search was conducted to identify various aspects essential for locating the most pertinent resources on academic performance, mindset, motivation, technology-enhanced education and existing pedagogies in science education. Recognising the literature review as a scientific process that encompasses data collection, analysis and findings, it is apparent that the researcher meticulously examined it to make well-informed decisions about selecting the most relevant evidence for this research. The study aims to investigate how applying brain-based learning techniques and technology in the undergraduate science classroom can potentially enhance motivation and mindset, and subsequently improve academic performance, especially for students from disadvantaged backgrounds.

The next chapter suggests a framework to achieve a technology-enhanced, brain-based learning framework for science education (the TBBaSK Framework).

2.2 SCIENCE PERFORMANCE

This section aims to highlight the shortage of qualified engineers, technologists and doctors, which can be linked to failures in Physical Science at the school or university level (Sebola, 2023). The reasons for poor performance in science are varied, with students' attitudes towards science being a crucial factor.

2.2.1 Factors influencing science performance

Many factors influence science performance. The following are important in this research. Students' attitudes are influenced by self-efficacy, their perception of the value of science, and whether they engage in activities beyond memorisation (Cavas, 2011; Rozek et al., 2015). These attitudes encompass affective, cognitive and behavioural components like interest, motivation, enjoyment and perceptions of science (Bedford, 2017).

Understanding what encourages students' motivations is important (Dweck, 2007; Fortus & Vedder-Weiss, 2014; Lee & Chung, 2014; Potvin & Hasni, 2014), as it encourages goal achievement (Bedford, 2017). While learning preferences vary, utilising diverse modalities like visual, auditory and kinaesthetic methods can impact attitudes toward science (Whitman & Kelleher, 2016).

Prior perceptions of science, familial experiences, learning environment, peer influence and prior knowledge can shape science learning. Children often adopt viewpoints and attitudes based on their parents' experiences, with negative parental experiences potentially leading to negative attitudes (Archer et al., 2013). Positive family experiences, on the other hand, can foster aspirations in the scientific field (Tan et al., 2020), although exceptions exist (Cavas, 2011; Sevinc et al., 2011). Parents are pivotal in motivating their children and contributing to their academic success.

Parents can positively impact their children's self-esteem by excessively praising their abilities and promoting a growth mindset (Haimovitz & Dweck, 2016). Parents' reactions to failure can inspire growth, persistence and motivation, ultimately boosting scientific achievement (Blackwell et al., 2007).

Teachers also play a significant role, as shown by the research of Hattie (2012) on how their actions affect students' attitudes. Emphasising growth and avoiding favouritism of confident students is highlighted by Seaton (2018). Student success and understanding science correlate with teachers' efforts to create effective learning environments (House & Telese, 2015; Whitman & Kelleher, 2016).

2.2.2 Factors influencing undergraduate science performance

According to the National Research Council (2011) (as cited by Baik et al., 2019), poor science performance is a worldwide problem. A study that researched the experiences of first-year Australian university students with poor tertiary admission scores found that the transition to university is a crucial factor that contributes to their success (Baik et al., 2019). Students must adjust to the academic demands and emotions of living away from home, university culture and loneliness. Baik et al. (2019) emphasise the significance of the first year's impact on a student's life in subsequent years. According to research from a Flanders open-admission institution, first-year science and engineering students perform poorly because they lack arithmetic abilities, have low maths and science grades, and were not properly advised by secondary school instructors (Pinxten et al., 2019).

The situation in South Africa is of significant concern. Less than half of all undergraduate students in South Africa who enrol, whether in contact or remote learning modes, fail to complete their degrees. This situation is a significant issue for the education system, as highlighted by the DHET (2017). Limited access to educational materials, tools and technologies can hinder students' ability to engage with their studies effectively. Stress from various sources, including academic pressure, financial concerns and personal circumstances, can negatively affect students' cognitive abilities and overall wellbeing. Nutritional deficiencies due to inadequate diets can impact cognitive function and negatively influence students' ability to concentrate and learn effectively. Lack of access to quality healthcare can lead to physical and mental health issues affecting students' academic performance. Insufficient funds for tuition, books and living expenses can limit students' access to resources and educational opportunities, negatively impacting their academic performance (Baik et al., 2019).

When researching the low science performance at South African universities, it is essential to consider science performance at school. South Africa was one of 64 countries that contributed to the Grade 4 TIMSS study in 2019, where an average of 324 points, well below the threshold of 400 points for science, was recorded. The South African Department of Basic Education stated that only 28% of learners had obtained basic science knowledge, while 72% of the South African students had not acquired basic science knowledge in Grade 4 (Mullis et al., 2020). South Africa also participated as one of 39 countries in the Grade 8 TIMSS study in 2019. Although the score of 370 for science resulted in an increase of 17 points from 2015, the report showed that only 36% of Grade 9 science learners had acquired basic science knowledge. To explain the alarming statistics, the Department ascribed it to students' unequal and different backgrounds. Learners with the lowest educational outcomes come from homes lacking basic amenities. According to the Department, this should be the starting point. The Department emphasised the importance of investment in education and training, and claimed it needed to be investigated (Mullis et al., 2020).

The Department of Basic Education (2011) states that the high failure rates in Physical Science have resulted in a decline in its popularity as a subject among students. As a result of these high failure rates, fewer students are choosing to study Physical Science at further education and training (FET) levels. The decline in interest and enrolment in Physical Science has broader implications for the availability of qualified scientific professionals in the country. If students are not succeeding in Physical Science as a subject, it could lead to a shortage of individuals pursuing careers in scientific fields. The situation requires immediate action to address the challenges and reverse the trend of declining interest and high failure rates in Physical Science. The DHET acknowledged the urgency of this situation in 2012 (DHET, 2012).

Research conducted by Claro et al. (2016) suggests a link between socioeconomic status, mindset and academic achievement. Students from economically disadvantaged backgrounds may develop a fixed mindset, believing that their intelligence and abilities are static and cannot be improved through effort. This mindset can hinder their belief in their potential for growth. A fixed mindset can contribute to poorer academic performance, as students may be less likely to persist in the face of challenges, put in extra effort, or seek out additional resources to improve their understanding.

The emphasis in this section was on the impact of specific elements on science performance. Following a discussion of these aspects, the subsequent section will delve into the topic of mindset in education.

2.3 MINDSET

According to psychologist Dweck (2018), a mindset refers to a person's belief or self-theory about their abilities, qualities and intelligence. Leggett (1985) studied the relation to achievement behaviour, where mindset plays a crucial role in shaping how individuals approach challenges, setbacks and learning opportunities. Dweck (1999) is known for her research on mindset, particularly the distinction between two main types: fixed and growth mindset.

2.3.1 Fixed and growth mindset

Dweck (1999) presented several studies conducted over the last 20 years on how pupils respond to failure in the classroom. Failure will be viewed as a challenge to learn something new that will improve a student's intelligence by those with a growth mindset. They will make plans to process data more passionately using feedback to identify fresh approaches to problem solving (Dweck & Master, 2008; O'Rourke et al., 2014). On the other hand, failure is seen by those with a fixed mindset as a sign of incapacity (Hong et al., 1999). When a task becomes difficult, they choose not to try because they fear criticism and failure (Blackwell et al., 2007; Paunesku et al., 2015). According to the mindset theory, also known as the Implicit Theory of Intelligence (Dweck & Leggett, 1988), people have one of two mindsets concerning intelligence: an entity or fixed mindset or an incremental or growth mindset. For clarity, terms referring to the same concept are summarised in Table 2.1.

Table 2.1: Summary of similar concepts

Implicit theories of intelligence		
Theorists	Incremental	Entity
Mindset	Growth	Fixed
Intelligence	Malleable	Fixed

Parents and teachers can help foster an intelligence mentality from a young age by praising noteworthy achievements. Parents typically applaud children because they feel it will increase their self-esteem and performance, rather than acknowledging the effort put forth in the task. They ought to use compliments as an opportunity to help their children learn from failure rather than see it as a setback (Haimovitz & Dweck, 2016; Hainovitz et al., 2011). Students will adopt a growth mindset if praised for their effort to gauge achievement (Mueller & Dweck, 1998). A fixed mindset is reinforced by praising the ability, according to Campbell et al. (2020). On the other hand, by applauding efforts that result in success, growth mindsets can be promoted. According to longitudinal studies, students who adopt a growth mindset have higher self-esteem than those who adopt a fixed mindset (Robins & Pals, 2002).

For elementary school children, Dweck (2006) and game developers created the game BrainPOP to encourage improvement in mindset. In this game, one earns points for finding solutions as rapidly as possible. They also developed a new game called Brain Points, where pupils are rewarded for effort, assiduity and approach rather than earning points for reaching a manageable level. Because they could succeed, they discovered that even the weakest student persevered for the maximum time. This results in growth and persistence. Therefore, a fixed mindset does not have to be permanent; a growth mindset can be acquired. According to Anguilar et al. (2014), a growth mindset intervention demonstrates to pupils that intellect is not fixed. If lecturers know the distinctions between incremental (growth) and entity (fixed) mindsets, they can forecast their students' behaviour. Then, students with a fixed mindset can be inspired to have confidence in their skills.

According to Blackwell et al. (2007), college-aged students had a more fixed mindset. After enrolling in an incremental thinking intervention, individuals may be aided in overcoming a problem (Blackwell et al., 2007). How students define their mindset can be strongly impacted by the interaction between the teacher and the student, and the feedback (Bonne & Johnston, 2016; Seaton, 2018). Despite being successful, students with fixed mindsets have more test anxiety. This causes them to study less, resulting in poorer academic performance. Mindsets can be changed by shifting emphasis from success to process (Campbell et al., 2020; Dweck, 2006). According to Blackwell et al. (2007), students with a growth mindset are more motivated to work harder or take on challenges with tremendous enthusiasm. Children follow your lead and not your instructions. Therefore, if lecturers do not believe that the mind can grow and practice a growth mindset themselves, they cannot inspire students to change their thinking (Shumow et al., 2013; Velayutham & Aldridge, 2012).

2.3.2 Relationship between mindset and academic achievement

Dweck (1999) asserts that current research indicates a relationship between mindset and specific subjects, suggesting that mindset can influence how students approach and excel in different academic areas. Mindset is linked to specific subjects, as evidenced by studies such as those conducted by Chen et al. (2020), Gunderson et al. (2017) and Priess-Groben and Hyde (2017). Blackwell et al. (2007) argue that a growth mindset is particularly beneficial for challenging subjects. It helps students approach these subjects with a positive attitude and the belief that effort and strategies can lead to improvement. Studies by Bostwick et al. (2017), Costa and Faria (2018) and Romero et al. (2014) emphasise that challenging subjects require more effort and strategies to overcome difficulties.

Yeager et al. (2019) developed an online growth mindset intervention to increase enrolment in advanced mathematics courses in schools. This intervention indicates the potential for mindset interventions to impact students' academic choices and pursuits.

Studies on the relationship between mindset and academic performance have yielded contradictory results. According to several studies, there is a correlation between mindset and academic achievement, with students with a growth mindset typically outperforming their peers. These studies include those conducted on secondary school or university students (Alesi et al., 2016; Costa & Faria, 2018; Müllensiefen et al., 2015; Wiersema et al., 2015; Yan et al., 2014; Yeager et al., 2016).

On the other hand, there is evidence from other studies suggesting that academic achievement is not significantly influenced by a growth mindset (Bahník & Vranka, 2017; Li & Bates, 2019; Moreau et al., 2019). Dweck and Leggett (1988) argue that mindset is foundational in achieving goals because it shapes beliefs that guide individuals' goal-setting behaviour.

Over the last 40 years, ongoing debate and discussion have existed about operationalising the mindset construct. This suggests that researchers have explored various ways of measuring and assessing mindset.

2.3.3 The influence of socioeconomic status and cultural differences, and the relationship between mindset and academic achievement

Studies conducted in different countries have investigated the relationship between a growth mindset and academic achievement among students from different socioeconomic backgrounds. King and Trinidad (2021) conducted research in the USA and found that students with a high socioeconomic status who adopted a growth mindset tended to experience better academic achievement. Bernardo (2020) conducted a study among Filipino students and found that students with a high socioeconomic status who embraced a growth mindset performed better academically.

Sisk et al. (2018) reported that facilitating growth mindsets can benefit academically at-risk students and students from low-income homes. Research results are inconsistent regarding the influence of socioeconomic status on the relationship between mindset and academic achievement. Claro et al. (2016) found that a growth mindset was associated with significant academic performance across all socioeconomic statuses in Latin America. This positive association between a growth mindset and academic performance was confirmed in Asia, Europe and Oceania, but in North America, a negative correlation was observed (Costa & Faria, 2018). While socioeconomic status may be fixed and challenging, it can impact students' academic achievement. Students from economically disadvantaged families may face setbacks in their academic achievement due to various factors related to their socioeconomic circumstances (Chiu & Chow, 2015; Claro et al., 2016; Walton & Cohen, 2011; Wormelli, 2018). Claro et al. (2016) found that children from economically disadvantaged families who embraced a growth mindset were more capable of protecting themselves against the negative impact of poverty on academic achievement.

A study in the USA indicated that students from high and low socioeconomic backgrounds performed better when they exhibited a growth mindset (Destin et al., 2019). Sisk et al. (2018) confirmed this finding through intervention analysis, suggesting that a growth mindset can positively influence the academic performance of students from various socioeconomic backgrounds. This finding suggests that a growth mindset could potentially be a factor in helping students who face academic challenges due to socioeconomic factors.

Different cultural backgrounds can contribute to varying outcomes in studies on mindset. This suggests that cultural factors play a role in shaping individuals' beliefs and attitudes about abilities. Costa and Faria (2018) and Dweck and Leggett (1988) have observed that cultural contexts can impact the understanding and expression of mindset.

2.4 MINDSET IN SCIENCE EDUCATION

Dweck (2006) and Dweck and Master (2008) state that fixed mindsets dominate science, technology, engineering and mathematics (STEM) areas. Fortunately, the literature shows that mindset can be changed (Blackwell et al., 2007; Dweck, 1999, 2007; Schmidt & Shumow, 2020).

Yeager et al. (2019) created an online growth mindset intervention to develop intellectual skills, raise students' grades and promote enrolment in advanced mathematics and science courses. The intervention aims to dispel misconceptions about learning in mathematics and science, promoting a growth mindset to enhance academic achievement. Growth mindset interventions address misconceptions about learning in mathematics and science, which can positively impact students' attitudes, motivation and performance in these subjects. A successful career in mathematics and science is linked to economic wellbeing in the long run. This suggests that mindset interventions could affect students' future career prospects and financial stability.

Haimovitz and Dweck (2016) conducted research suggesting that the connection between mindset and motivation also applies to parents' intelligence and their children's perceptions. The study looked at primary school students in the USA across subjects such as Mathematics, Science, Social Studies and English. They found that children can accurately describe their parents' failure mindsets, but may not accurately perceive their parents' intelligence mindset (growth or fixed). Parent's failure mindsets influence their reactions to their children's theoretical failure, suggesting that parental mindset can impact children's responses to challenges and setbacks.

A study by Lytle and Shin (2020) investigates first-year STEM undergraduate students and the stereotype that success in STEM requires innate skills. They emphasise that intelligence is malleable and that promoting a growth mindset can protect students from the adverse effects of STEM stereotypes. By supporting a growth mindset, students are encouraged to develop positive attitudes and beliefs about their abilities in STEM fields. The study found that STEM students with growth mindsets tend to have higher self-efficacy and greater interest in STEM fields.

A study by Campbell et al. (2020) focuses on low-income STEM undergraduates at the University of Cape Town in South Africa. The researchers developed a framework that addresses various factors, including challenges, perseverance, effort, praise, the success of others and learning objectives. They found that fixed and growth mindsets exist on a continuum, even though there may be a gap between students' beliefs and actions. The researchers found that academically high-risk students benefit most from developing growth mindsets.

This section comprehensively explores the distinctions between a fixed mindset and a growth mindset, along with an in-depth examination of the correlation between mindset and academic achievement. The influence of socioeconomic status and cultural differences on mindset and their relationship with academic achievement is also thoroughly discussed. Furthermore, the application of mindset principles in the context of science education is addressed in this section. The following section will cover motivation, how it relates to mindset, and how it affects science achievement.

2.5 MOTIVATION

Motivation is the process that initiates, guides and sustains goal-oriented behaviour. It is frequently used to describe why a person does something daily. In a sense, it is the driving force behind human actions (Cherry, 2023). Motivation can be divided into two subconstructs, depending on the reasons that encourage action. Students who experience innate fulfilment will demonstrate intrinsic motivation, whereas a student who follows steps to receive rewards is extrinsically motivated (Cherry, 2023). Several theories of motivation are used in education. This study looks at a few theories that influence intrinsic motivation and goal achievement, which is needed to enhance science performance, such as self-determination, goal, social cognitive and self-regulated theories.

2.5.1 Intrinsic-extrinsic motivation

The underlying drive to accept challenges and options associated with cognitive and social development is known as intrinsic motivation. Students engage in activities for their satisfaction and not to meet the needs of external targets (Irvine, 2018). Intrinsically motivated students study because they find the subject exciting and love to take on challenges, not because of external pressure (Cherry, 2023). Intrinsically motivated students spend much time on tasks and are determined to complete them even when facing failure (Irvine, 2018).

An externally motivated student will perform an activity to achieve the desired goal or receive another reward. Extrinsically motivated students study to get good marks because they get rewarded for it (Cherry, 2023).

The conflict between intrinsic and extrinsic motivation affects education. Several studies have shown that students begin school with a high level of intrinsic motivation that rapidly declines, peaks around age 16 and remains constant (Martinek et al., 2016).

Researchers have concluded that lifelong learning requires intrinsic rather than extrinsic motivation (Ryan & Deci, 2000; Spinath & Steinmayr, 2012). According to several studies, extrinsic rewards may reduce intrinsic motivation (Deci et al., 2001; Ryan & Deci, 2000). School tasks that are not primarily enjoyable or interesting cause a decline in motivation, according to Ryan and Deci (2000). This may happen when high school lecturers are more concerned with the work's content than their students' motivation.

2.5.2 Motivational education theories

Several educational theories have impacted intrinsic motivation and goal achievement over the past decades. These theories provide insights into how learners' motivations, goals and learning processes intersect. By exploring these theories, the study aims to understand better how educators can enhance students' intrinsic motivation and support them in achieving their educational objectives.

This section provides an overview of four theories examined in this study.

2.5.2.1 Self-determination theory (SDT)

Self-determination theory is based on autonomy, relatedness and competence. It offers a framework for comprehending what motivates human behaviour, how motivation is fostered and the circumstances that result in the best possible wellbeing and personal development (Ryan & Deci, 2000). Ryan and Deci (2012) explain the three basic needs as follows:

Autonomy is the urge for people to feel in control of choosing their activities and behaviour. It involves feeling that one's actions are guided by one's values, interests and desires rather than being dictated by others. Autonomy encourages intrinsic motivation by promoting ownership and a willingness to participate in activities.

Relatedness describes people's desire to relate to and identify with other people. It entails creating deep connections with people, receiving emotional support and connecting with others. Relatedness promotes wellbeing and motivation by gratifying our need for social connection and community.

Competence refers to the need for individuals to feel adequate and capable in their actions and endeavours. It entails looking for challenges, developing talents and feeling accomplishment. When people feel competent, their self-esteem and intrinsic motivation increase because they feel good about their accomplishments (Figure 2.1).

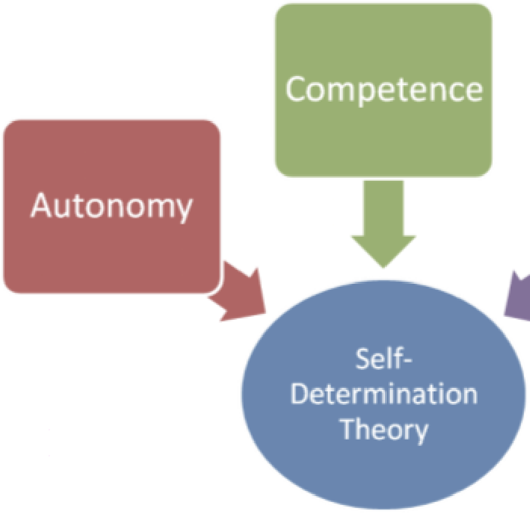


Figure 2.1: The three basic needs of self-determination (Deci & Ryan, 1985)

Students with intrinsic drive succeed if they can relate to and comprehend a particular task (Grolnick & Ryan, 1984). Students who lack intrinsic drive and have their relevant needs unmet will perceive their educators as cold and emotionless. As a result, prompt guidance regarding such needs must be supplied. An external justification for why work is completed could encourage students. By highlighting the task's importance, locating its hidden values, and assisting students in understanding how the lesson might benefit them, lecturers can encourage students when engaged in dull tasks (Wright et al., 2021). White (1963) and DeCharms (1968) predicted the demand for autonomy and ability as the basis of intrinsic motivation. Logan et al. (2011) found a correlation between students' academic effort and intrinsic drive. According to growing empirical research, intrinsic motivation is crucial to academic achievement (Froiland & Worrell, 2016; Vervaeke & Ferraro, 2013).

2.5.2.2 Goal theory

Goal theory, including mastery and performance goals, examines how different goals influence learning behaviour (Dweck & Leggett, 1988). According to Irvine (2018), many factors determine whether a person will choose mastery or performance goals, including feelings of self-worth, personal intelligence, failure, fears and anxiety about appearing weak. A mastery-oriented individual seeks to develop their abilities. They believe that learning is intrinsically valuable, that effort is the key to success, and that they assess their competency according to self-determined standards (Pintrich, 2000). Students who are mastery-oriented focus on learning, understanding and mastering tasks. They would likely perform better because self-efficacy, task value, cognitive strategy use and learning self-regulation are positively correlated (Irvine, 2018). According to the research of educational psychologist Pintrich (2000), a performance goal is an extrinsic goal that focuses on the aim of outperforming or appearing better than others. It is driven by external factors such as seeking recognition, praise or avoiding negative judgments from others. Performance-oriented students aim to show their abilities rather than necessarily focusing on the learning process. This can lead to choosing tasks and courses they believe will be easier for them to excel in. They might be less likely to take on challenging tasks that could fail, as failure could be perceived as a reflection of their abilities (Irvine, 2018).

Irvine (2018) set up a framework to compare theories related to motivation in education and plotted specific theories on two axes: expectancy-value (horizontal) and intrinsic-extrinsic (vertical). Figure 2.2 shows the placement of mindset and goals on the intrinsic-extrinsic and expectancy-value axes, as researched in the study of Irvine (2018).

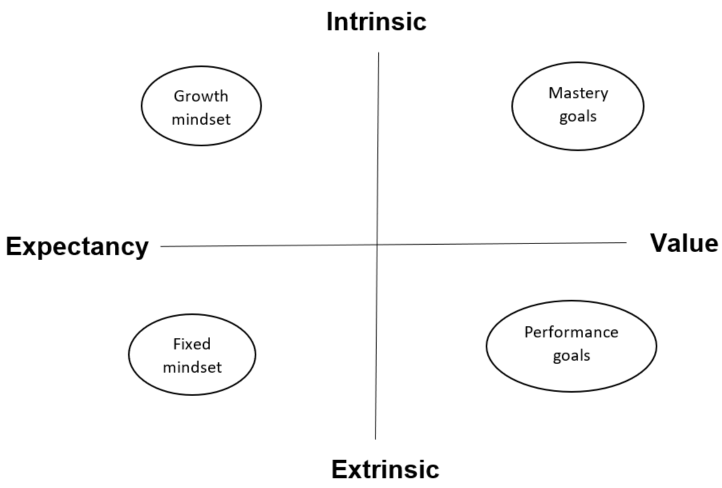


Figure 2.2: Location of the intelligence and achievement goal theories (Irvine, 2018)

Figure 2.2 illustrates that mastery goals fall in the value-intrinsic quadrant, whereas performance goals are in the value-extrinsic quadrant. The words and attitudes of teachers and parents toward students are examples of external influences that impact performance goals. The findings of Ryan and Deci (2000) align with the placement of performance goals in the expectancy-extrinsic quadrants.

The concept of a growth mindset is situated within the quadrant that combines expectancy and intrinsic motivation, while a fixed mindset is in the quadrant that aligns with expectancy and extrinsic motivation. While both mindsets are essentially rooted within internal perspectives on intelligence, it is important to recognise that a fixed mindset emerges from interactions with external elements, including the type of praise received and the expectations set by others. Similarly, external factors like praise can affect a growth mindset, but its core orientation remains primarily intrinsic, stemming from students' self-perceived efficacy. See section 2.4 for a more detailed explanation of mindset.

According to the research conducted by Ryan and Deci (2000), students who are highly intrinsically motivated tend to adopt mastery goals. On the contrary, extrinsic motivation tends to encourage the pursuit of performance goals, as highlighted by Spinath and Steinmayr (2012). When individuals set performance goals, their sense of accomplishment is often measured by comparing their achievements with those of their peers, as Pintrich (2000) noted. In this context, their evaluation of competence and self-worth is intertwined with their ability to outperform others and attain their goals with relative ease. External factors like comments or attitudes from teachers or parents can influence the adoption of performance goals and how they are pursued.

2.5.2.3 Social cognitive theory

Albert Bandura (1986) published the social learning theory in the 1960s. In 1986, his social-learning theory changed into the social-cognitive theory, which strongly focuses on the role of cognitive processes in learning and behaviour. According to this hypothesis, people learn from first-hand experiences, watching others and the results of their behaviour.

In observational learning, the behaviour and activities of others and the results of that behaviour are followed. Self-efficacy is the belief that someone can successfully carry out a task or behaviour by fostering drive and perseverance in learning and carrying out new activities. According to Bandura (1986), personal elements (ideas and feelings) interact with and impact individual behaviour and the environment. Setting objectives, tracking development and changing behaviour are all parts of self-regulation (Bandura, 1986).

2.5.2.4 Self-regulated learning theory

The self-regulated learning theory developed by Pintrich (2000) focuses on understanding how learners actively participate in the learning process, including planning, monitoring and adapting their strategies to achieve academic goals. It aligns with Bandura's notion of self-regulation (Bandura, 1986). This theory emphasises the importance of metacognition and self-regulation in learning. The study of Pintrich (2000) investigated an individual's goal orientation and the impact of this on their engagement in self-regulated learning strategies.

Most of his research (Pintrich & Garcia, 1991; Pintrich et al., 1994) discovered a connection between motivational orientation, self-regulation and student grades.

Pintrich's model (Pintrich, 2000) considers internal and external factors, classroom dynamics, cognitive processes and individuals' active strategies to optimise their learning experiences. The five-component structure provides a structured way to examine and analyse how these aspects interact and contribute to students' overall motivation, self-regulation and learning outcomes (Figure 2.3).

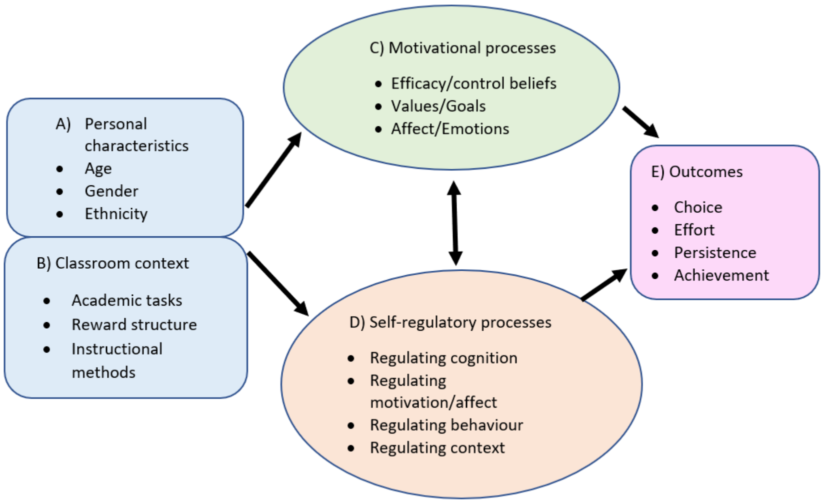


Figure 2.3: Model of motivation and self-regulated learning (Pintrich and Zusho, 2007)

This model's first component encompasses specific qualities related to student motivation and self-regulation, followed by the classroom environment. The model further elaborates on students' motivating processes as they assess and interpret various situations and the self-regulation strategies they can employ to effectively monitor, manage and control their cognition, motivation, behaviour and contextual factors. Finally, the outcomes of these processes are described.

Pintrich (1991) made a notable and impactful contribution to the study of self-regulated learning by introducing the Motivated Strategies for Learning Questionnaire (MSLQ). This questionnaire assessed various aspects of students' learning approaches and motivations within an educational context. This tool evaluates different dimensions of learning, including cognitive and metacognitive strategies and dynamic decision-making processes. Additionally, the questionnaire assesses various motivational factors that influence learning outcomes, such as self-efficacy (confidence in one's abilities), intrinsic value (perceived importance and interest in the material) and test anxiety (feelings of apprehension related to assessments). The MSLQ's application primarily focuses on college students, providing insights into how they approach learning, their strategies to comprehend and retain information, and the motivational factors that impact their engagement and performance.

2.6 MOTIVATION IN SCIENCE EDUCATION

Liu (2021) conducted a study to understand students' intrinsic motivation in Singapore by investigating the relationships between implicit theories of intelligence, accomplishment goals theory, intrinsic motivation and mathematical performance. The study focused on students from the lower-progress stream, specifically those aged 13 to 17. The research employed questionnaires and structural equation modelling to analyse correlations and relationships among these variables.

The study examined the impact of a fixed mindset and performance-based goals on intrinsic motivation and mathematical performance. It also explored the effects of incremental mindset and mastery approach interventions on intrinsic motivation for math achievement. The study revealed that adopting performance-based goals could slightly enhance intrinsic motivation and achievement, although its influence was relatively uncertain compared to alternative strategies like mastery-approach goals. The research by Liu (2021) indicated that different cultures influence students' motivation, goal-setting and mindsets. Cultural variations shape how students perceive success, effort and learning. In response, researchers introduced interventions centred on an incremental mindset and mastery approach to boost students' intrinsic motivation in math achievement.

An experiment performed by DiBenedetto and Zimmerman (2010) involved 51 high school science students. They gave the students a reading passage about tornadoes and a subsequent test. The study employed a self-regulated learning model to assess planning, task value and self-evaluation strategies. Most lecturers realised they needed to motivate the students by setting goals. This observation was consistent with findings by Cleary and Kitsantas (2017); Schunk (1991) and Zimmerman (2011). Furthermore, Cleary and Kitsantas (2017) extended these insights by suggesting that self-regulated motivational strategies could potentially aid students in enhancing their self-efficacy and improving their academic performance. This highlights the potential benefits of utilising self-regulation techniques to enhance students' sense of capability and their overall educational achievements.

Jackman et al. (2011) found that secondary school learners' perceptions, task values and mastery goal orientation were directly related to learning and achievement, even with relatively short interventions. They found that students with a maladaptive orientation showed improvement in science motivation, but not necessarily in achievement. However, students with an adaptive orientation to science did not exhibit a shift in motivation, but a notable rise in science achievement. In their study, the following factors were important: the enjoyment of a task or skill, its intrinsic value and the importance of achieving success. According to Olić et al. (2016), the importance of these aspects varies from student to student.

Between 2008 and 2018, McDowell (2019) reviewed empirical studies in the USA concerning self-regulated learning. This review specifically concentrated on undergraduate students majoring in Chemistry, Physics and Engineering. The research findings indicated that students' experiences significantly influence the trajectory of persistence in STEM-related programmes during their initial two years of college. Despite a high level of consensus regarding the definition of self-regulated learning, the reviewed studies revealed variations in the factors perceived as being most impactful in cultivating self-regulated learners. Numerous studies showcased connections between motivational aspects.

Interestingly, less than half the studies surveyed incorporated a performance measure, and even fewer utilised an experimental design. Most studies have found correlations between motivational variables. A sample of studies demonstrated the need for a self-regulated intervention in science. Rather than simply teaching students the science content, it is vital to teach them how to learn (McDowell, 2019). Learning and teaching are related procedures, and studies have demonstrated that fostering self-regulation in learning helps students make impressive progress (Lopez et al., 2013).

In a study conducted by Dunn and Lo (2015), undergraduate science learning was assessed through student surveys. The research revealed a notable correlation between students' sense of self-efficacy and their employed strategies for studying science. Significantly, this sense of self-efficacy impacted the orientation of learning goals substantially.

In this section, the focus was on motivation and its connection to in-class effort. Low self-efficacy learners select complex tasks, put up better effort, persist longer in facing challenges and do better. The relationship between mindsets, achieving goals, intrinsic motivation and academic success are discussed. The impact of technology on education is described in the next section.

2.7 TECHNOLOGY AND EDUCATION

Technology has profoundly changed education over the past few years, affecting instructional strategies, student learning and administrative practices.

Online courses and e-learning platforms have increased access to education. Bower (2016) states that students can study swiftly and conveniently using e-learning. This frequently allows for self-pacing. Using digital textbooks, e-books and free online resources decreases the price of educational materials (Hollister, 2020). Understanding and engagement are improved by multimedia information, including videos, interactive simulations and animations (Clark & Mayer, 2023). Mobile games, and virtual and augmented reality technologies produce immersive learning opportunities (Cheng et al., 2015). They can be utilised for learning activities like simulations and virtual field trips. Technology makes online quizzes, tests and automatic grading possible. The value of combining technology with conventional teaching methods is acknowledged by top educational institutions around the world (Rapanta et al., 2021).

Educators can manage courses, assignments and evaluations using learning management system (LMS) platforms like Moodle, Canvas and Blackboard. Student and teacher collaboration is made possible with Microsoft Teams and Zoom.

While technology has dramatically benefitted education, it has also brought up several problems, such as the digital divide, problems with screen time, cybersecurity worries and the need for digital literacy skills. To ensure that technology improves learning outcomes, effective technology integration in education necessitates careful planning, continual training and an emphasis on pedagogy (Ahirwar, 2020). Developing innovative technological practices is more accessible in schools with infrastructure, equipment, a positive school culture and staff support (Demartini et al., 2020).

2.7.1 Educators' knowledge of technology

When creating classes using technology, lecturers promote teaching principles. They should be aware of the purposes of various types of software and how they can be utilised to organise their work (Postholm, 2007).

The importance of technology in education has increased due to the COVID-19 pandemic (Adov & Mäeots, 2021). Technology has become crucial for preserving educational continuity when shifting to remote and hybrid learning. Erlangga (2022) claim that the role of online learning in the educational system has grown significantly. According to Adov and

Mäeots (2021), instructors’ readiness to adopt technology is essential for overcoming potential challenges.

2.7.2 Different technologies used in education

As Morgan et al. (2022) outlined, Gartner's hype cycles highlight a heightened emphasis and augmented investment in classroom technology. This includes video, audio, presentation and content capture, whiteboarding, discussion tools, polls and group activities. Notably, these cycles are mainly centred on technologies post-COVID-19, specifically tailored for online learning. Educational institutions have embraced the technologies embedded within their LMS ecosystems and specialised web-conferencing platforms like Microsoft Teams and Zoom.

While Gartner provided more recent insights, the study conducted by Lai and Bower (2019) offered a more detailed examination of the specific technologies employed in education. Therefore, the researcher opted to utilise the findings from this study.

Lai and Bower (2019) stated that the reviewed papers covered a broad spectrum of education levels, disciplines and technologies, aligning broadly with how other studies characterise the learning technology field. The analysis revealed that the assessment of learning technology was centred around eight key themes: learning outcomes, affective elements, behaviour, design, technology components, pedagogy, presence and institutional environment. This would ensure that the review encompassed the evaluation of learning technology across diverse contexts. This approach also provided confidence that the evaluation practices were both contemporary and of a high quality.

A thorough study of technology application in education between 2015 and 2017 was released by Lai and Bower (2019). They identified the subsequent groups of instructional technologies (Table 2.2):

Table 2.2: Educational technologies as identified in the reviewed papers (Lai & Bower, 2019)

	Technology	**No of papers**	**%**
1	Games/mobile games in different disciplines	67	18.4
2	Web 2.0 learning technologies (e.g. social media, social network systems, wikis or blogs)	54	14.8
3	Mobile devices (e.g. tablets, iPads, computers, interactive tools/technologies or mobile devices)	54	14.8
4	Virtual world/virtual reality	24	6.6
5	Digital instructions or instructional visual aids	22	6.0
6	Management systems (e.g. classroom management systems, learning management systems or self-regulated learning systems)	21	5.8
7	Animations and simulations (e.g. instructional animation or computer animation)	18	4.9
8	Discussions/online discussion platforms (e.g. online interaction platform, online collaboration network or collaborative simulation)	18	4.9
9	The online learning course delivery, e-learning or massive open online courses (MOOC)	16	4.4
10	Blended learning (i.e. the use of technology with face-to-face learning)	12	3.3
11	A technology-enhanced system, online feedback system or audio feedback system	11	3.0
12	MOOCs	10	2.7
13	Student response system	10	2.7
14	Programming	8	2.2
15	Embodied agents. Non-player agents, pedagogical agents or teachable agents	7	1.9
16	Augmented reality (AR) technology	5	1.4
17	Robotics	4	1.1
18	Online books. E-books or digital storytelling	4	1.1
		365	**100**

Some of the technologies mentioned in the table are discussed in more detail.

2.7.2.1 Mobile games

Plass et al. (2020) distinguished between gamification and game-based learning. Game-based learning uses a game to teach knowledge and skills, while gamification involves incorporating certain game elements into a learning programme.

Game-based learning provides opportunities to apply theoretical concepts in practical scenarios. These scenarios simulate real-life situations where learners can test their knowledge and skills. Games can be designed to assess learners' knowledge and skills.

The data collected from game play can offer insights into learners' performance and areas that need improvement. One of the primary benefits of game-based learning is that it makes the learning process enjoyable. When learners are having fun, they are more likely to be engaged and retain the information (Plass et al., 2020).

Kahoot! and Quizizz are popular game-based learning systems that both students and educators' favour. These platforms offer interactive quizzes and activities that engage learners, while enhancing their knowledge. In Quizizz, questions and answers are displayed on the same device. Students receive questions randomly, enhancing variety and engagement.

Luo (2022) found in a study that the acceptance of gamification has improved in numerous fields, including education, since the end of 2010. The aim is to increase learners' interest, participation, motivation and loyalty (Simões et al., 2015). Learners are motivated and perform better when applying game design elements to real-world situations. Gamification in the classroom brings competitiveness and active participation to class. Students who share their screens with the class, participate in discussions and ask questions can receive badges as a reward (Dey et al., 2021). Through gamification, learners gain learning experiences in a fun and engaging environment.

2.7.2.2 Web 2.0 learning technologies

The term Web 2.0 tool refers to a collection of online software applications and platforms that enable users to engage in diverse activities and tasks, fostering interaction, collaboration and creativity (Aljawarneh, 2020). It allows educators to integrate technology into their teaching practices and can be used to teach curriculum content in more dynamic and interactive ways, enhancing student engagement and understanding. Users can often create and modify multimedia content, such as videos and photographs, without advanced technical skills.

Web 1.0, the initial phase of the internet, was characterised by static and read-only websites, where users could only consume information (Lomicka & Lord, 2016). In contrast, Web 2.0 emerged in 2006, significantly shifting towards interactive and user-generated content. Many Web 2.0 applications are lightweight and accessible online without requiring users to install additional software. This accessibility extends to various devices, including computers and phones, making it convenient for users to participate and engage (Prabhu, 2017).

The World Wide Web, known as www, was invented in 1989 by Tim Berners-Lee. The primary purpose of this invention was to create an interface for the internet that would allow users to share information and access resources (Berners-Lee et al., 1992). It was developed to serve as a platform for users to share and access information on the internet. It was a way to organise and present content in a user-friendly manner, enabling people to interact with online resources.

The evolution of the web is analysed in an article by Haile (2024), following its progress from the early stage, Web 1.0, to its present form, Web 3.0. The primary goal is to change user behaviour, shifting from Web 1.0's passive content consumption to Web 2.0's active content creation and, finally, Web 3.0's content validation. Users could only passively read static web pages during the first phase of the internet (Web 1.0). With the introduction of Web 2.0, people could actively create and distribute information online. However, in the current Web 3.0 era, machine learning-powered personalised content suggestions are the focus, underscoring the growing importance of content validation. This paper explores the implications of Web 2.0 for educational purposes (Haile, 2024).

YouTube is a prime example of a Web 2.0 tool that emphasises user-generated content and interaction. YouTube enables users to upload, collaborate and share videos, fostering engagement and collaboration. As a valuable educational resource, it offers videos and tutorials that cover various concepts, developments and applications (Majhi et al., 2016). This content can enhance student learning by providing visual explanations and demonstrations. YouTube can be accessed through various devices, including phones and laptops. This accessibility makes it convenient for users to engage with content anywhere and anytime (Shoufan & Mohamed, 2022).

As described by Aldahdouh et al. (2020), social media encompasses various tools, including wikis, blogging platforms, discussion forums and bookmarking services. These tools enable communication, collaboration and the sharing of information among users. Hamid et al. (2015) and Lim (2016) have investigated the potential benefits of social media for shy students who may find it challenging to express their thoughts directly to their peers. Social media platforms can offer a more comfortable environment for such students to engage and communicate. According to Hassan et al. (2019), leveraging social media in education can foster student engagement and interaction. Demir and Şad (2020) found that the interaction between lecturers and students through social media can contribute to building a positive relationship. This interaction can enhance communication and understanding between educators and learners.

Students commonly use social media platforms to connect with their peers, stay in touch with friends and engage with their lecturers. Platforms like WhatsApp, Twitter, Instagram and Facebook serve as avenues for networking and communication. According to a study conducted by Ansari and Khan (2020), students who engage in collaborative learning through social media tend to perform better academically. The study revealed that for every 10% increase in student involvement in collaborative learning through social media, there was an associated increase in academic performance by 9.72%. Social media's online environment enhances students' creativity and fosters a stronger connection with instructors.

A wiki is a collaborative platform that allows multiple users to create, edit and organise content on a website. Wikis enable people from various locations to work together on the same website or database, making real-time updates and contributions. Wikipedia is one of the most well-known examples of a wiki, where users collaboratively create and edit encyclopaedia articles. A blog, short for "weblog", is a website where an individual or a group of individuals regularly post and update content. Unlike a wiki, where multiple users collaborate on content creation, a blog is managed by one or a few authors who share their thoughts, opinions or information with the public (Jena et al., 2020).

According to Haşiloğlu et al. (2020), social media can distract students from their academic studies. The ability to send and receive messages through social media platforms might divert their attention from concentrating on their studies. Nuuyoma et al. (2020) point out certain limitations of using WhatsApp for academic purposes. These drawbacks include distractions caused by excessive messaging and potential issues related to spelling and grammar.

2.7.2.3 Mobile devices

Information can be received or presented in any format via a mobile device. Kelly (2021) argues that the goal is not to move educational information to a small screen and use a mobile device, but to introduce innovative learning forms and create creative mobile educational materials (Kelly, 2021).

Computers are electronic devices that process data based on instructions and can execute pre-recorded programs, which are instructions that define specific tasks and operations (Null & Lobur, 2018).

Laptops are portable devices that can be used without requiring a desk or surface. They have built-in batteries that allow usage even when not connected to a power source (Reisdorf et al., 2020). Unlike laptops, desktop computers are bulkier and heavier. They are typically stationary and must always be connected to a power source due to their larger components.

Connecting a laptop to a video projector can enhance the interaction between lecturers and students. This setup can boost student motivation, engagement and learning (Dos Santos et al., 2023). Projectors can display the laptop screen's content on a larger scale on a whiteboard, making it visible to the entire classroom.

Virtual whiteboards enable users to write, draw, present media and collaborate. The content displayed on the virtual whiteboard facilitates engagement and interactive teaching methods (Ivone et al., 2020). Digital whiteboards have been shown to foster active, engaged and reflective learning experiences (Helmold, 2021).

2.7.2.4 Virtual worlds

A virtual world is a computer-generated, immersive and interactive environment that simulates real-world aspects or creates entirely fictional realms. These digital spaces can vary widely in terms of their purpose, design and level of realism. Here are some key aspects of virtual worlds:

Augmented reality (AR)

Augmented reality (AR) is a technological innovation that integrates three-dimensional (3D) virtual objects into the actual 3D environment. Frequently employed as an instructional aid, the 3D model enhances students' comprehension of presented information. AR technology finds applications across diverse fields, notably in education. According to findings from a study conducted by Guntur et al. (2020), the utilisation of AR has demonstrated enhancements in spatial abilities, problem-solving proficiency, and student motivation.

Virtual reality (VR)

Virtual reality allows users to view, navigate and interact with 3D environments as if they were real. It creates a sense of immersion by simulating the user's presence within a digital space. The concept of illusion plays a significant role in VR, as it aims to create a fantasy world that appears real through computer-generated graphics. The illusion in VR is about creating a mental and sensory experience that mimics reality. The graphics on the screen act as a window, allowing users to perceive and interact with a virtual world that feels authentic, natural and immersive (Mujber et al., 2004; Shafie et al., 2019).

2.7.2.5 Digital instruction

Digital instructions are the fundamental building blocks of software and hardware systems, which allow computers and other digital devices to achieve particular operations. They take many forms, from simple machine code to complex programming languages, and control how computers operate (Stoetzel & Shedrow, 2021).

2.7.2.6 Management systems

Learning management systems like Moodle, Blackboard, Schoology and Google Classroom are online platforms for multiple educational functions, including group discussions, uploading course material and assessing student activities (Hu et al., 2020). They provide a range of tools for instructors to facilitate students' learning experiences, such as course guidelines, assignments, marks, knowledge sharing, and online exams and quizzes (Hu et al., 2020; Kasim & Khalid, 2016). With an internet connection, students can access course material, discussions and assignments from anywhere. It offers communication tools such as discussion boards, announcements and messaging, facilitating interaction and collaboration between students and instructors. Educators can incorporate multimedia elements like videos, audio and interactive quizzes to make the learning experience engaging and interactive for students. The integrated Moodle is a collaborative learning environment that significantly impacts how people interact with each other, their culture and society (Kasim & Khalid, 2016). Its user-friendliness, accessibility and flexibility make it easy for educators and learners to engage with the platform. Moodle can be integrated into other systems, enhancing its versatility and adaptability. The platform also offers tools to manage personal and private information (Turnbull et al., 2020).

Blackboard is a widely used LMS that is designed to facilitate online education and course management. It provides a platform for educators to create, manage and deliver educational content and activities to students in various formats (Turnbull et al., 2020). Blackboard cannot be integrated into other systems like Moodle.

Schoology is described as a leading platform in teaching and learning technology for schools. Its primary goal is to enhance student performance, while providing online access for every student. The platform enables educators to organise curricula, create lesson plans and conduct student assessments (Saepuloh et al., 2021).

Google Classroom is introduced as an online platform designed for creating a virtual classroom environment. The platform integrates with Google Drive, allowing easy document management and storage (Gupta & Pathania, 2021).

2.7.2.7 Visual aids, animations and simulations

Visual aids

Visual aids are supplemental resources or instruments that provide visual information to verbal communication, presentations or educational content to strengthen and reinforce it. They are intended to improve the audience's comprehension, interest and content retention. The goal of visual aids, which come in various shapes and sizes, is to emphasise, clarify or visually represent essential ideas.

Slideshow presentations are a skill that involves creating content and effectively delivering it to an audience. Only a few presentation tools will be discussed in this study.

Microsoft PowerPoint (PPT) is introduced as a user-friendly presentation tool within the Microsoft Office suite. It empowers users to generate presentations efficiently and effectively (Francique, 2021). Lecturers can use PowerPoint as a presentation tool to create engaging visual presentations enriched with multimedia content. Utilising various modalities and visual effects in PowerPoint presentations can enhance students' focus and interaction with the material. PowerPoint allows one to integrate multimedia elements like videos and audio recordings, adding depth and interactivity to the presentations. Students can easily revise the presentations as they are saved digitally. Presenters can make the content more exciting and visually appealing by using different design elements like layouts, backgrounds, transitions and animations (Francique, 2021).

Prezi is a sophisticated online presentation and analytics software solution. Students can use Prezi for free to create individual or group presentations, similar to PowerPoint. However, Prezi offers a unique canvas-based presentation style as an alternative to traditional slides. Prezi allows the integration of various media elements, such as images, videos, audio, animations and links, which can be edited throughout the presentation. The collaborative nature of Prezi is valued in educational settings, enabling group work (Sanchez et al., 2020). Interactive elements like multiple-choice, quizzes and open-response questions are substantial. Instructors can provide support, correct misinformation and facilitate class discussions based on responses. Prezi enables visual aids like pie charts to display correct responses and the anonymous discussion of open-ended questions to promote a more comfortable and less intimidating learning environment (Sanchez et al., 2020).

Nearpod is an online tool that enhances learning interactivity in physical and virtual classrooms. It offers interactive presentation features such as quizzes, polls, videos and collaborative boards (Hakami, 2020). Teachers provide students with a live presentation by sharing a code, allowing students to interact with the media as the lesson progresses. Nearpod supports a student-paced mode, where students can control the class flow, enhancing learning autonomy. Any device with an internet connection can use Nearpod due to its web-based nature, making it suitable for various learning scenarios, including online, hybrid, sub-days, homework assignments and individual work (Sanmugam et al., 2019). While traditional software like Microsoft PowerPoint is used for virtual presentations, Nearpod offers distinct advantages that make it more powerful and interactive.

Animations and simulations

Animations and simulations are valuable educational tools, as they can enhance the learning experience, improve understanding of complex concepts and provide real-world contexts for learning. They demonstrate how theoretical knowledge is applied in practical situations, making learning more relevant. They are powerful educational tools that promote active learning, critical thinking and a deeper understanding of complex subjects. They have become an integral part of modern teaching and learning practices.

Animations can incorporate visual and auditory elements, catering to different learning styles and increasing engagement. Students can actively engage with the content, manipulate variables and observe the outcomes, promoting experiential learning. Simulations allow students to conduct experiments and explore scenarios that may be unsafe, expensive or logistically challenging in a physical laboratory.

Simulations often present students with problems or scenarios to solve, encouraging critical thinking and decision-making skills. Many simulations provide immediate feedback, allowing students to see the consequences of their actions in real-time.

Digital animations and simulations are accessible from various devices, making learning flexible, and accommodating different learning environments, including online and hybrid learning (Shuo, 2021).

2.7.2.8 Online discussions platforms

An online discussion platform is a cloud-based video conferencing service. It allows users to meet virtually through video or audio. People can meet one by one or in groups. The presenter and participants may share their screens to collaborate efficiently. The participants can listen to recordings of lessons later. These meetings can be joined via a webcam or phone from conference rooms. Breakout rooms are used to improve teaching. Invitations are sent out to participants via the LMS or a link to share information professionally and provide a possibility for discussion (Tillman & Willings, 2020). See Table 2.3 for a comparison of some online discussion forums.

Table 2.3: Comparison of online discussion forums (Hughes, 2020)

	Free version available	Meeting participants	Screen sharing	Whiteboard	Meeting recording	E-to-E encryption
Zoom	Yes	100	Yes	Yes	Yes	No
Microsoft Teams	Yes, limited time	250	Yes	Yes	Yes	No
Google Meet	Yes	100	Yes	Yes	Yes	No
Skype	Yes	50	Yes	No	Yes	Yes (optional)

2.7.2.9 Online learning course delivery

Online learning is a structured educational approach using electronic resources to support formal teaching. Technology enhances effectiveness by catering to diverse learning requirements (Rapanta et al., 2020). Online learning allows students to study independently and review complex concepts when needed. This contrasts with face-to-face learning, where managing all students' attention can be challenging. A positive relationship encourages students to comfortably ask questions, seek clarification and actively engage with the course material. E-learning platforms can facilitate discussions, polls and interactions. Dey et al. (2021) state that student-instructor relationships significantly impact learning outcomes. Students who connect positively with their instructors are more likely to be engaged and participative in the course.

2.7.2.10 Blended learning

Blended learning is a teaching and learning approach that combines both traditional in-class instruction and digital or online learning components. Blended learning is associated with improved learning outcomes (Kumar et al., 2021). Students can benefit from various instructional methods and resources. The learning environment offers the advantage of personalised instruction. Educators can tailor their teaching and activities to meet each student's learning needs and interests, enhancing the learning experience. The digital components of blended learning provide access to simulations that may not be feasible in traditional classrooms due to financial, time or safety constraints (Washington, 2020). These simulations offer students hands-on experiences and a deeper understanding of complex concepts. Virtual laboratories and simulations allow students to observe and interact with scientific phenomena, making learning more engaging and practical. Students are allowed to progress at their own pace. They can choose content that aligns with their learning needs and preferences (Kumar et al., 2021). This flexibility promotes independent learning and student autonomy. Digital tools offer immediate feedback to students to track their progress, identify areas for improvement and make adjustments accordingly. Students' progress is visible to teachers and families, promoting transparency and accountability in the learning process. This visibility can lead to more informed discussions about a student's educational journey.

2.7.2.11 A technology-enhanced system, online feedback system or audio feedback system

Online feedback is a digital platform or application designed to gather and manage student feedback. These systems are often web-based and offer a convenient way to collect opinions, reviews or responses electronically. Users can provide feedback from anywhere with an internet connection. Feedback is collected digitally, making it easier to organise and analyse via communication channels, email, websites and social media.

An audio feedback system involves recorded spoken feedback rather than written comments. Educators use audio feedback to provide detailed explanations, suggestions or critiques. Complex concepts can be explained more clearly through spoken words. It can benefit individuals with reading disabilities or those who prefer auditory learning. Audio feedback systems are often integrated into an LMS for educational purposes (Sarcona et el., 2020).

2.7.2.12 Massive open online courses

An MOOC is an online course designed for many participants. It has become a popular mode of online education. It is open to anyone and often includes many learning materials, such as readings, lectures and videos. Experts contribute to the development of MOOCs through social networking platforms. Users have access to various learning resources to enhance their knowledge and skills. Learning from friends and peers through social networking sites is considered advantageous in the context of MOOCs (Pant et al., 2021). Despite their benefits, MOOCs also have drawbacks. Completion rates can be low, mainly when there are fees involved. Not all courses are conducive to visually impaired students, and those who struggle with a subject might not receive personalised attention from instructors (Pant et al., 2021).

2.7.2.13 Student response system

A student response system (SRS) supports student interaction and feedback. It facilitates student-to-student discussion and collaboration, fostering a dynamic learning environment. It encourages students to participate actively in class, creating a more inclusive learning experience linked to various positive outcomes, including improved problem-solving skills, concentration, motivation, peer-to-peer interaction and overall enjoyment of learning. Instructors can use a student response system to assess student understanding and give immediate feedback (Joshi et al., 2020).

Some of the most known student response systems are polling, clickers and Mentimeter.

Polling involves gathering opinions or preferences from individuals through voting. It lets instructors quickly gather student feedback and opinions during presentations (King, 2016).

Clickers are handheld devices resembling remote controls that allow students to respond to questions. Clickers provide a way for students to participate actively and respond to questions posed by the instructor. Clickers offer immediate and real-time response collection, allowing instructors to gauge student understanding instantly. However, clickers have high costs, limited mobility, technical installation and setup challenges (Lantz & Stawiski, 2014).

Mentimeter is an interactive presentation platform that allows presenters to engage their audience through polls, quizzes and interactive question-and-answer sessions (Mayhew et al., 2020). Mentimeter uses available technology like laptops, tablets or smartphones. Students can access the system quickly if they have an internet connection to the web page. It offers an accessible method of inviting audience responses (Mayhew et al., 2020).

Kahoot! and Quizizz are examples of student response systems that utilise game-based learning principles (Owen & Licorish, 2020). They offer interactive quizzes and activities that engage learners, while enhancing their knowledge. In Quizizz, questions and answers are displayed on the same device. Students receive questions randomly, enhancing variety and engagement.

Kahoot! is a widely used SRS with a large user base. It uses projectors to display questions and feedback on the screen. Lecturers need the University's Wi-Fi network, a laptop or cell phone, and a classroom projector to use Kahoot! (Lashari et al., 2023).

A three-dimensional model depicts an object or product in three-dimensional space. It provides a more comprehensive and realistic representation compared to traditional two-dimensional visuals. The depth, texture and spatial realism in 3D models enhance the viewer's understanding and appreciation of the subject (Astuti et al., 2020).

2.7.2.14 Programming

Programming, in computer science and software development, refers to creating and designing instructions (code) that a computer can follow to perform specific tasks or achieve particular goals. These instructions are written in programming languages, with rules and syntax for computer communication. Programming is a versatile skill with applications in various domains, including web development, mobile app development, data analysis, artificial intelligence and game development. Learning to program requires practice, problem-solving skills, and a deep understanding of the chosen programming language and its associated tools and technologies. It is a dynamic field that is continually evolving as new languages and technologies emerge (Alam, 2022).

2.7.2.15 Robotics

Robotics is an interdisciplinary field that combines principles from computer science and engineering. Robots can serve as educational tools to engage students in the classroom, especially those facing barriers to traditional participation (Anwar et al., 2019). They offer an interactive and engaging way of learning. Working with robots can enhance students' engineering intuition. Hands-on experience with robots allows students to apply their theoretical knowledge to practical applications. Educational robotics facilitates problem-based learning. Engaging with robots in an educational context can develop various skills, including higher-order thinking, logical reasoning, and analytical skills (Alam, 2022).

2.7.2.16 Online books

Interactive e-books are digital printed book versions, incorporating multimedia elements such as videos, photographs, animations, mini-tests, maps and special symbols. These elements enhance the learning experience by providing dynamic and engaging content.

Mobile devices like smartphones and tablets enable users to access e-books from anywhere, making learning more flexible and convenient (Eshnazarova & Katayeva, 2021). One of the benefits of e-books is their portability. Users can carry a wide range of books, textbooks and manuals in digital form on their devices. Unlike traditional printed books, e-books do not wear out or become outdated. They remain accessible and retain their quality indefinitely, making them a long-lasting resource. E-book readers often allow users to customise their reading settings, such as font size, colour and background, to suit their preferences.

2.8 TECHNOLOGY IN SCIENCE EDUCATION

The value of incorporating technology in education was covered in the previous section. It suggests that technology has the potential to transform conventional teaching methods and enhance the way subjects like science are taught and learned.

Bernacki et al. (2020) emphasised that integrating technology into science education can help students enhance their understanding of the subject and develop skills relevant to the modern workplace. Salar et al. (2020) indicated that various technological devices like computers, whiteboards and smartphones have significant potential to support students' learning and comprehension of science. By leveraging these technologies, educators can create more engaging and effective learning experiences for students in the field of science.

More science lecturers use technology in their classes to communicate science concepts and develop problem-solving skills. They found that performance outcomes are improved when technology facilitates more significant student interaction in the classroom and motivates the learners (Salar et al., 2020).

2.8.1 Different technologies used in science education

Some of the technologies listed by Lai and Bower (2019) (Table 2.2) are discussed below as technologies used in the science classroom.

2.8.1.1 Mobile games

Several studies have investigated the utilisation of digital games in the teaching of secondary school science. By integrating new technologies into the teaching process, digital game-based learning stimulates cognitive development and keeps students engaged. There is a growing concern regarding teacher-centred conventional science teaching methods in the Pakistani education system, as disengaged students are more likely to drop out (Khan et al., 2017). Khan et al. (2017) discovered that learning through game-based approaches was highly effective and significantly improved the engagement of secondary school students compared to traditional teaching methods.

Cheng et al. (2015) also noted a rising interest among researchers and educators in incorporating game-based learning into science education. They observed an increased volume of research between 2002 and 2013 focused on evaluating the effectiveness of game-based learning in science education. It offers a viable alternative to traditional learning methods such as simulations or experiments.

Riopel et al. (2019) concurred that game-based learning yielded superior results to conventional instructional techniques. A systematic study by Kara (2021) on using game-based learning in science education found that 29.73% of the publications primarily emphasised academic performance. Motivation was explored in 10.81% of the articles published between 2016 and 2020, while cognitive attributes were the focal point in 9.46% of the articles.

Chen et al. (2020) agreed that digital games in science education effectively contribute to students' learning, affirming the potential of well-designed educational games to enhance the educational experience.

One example of implementing gamification in the science classroom is using Kahoot! Kahoot! leverages technology to boost student participation in science lessons (Janković & Lambić, 2022; Khazanchi & Khazanchi, 2019). In a study by Rahmahani (2020), students' perceptions of Kahoot! were examined. An innovative chemistry lecturer used Kahoot! for three months and collected data to assess its impact. They also compared the academic results of a chemistry lesson before and after incorporating Kahoot! Remarkably, over 90% of the students reported that using Kahoot! enhanced their appreciation for chemistry lessons.

Another gamification technique involves the use of badges. In a systematic review, Kalogiannakis and Papakadis (2021) found that incorporating badges in science teaching increases external motivation more than internal motivation among students.

In 2019, Garneli et al. (2019) developed a multiplayer serious games (MSG) tool tailored for educators in science education. This tool represents a framework that empowers educators to create multiplayer serious games designed to enhance the learning experience. These games promote student collaboration and offer an engaging and interactive approach to teaching science concepts. This approach aligns with the broader trend of utilising technology and gamification to make education more engaging and effective (Chen et al., 2020).

2.8.1.2 Web 2.0 learning technologies

Over the past five years, the use of social media platforms has significantly increased. This trend has had a noticeable impact on how students engage with educational content and communicate with peers and educators. Social media sites like Facebook, WhatsApp, YouTube, wikis and others are being leveraged as platforms for collaborative learning in science education. These platforms allow students to collaborate on projects, share resources and discuss scientific concepts (Ansari & Khan, 2020).

A study conducted by Mpungose (2020) highlights a notable shift in the educational landscape from traditional LMSs to social media as a preferred platform for students. This shift suggests that students increasingly use social media to fulfil their learning needs and preferences. Mpungose's research indicates that using text-based communication on social media positively impacts the learning experience. Real-time and convenient communication through text, voice and video calls can enhance the overall learning process. Furthermore, social media technology is highly adaptable and compatible with various devices, ensuring accessibility for students who use smartphones, tablets, laptops or desktop computers.

In a related study, Haşiloğlu et al. (2020) found that science educators have embraced social media platforms as valuable tools for sharing educational content with their students. This content includes animations, images, videos and other educational resources. Social media integration has transformed students' learning experiences by facilitating collaboration and communication with peers and educators. It has also created a real-time interaction, content sharing and mutual learning platform.

While social media offers numerous educational advantages, it also raises several important considerations. These include issues related to privacy, digital literacy and responsible online behaviour. Educators and institutions must proactively address these concerns to ensure that the use of social media in education remains safe and effective (Haşiloğlu et al., 2020).

2.8.1.3 Mobile devices

In today's digital era, educational environments must leverage the benefits of technology, which significantly shape our thinking and learning approaches, as Kelly (2021) emphasised. Technological tools, including computers, smart boards and smartphones, have demonstrated immense potential in aiding students' comprehension of scientific concepts and seamlessly integrating them into the learning process, as Blumenfeld et al. (2000) highlighted.

Salar et al. (2020) conducted a study assessing students' technology usage patterns, and found that 99% of students utilised smartphones, while 52% preferred laptops. Desktop computer usage was comparatively low at 19%. Importantly, students who engaged with computers, tablets or smartphones experienced a notable increase in their interest in the subject matter.

As access to technology increased, many science educators incorporated technology into their teaching methodologies. This integration aimed to convey scientific concepts effectively and foster students' problem-solving skills, as Astuti et al. (2021) observed. Notably, studies have indicated that when technological applications promote greater student interaction in the educational setting and enhance motivation in the classroom, performance outcomes tend to be significantly improved Chans and Portuguez Castro (2021).

2.8.1.4 Virtual world

Salar et al. (2020) systematically reviewed the correlations between interest, usability, emotional investment, attention focus, presence and flow when using augmented reality (AR) technology in science education. Interest in technology increases attention and concentration. Researchers demonstrated that AR improves students' sense of presence in science education (Huang et al., 2019). Sahin and Yilmaz (2020) found that using AR in Physics courses can help students visualise magnetism, which enhances their understanding of the subject. AR has the additional benefit of enriching real scenarios, as experiments are often impractical in natural laboratories due to the high risk, high cost and complexity (Bogusevschi et al., 2020).

Virtual reality (VR) has proven to be a powerful tool in science education, offering students immersive and engaging experiences, as highlighted in various studies.

Makransky et al. (2020) emphasised that VR allows students to get up close and personal with scientific concepts, making them feel like active participants in the learning process. This immersive experience engages multiple senses, including visual and auditory cues. VR is commonly employed for experiential learning in science education, as noted by Lamb and Etopio (2019). It allows students to engage with scientific content through hands-on experiences. It offers students a range of representations, enabling them to visualise complex scientific concepts more effectively. It allows interaction with virtual objects, the conduct of virtual experiments, and the exploration of virtual scientific phenomena, as highlighted by Elfeky and Elbyaly (2018), Makransky et al. (2020) and Mujber et al. (2004).

Integrating VR with traditional textbooks can potentially enhance the effectiveness of science education in the classroom, providing students with interactive and dynamic learning resources that add depth and engagement to the learning process.

2.8.1.5 Learning management systems

Learning management systems, such as Moodle, are practical tools for incorporating technology into education. In science education, LMSs are crucial in efficiently organising and delivering course modules. A study by Krasnova and Shurygin (2020) revealed a clear connection between the performance of LMSs and the effectiveness of learning when preparing for practical sessions in science classrooms. This correlation underscores the importance of well-implemented LMSs in facilitating effective learning experiences.

Moreover, LMSs enable students to take an active role in their education. Prahani et al. (2022) noted that students can use these systems to prepare for class, maximising their benefit from classroom interactions. This emphasises the role of LMSs in promoting self-directed learning and ensuring that students are well prepared for their science education experiences.

2.8.1.6 Visual aids

Slide show presentations

Despite the popularity of Microsoft PowerPoint, Nearpod has emerged as a valuable tool for enhancing interactive learning in science education, offering several advantages over traditional methods like PowerPoint. A study by Siswati et al. (2023) found that Nearpod significantly boosted students' confidence and engagement in science classes. One key benefit of this technology is that it allows students to participate anonymously, reducing the fear of embarrassment in front of peers. This anonymity has not only improved classroom management, but has also increased student participation. Additionally, Nearpod is a valuable resource for educators, saving them time, providing automatic grading capabilities and aiding in retaining new information during science laboratory work.

Animation and simulations

Unsworth's research in 2020 (Unsworth, 2020) highlights the growing prevalence of animation in science education, emphasising its importance for scientific exploration and communication. These studies underscore that science animation is inherently transdisciplinary, requiring consideration of cognitive, social, educational technology and pedagogical perspectives to effectively address the academic challenges of introducing students to this vital aspect of scientific discourse. These studies also demonstrate the increasing cross-disciplinary nature of science education and the continuous improvement in available animation approaches for teaching science. Ongoing transdisciplinary efforts are enhancing learning in science through animation and digital multimodal representation.

For instance, chemistry simulations can help students understand chemical reactions without handling dangerous chemicals.

2.8.1.7 Online learning

Krasnova and Shurygin (2020) conducted a study centred on designing modules to deliver diverse teaching methods for Physics. Their research yielded valuable insights, highlighting the potential of e-learning to enhance the quality of the instructional process. Through e-learning, instructors can effectively structure course content and guide students to relevant information sources. This enables the monitoring of students' progress and time allocation for each lesson.

E-learning courses, particularly in science, complement traditional teaching methods by providing students with opportunities for independent study. Consequently, students develop valuable self-management and self-discipline skills. However, educators must adapt and enhance their presentation skills to effectively facilitate e-learning experiences (Krasnova & Shurygin, 2020).

2.8.1.8 Student response system

Several studies by Tirado-Olivares et al. (2021) including those conducted by Mader and Bry (2019), have consistently shown that student response systems are highly effective tools for enhancing various aspects of the classroom experience. These studies demonstrate that Student Response Systems play a valuable role in enhancing student engagement, attitudes toward science, the perception of the learning environment, attendance rates, and content retention in the classroom. These systems contribute to a more dynamic and effective teaching and learning experience.

2.8.1.9 Online books

Interactive e-books have positively impacted students' attitudes, motivation and science interests. This technology-enhanced learning environment has effectively guided students towards gaining a newfound appreciation and affection for science. This transformation is especially noteworthy since many perceive science as a complex and challenging subject (Ormanci & Çepni, 2020). As outlined by Tatar and Kuru (2009) and Wu et al. (2014), science education programmes play a crucial role in nurturing students' various essential skills and attributes. These programmes contribute to developing critical thinking skills, problem-solving abilities, effective decision making, and cultivating values, attitudes and identities aligned with the scientific understanding of nature.

2.8.2 Summary of technologies used in science education

In accordance with the work of Lai and Bower (2019), this section provides detailed descriptions of various technologies employed in education. Table 2.4 offers a concise summary of those technologies specifically applied in the context of science education.

Table 2.4: Technologies used in science education

Technology focused on science education
Games/mobile games in different disciplines (section 2.9.1.1)
Web 2.0 learning technologies (e.g. social media, social network systems, wikis or blogs) (section 2.9.1.2)
Mobile devices (e.g. tablets, iPads, computers, interactive tools/technologies or mobile devices) (section 2.9.1.3)
Virtual world: virtual reality, augmented reality (section 2.9.1.4)
Management systems (e.g. classroom management systems, learning management systems or self-regulated learning systems) (section 2.9.1.5)
Animations and simulations (e.g. instructional animation or computer animation like slideshow presentations) (section 2.9.1.6)
The online learning course delivery, e-learning (section 2.9.1.7)
Student response system (section 2.9.1.8)
Online books. E-books or digital storytelling (section 2.1.9.9)

The use of technology in science and education was covered in this section. Existing pedagogies are discussed in the section that follows.

2.9 PEDAGOGIES AND RELATED TEACHING APPROACHES IN SCIENCE EDUCATION

The following section discusses behaviourism, cognitivism, constructivism and social cognitivism as existing pedagogies.

2.9.1 Behaviourism

Behaviourism is a psychological theory that emphasises objective behaviour and external stimuli above inward mental processes or subjective sensations. Psychologists like John Watson and B.F. Skinner played a significant role in its development in the early 20th century (Skinner, 1976; Watson, 1926). Teaching strategies based on behaviour had the best results when the content was straightforward to memorise, or there was a correct response. According to Skinner (1976), knowledge is a repertoire of behaviours. The regular repetition required to reinforce response patterns properly is provided via so-called “skill and drill” activities, a mainstay of behaviourist teaching methodologies.

One of the teaching approaches categorised under behaviourism is direct instruction.

Direct instruction

Direct instruction is teacher-centred teaching. Rather than integrating student preferences or providing opportunities for hands-on learning, most lessons consist of lectures or scripted lesson plans (Lathan, 2018). Textbooks and workbooks are used more than computers or mobile devices (Figure 2.4). Olatunde-Aiyedun and Ogunode (2020) noted that direct learning is when a teacher prepares and delivers a presentation on a topic. A challenge is that students may lose focus after listening. According to Ramnarain (2014), it is the best way to introduce new concepts or topics to students. Direct instruction is recognised for its methodical and explicit approach to teaching to ensure that students acquire the necessary knowledge and abilities. It aims to provide clear explanations, modelling and guided practice (Olatunde-Aiyedun & Ogunode, 2020).

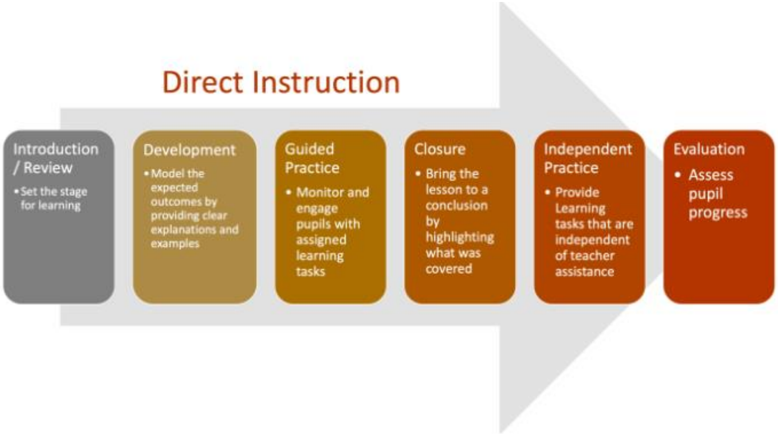


Figure 2.4: Direct instruction (Carnine et al., 1997)

A limited number of resources and many learners in a classroom make direct instruction the preferred lecture method for science education, according to Zenda (2017). Due to its focus on lecturers, the lecture method allows lecturers to finish their syllabus on time without learners' participation.

Direct instruction uses a systematic and explicit method of teaching that aims to give clear explanations, modelling and guided practice to ensure that students are learning. While it may be effective for specific subjects and learning objectives, it may not be suitable for all learners or all types of content. Different teaching methods and approaches may be more appropriate in specific contexts to promote critical thinking, problem solving and student engagement.

2.9.2 Cognitivism

Because they were dissatisfied with Behaviourism's exclusive concentration on observable behaviour, educational psychologists like Jean Piaget and William Perry promoted an alternative approach to learning theory that focused more on what was happening inside the learner's head. They developed a cognitive technique that prioritised internal thought above outward behaviour. Cognitivist teaching methods aim to assist students to incorporate new information into their past understanding so that they can modify their mental models to accommodate it. The cognitive approach, which acknowledges mental preparation, goal setting and organisational processes, focuses on the learner's mental activity prior to a response (Shuell, 1986).

2.9.3 Social constructivism

Social constructivism promotes constructivism by emphasising the social and cultural facets of learning (Leeds-Hurwitz, 2009). It emphasises what social learning is and how it occurs through interactions. According to the social constructivism theory, knowledge is created through group projects, conversations and bargaining within a social setting (Gray, 1997). It acknowledges that social interactions, cultural norms and shared knowledge within a community impact learning. Peer learning, engagement in communities of practice and cooperative group work are frequently incorporated into social constructivist approaches.

Collaborative and cooperative learning, categorised under social constructivism, are discussed below:

Collaborative learning

Collaborative learning is a student-centred teaching method where students work independently or in groups to discuss concepts or find solutions to problems. Lecturers are well suited to this sort of intellectual method. Students teaching or helping each other can be an effective teaching strategy (Steinhauser & Yeung, 2010). Armbruster et al. (2009) stated that collaborative learning improves reflection, intrinsic motivation and achievement. The common goal is continuously enhanced learner outcomes. Lecturers are actively involved in planning and research to make proper decisions. Encouraging collaborative learning activities, such as group projects, discussions and debates, allows students to interact with their peers and engage in scientific inquiry. Collaboration promotes teamwork, communication skills and exchanging ideas (Ansari & Khan, 2020; Esteves et al., 2017).

In some research, collaborative and cooperative learning are used as synonyms, but there is a slight difference (Armbruster et al., 2009). Cooperative learning is required for all students in the classroom, whereas collaborative learning is a voluntary activity in which sincerely interested students can participate. They must go through it to complete the task, and the instructor is available to provide direction (Figure 2.5).

Figure 2.5: Illustration of collaborating (ResourceEd, 2019)

A meaningful choice can only be made among several options. Students can compete or work cooperatively by taking responsibility for each other's learning and their own.

Cooperative learning

Cooperative learning is also defined as "stronger together" (Lin, 2006). The approach has students working in small groups to accomplish learning objectives. Lecturers use this student-centred methodology to let students discuss issues in groups – from solving a multi-step math problem together to developing a design (Figure 2.6). Makokha and Ongwae (1997) explained that students' attention, involvement and knowledge acquisition improve brainstorming to discover new ideas when all thoughts are given equal credibility. A group member can sometimes be separately responsible for specific tasks, or group members work together spontaneously (Johnson & Johnson, 1989). Cooperative learning helps students stimulate different perspectives to increase their self-esteem, motivation and empathy.

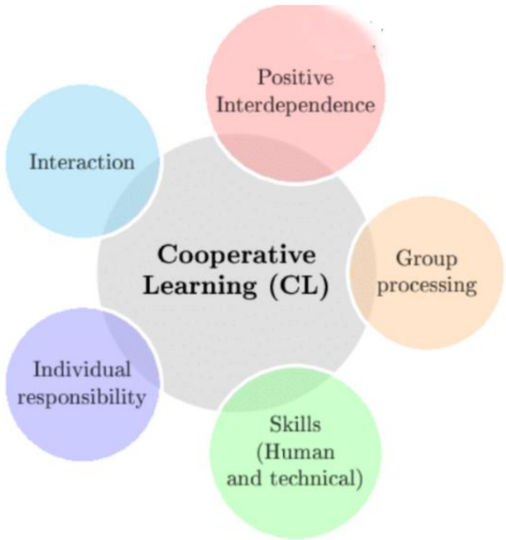


Figure 2.6: Presentation of cooperative learning (Duran et al., 2019)

The transition to a working group system has not been difficult for science lecturers who used to work in small groups (Roseth et al., 2008). Johnson and Johnson (1989) examined research in STEM classes in a college-level meta-analysis. They found that students learnt considerably more working alone than when they worked together. Students were also more determined in the small group teaching setting (Springer & Stanne, 1999).

No matter the student's ability or ethnic background, Lin (2006) agreed that science students learn more when they work cooperatively than independently. Mehta and Kulshrestha (2014) participated in a discussion of science teaching experts' interest in designing a curriculum that encourages students to work cooperatively, solve problems and make decisions.

2.9.4 Constructivism

According to Vygotsky and Cole (1978), constructivism is a learning theory that actively creates knowledge and comprehension by fusing new data and experiences with pre-existing mental models. Constructivism holds that learning is a personal and meaning-making process in which students actively create information rather than passively absorb it. Hands-on activities, problem solving and group learning are frequent components of constructivist teaching methods.

Some of the teaching approaches categorised under constructivism are discussed below.

Project-based learning

Project-based learning is a student-centred, active learning method that focuses on creating a project as the output (Armbruster et al., 2009). It addresses multiple content areas to understand how real-life problem-solving functions (Figure 2.7). As it is hands-on work, internet access is advantageous for research, presentations and project execution. Cattaneo (2017) agreed with Yilmaz et al. (2017) that project-based learning is focused primarily on a project as specific student output, where knowledge is transferable in small groups with trustworthy assessments. Evaluation is done after completion.

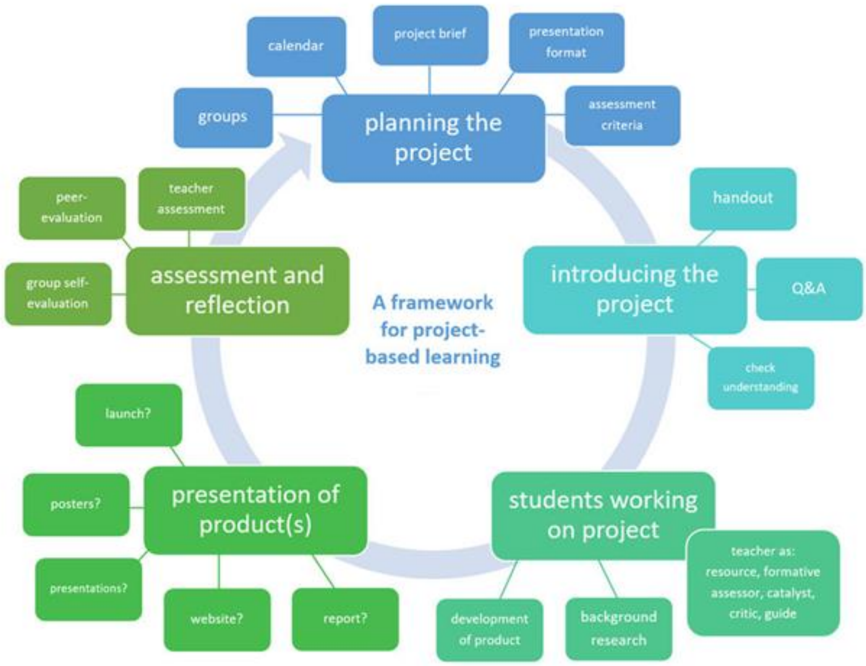


Figure 2.7: Framework for project-based learning (Anderson, 2021)

According to Baran and Maskan (2011), group collaborations and difficulties relevant to real-world experiences for students are highly associated with STEM project-based learning. According to several investigations, students enrolled in STEM project-based classes are less likely to quit their studies (Domínguez & Jaime, 2010; Han et al., 2015; McMullan, 2016).

A study by Samsudin et al. (2020) focused on the pendulum and pulley system in Malaysian students in Physics courses. Students became more skilled at solving mechanics and physics problems using STEM project-based learning techniques. In addition to this study, several additional investigations (Baran & Maskan, 2011; Clark & Mayer, 2012) have discovered similar outcomes.

Inquiry-based learning

Inquiry-based learning involves students considering their intrinsic motivation and philosophical processes (Armbruster et al., 2009). It is a personalised, student-centred model (Figure 2.8Figure 2.8). As an alternative to being the sole authority figure, lecturers assist students as they work on projects that require them to become more focused and to be active participants in their learning (Lathan, 2018). In an inquiry-based classroom, Cattaneo (2017) suggests that the focus is on questions that frame the inquiry, while in a problem-based classroom, the focus is on the problems that lead to learning (Owens et al., 2002).

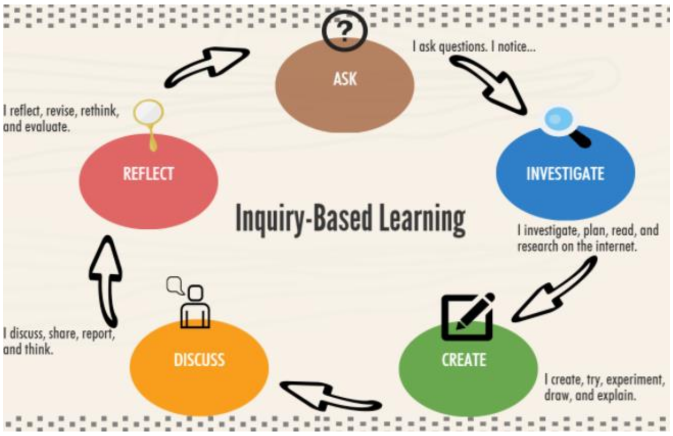


Figure 2.8: Inquiry-based learning model (Furtak et al., 2012)

As students construct knowledge collaboratively through inquiry-based learning, they actively participate in the learning process. An investigation of high-school Chemistry classes was conducted by Ferreira and Trudel (2012). Students' attitudes towards science were significantly impacted by inquiry-based learning. The results indicated that students learning through inquiry-based learning improve their problem-solving skills.

Problem-based learning

In a problem-based learning setting, students can improve their metacognitive skills (Bransford et al., 2000). Problem-based learning has been shown to increase student attitudes and performance in numerous studies (Marbach-Ad et al., 2001; Preszler et al., 2007; Prince, 2004). In their study, Armbruster et al. (2009) claimed that problem-based learning could include active learning and group problem solving. In most cases, a PowerPoint slide displayed a group problem, and the groups were given three to five minutes to resolve it. During this period, lecturers monitored student progress and suggested solutions when a group encountered difficulties (Cattaneo, 2017). After each problem-solving session, the class was asked to hear reports from randomly selected representatives from each group. In this way, weekly quizzes allowed students to receive regular feedback about their performance in a low-pressure environment and maintain their interest in the material (Figure 2.9).

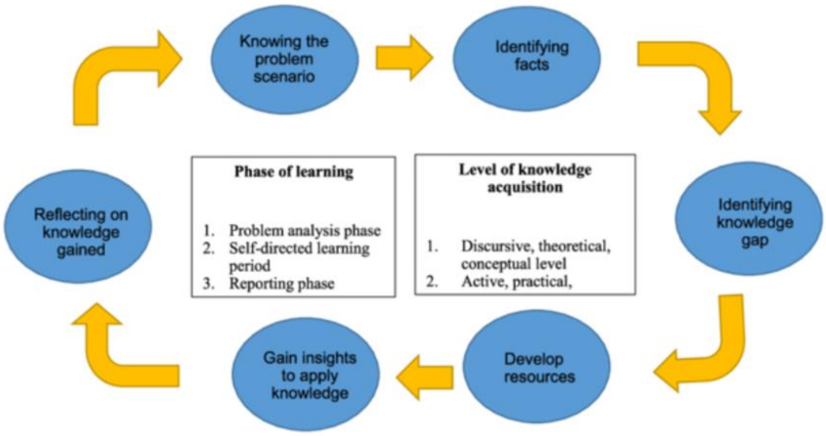


Figure 2.9: Problem-based learning framework (Chung, 2019)

A study by Tasoğlu and Bakaç (2014) examined the impact of problem-based learning in a Magnetism class on conceptual understanding. In the control group, active teaching methods were used. During problem-based learning activities, the experimental group collaborated in groups with guidance from the teacher, tackling real-life problems. To help students connect theory with real-life applications, they worked on scenarios that involved several exact and complex issues. It was discovered that problem-based learning, as opposed to traditional teaching techniques, had a more significant beneficial effect on students' conceptual understanding of magnetism themes.

Using problem-based learning, Sahin (2010) found that students gained a deeper understanding of Newtonian mechanics than they did through conventional instruction. An investigation on moving subjects, force and motion, and energy was conducted by Akınoğlu and Tandoğan (2007). As a result, students' academic achievement, attitudes about the science course, and concepts and misconceptions about the course improved through the problem-based learning approach.

2.9.5 Summary

Behaviourism focuses on the idea that all behaviours are learned through environmental interaction. Cognitivism focuses on the internal mental processes of the individual. Social constructivism highlights the social and cultural aspects of learning, emphasising the role of interactions with others in constructing knowledge. Constructivism emphasises the active construction of knowledge by individuals.

The principles and application of brain-based learning in the classroom are covered in the following section.

2.10 BRAIN-BASED LEARNING

"…lecturers who can visualise how the child's brain works will, spontaneously, conceive better ways of teaching (Dehaene, 2011, p. 26)."

By comprehending how the brain learns, brain-based learning seeks to optimise human learning capacity (Caine et al., 2005). Focusing on habit and the brain's development emphasises the student's learning process. No restrictions should be placed on the learner's brain, since the learning process will occur naturally. To help the brain build synaptic networks to understand and retain information, educators are encouraged to use strategies natural to the brain's functioning (Jensen, 2008; Madsen et al., 2015). Brain-based learning aims to enable students to learn through meaningful experiences tailored to their needs, regardless of age. Furthermore, it acknowledges the uniqueness of each student and respects their differences (Jensen, 2008). This strategy might make studying more enjoyable and meaningful, while enhancing students' academic achievement (Jensen, 2008).

2.10.1 Brain-based learning considered a pedagogy

Brain-based learning is considered a pedagogy and is discussed in section 2.11. Because of their shared emphasis on active involvement, meaningful experiences and the significance of past knowledge in learning, there is a potential alignment between brain-based learning and constructivism. Both methods stress the significance of creating a supportive and exciting learning environment that considers learners' cognitive processes and individual requirements (Gülpinar, 2005).

Kahveci and Ay (2008) investigated how brain-based learning concepts intersected and complemented constructivist ideas. They emphasised how creating education based on brain function can improve the use of constructivist methodologies and produce more effective learning outcomes.

Bada and Jita (2022) agreed that brain-based learning is a significant pedagogy that may enhance teaching philosophies or methods. In order to get around the limitations of conventional teaching strategies and achieve the classroom's goals and objectives, it uses critical components from brain-based theory.

Medina (2011) claimed that education is the business of brain development.

Several researchers agree that it is inevitable that lecturers' teaching styles must change to give students the opportunity for optimal learning (Ansari et al., 2017; Medina, 2014; Thomas et al., 2019; Tokuhama-Espinosa, 2021). The mutual interest that neuroscientists, psychologists and lecturers share leads to a subfield of learning sciences, sometimes considered a pedagogy. It is known under different names: neuroeducation, brain-based learning, educational neuroscience in the UK or mind-brain education (MBE) in the USA (Table 2.5).

Table 2.5: Different terms referring to the use of neuroscience in education

Name of discipline	Reference
Neuroeducation	Ansari et al., 2012
Brain-based learning	Caine & Caine, 1991; Jensen, 2008
Educational neuroscience	Thomas et al., 2019
Mind-brain education	Tokuhama-Espinosa, 2021

In the following section, all these terms will be discussed briefly, but in this study, we refer to this growing field as brain-based learning.

Neuroeducation

Neuroscientists spend much time researching the underlying biological processes, such as memory formation, creativity, and social and emotional cognition. According to Ansari et al. (2012) and Bidshahri (2017), researchers serve as a link between academic lecturers and practitioners. Neuroeducation research depends on various procedures, including behavioural analysis, cognitive psychology tests and educational research. Additionally, it uses brain imaging techniques (such as fMRI). By using these techniques, researchers hope to increase understanding of the neural networks in the brain that govern learning, memory, motivation and other critical cognitive functions in education.

Educational neuroscience

This interdisciplinary research focuses on translating neural learning mechanisms into educational practices and policies, and understanding the consequences of educational changes for the brain. The European Association for Research on Learning and Instruction (EARLI) has held meetings on neuroscience and education twice a year since 2010 (Thomas et al., 2019). Educational neuroscience studies show that our growing understanding of the brain may influence curriculum, instruction and assessment practices over time. It enables educators to consider studies that may impact their teaching methods. Through direct dialogue between lecturers and researchers, educational neuroscientists aim to bridge the gap between the two fields (Vaughn et al., 2020).

Mind-brain education (MBE)

In 2004, an innovative field of MBE science was established at the Harvard School of Education (Fischer et al., 2007). During 1997–2001, the foundation was laid to create the international MBE Society. In 2007, the MBE Journal was established. The 2016–2017 International Delphi Panel on MBE set out to chart the field's advancements for the following ten years and identify any unresolved issues that might inform further research and development. A consensus was reached by 40 experts from 11 countries on what direction to take (Tokuhama-Espinosa, 2017).

MBE includes factors like understanding brain structure, stress management, nutrition and exercise. Learners can be influenced to make the right decisions by encouraging daydreaming, problem solving and critical thinking (Ansari et al., 2012; Bowers, 2016; Masson & Brault Foisy, 2014; Ozden & Gultekin, 2008; Pincham et al., 2014). In her book "Bringing the neuroscience of learning to online teaching", Tokuhama-Espinosa (2021) stated that learning depends mainly on two pillars: memory and attention. She highlighted the importance of acknowledging the differences between various students, as emphasised by the Organisation for Economic Cooperation and Development (OECD, 2015).

Understanding the brain can improve classroom instruction by developing new teaching techniques. For these new teaching methods to be effective, lecturers must adapt them (Bowers, 2016). They found that using neuroscience will improve classroom instruction (Coch & Ansari, 2009; Goswami, 2006; Sigman et al., 2014). Tokuhama-Espinosa (2019) developed the MBE framework as an interdisciplinary approach that integrates cognitive neuroscience, psychology and education research to inform teaching and learning practices.

It strives to close the knowledge gap between educational practices and scientific knowledge of the mind and brain to improve educational outcomes. By applying the principles of the MBE framework, educators can design instructional strategies and learning environments that are aligned with the brain's natural learning processes. This approach aims to improve student engagement, motivation and learning outcomes by leveraging insights from cognitive neuroscience and related fields (Figure 2.10).

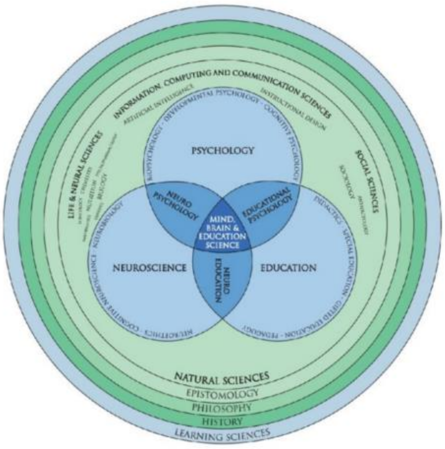


Figure 2.10: The MBE framework (Tokuhama-Espinosa, 2019b)

In an international Delphi study, the panel's most significant discovery was agreement on guiding concepts and tenets in the discipline, which may be used to adjust the design of general teacher education curricula (Tokuhama-Espinosa, 2017).

They found six principles, 21 tenets, and 70 neuromyths. The principles and tenets are discussed below. The neuromyths are discussed in section 2.13.

2.10.2 Principles in MBE according to Tokuhama-Espinosa (2017)

A principle is an ethical guide or belief that helps determine right and wrong, and influence actions. After four rounds of consensus building, the Delphi panel, led by Tokuhama-Espinosa (2017), identified six principles. These results were confirmed in the follow-up in 2020, in which educational neuroscientists from 30 different counties participated (Table 2.6).

Table 2.6: Mind, brain and education principles – 2020 results (Tokuhama-Espinosa & Nouri, 2020)

	2020 principles in MBE	Percentage of agreement
1.	Human brains are unique – like fingerprints, although the basic structure of the brain is the same	94.64%
2.	Every brain has a different potential for learning	90.18%
3.	Prior experiences influence new learning	84.68%
4.	Experience changes the brain constantly	93.69%
5.	Neuroplasticity	96.40%
6.	No learning can take place without some form of memory or attention	74.55%

1. Human brains are unique – like fingerprints, although the basic structure of the brain is the same

Although the brain's basic structure is the same, every brain is wired differently. None of us store our memory of language in the same places. Our brain map changes daily and is rewritten in response to individual experiences (Medina, 2011). Due to their unique experiences, people interpret top-down analysis from different perspectives. A person can perceive the same input differently, even after looking at the same information (Medina, 2011). Information from our senses is initially assimilated and transformed into electrical signals (some for sight, others for sound, etc.). These signals are then dispersed to separate areas of the brain, which are processed, allowing us to reconstruct events. That means that two individuals can perceive an event differently based on their experiences.

Questions such as why some students' eyes glaze over after a few minutes of lectures and why one teaching strategy works in one classroom, but fails in another can be answered by understanding how the brain works. Medina (2011) directs the Brain Centre for Applied Learning Research at Seattle Pacific University. He states in his book "Brain rules: 12 principles for surviving and thriving at work, home and school" (Medina, 2011, 2014) that there are several things we do not know about the brain, but there are also things that we know for sure. It is essential to realise that our brains change and vary from person to person. The term orchestrated immersion refers to creating immersive learning environments (multisensory learning experiences), where learners are fully immersed in a rich and complex educational experience. This means that a learner consolidates and integrates information meaningfully and coherently. Listening and questioning are essential elements of dynamic processing (Caine et al., 2005).

2. Every brain has a different potential for learning

Every individual's brain has a unique learning potential, and is made up of various elements, including genetics, environment, upbringing and personal experiences. People's genetic make-up can influence their cognitive abilities, such as memory, processing speed and problem-solving skills. Factors such as access to education, socioeconomic status and exposure to stimulating experiences can impact a person's ability to learn and acquire new knowledge. Early education and the quality of caregiving can have a lasting impact on a person's cognitive development. Success in prior learning endeavours can boost confidence and willingness to learn, while previous failures may have the opposite effect (Medina, 2011).

3. Prior experiences influence new learning

Learning is the process of relating new knowledge to prior understanding. We struggle to interpret and give meaning to new knowledge when we do not see the connection between it and what we already know. A student can learn more with prior knowledge, which has enormous implications for lecturers (Brown et al., 2014).

Activating students' knowledge is a way to prime their neural networks and activate their plans. Pre-testing students on the lesson content is another way to start a student schema. Even though many teachers would not want to test their students on something they have not yet taught, research has found that knowing the answer may not be the most critical part of learning. In 2009, an experiment found that pre-testing before knowledge is learnt significantly increased the likelihood of student learning, even when the students' initial answers were incorrect. To activate the learning schema, students must think about a question before they know the answer. At that point of understanding, the "aha" moment occurs (Richland et al., 2009).

Lecturers can connect the newly acquired knowledge to students' lives outside the classroom after the course. Students were split into two groups for one study. The first group reviewed the lessons from the day, while the second group looked at how they applied to daily life. Zadina (2014) discovered that, at the end of the semester, the second group of students outperformed the first group. Ensure the students know the relationship between what they learn in class and their daily lives. The best way to clarify this connection is to brainstorm how students apply the knowledge daily. The best questions are: “Why are we learning this?”; “How will it benefit me?”; and “What will you do with this outside of class?” (Zadina, 2014).

4. The brain constantly changes with experiences

The brain retains traces of everything it experiences. During a learning episode, neurons form new connections and develop new projections. As a result, different experiences activate other brain regions and, thus, different receptors. Conversely, stress, despair, ageing and illness lead to neuron breakdown and even death. Depending on the combination, receptors can promote either neuron death or survival. Specific brain cells can also be stimulated to remain dormant or produce new neurons (Li & Bates, 2019) (Figure 2.11).

Neuroplasticity is the ability of the brain to change in response to experience (Li & Bates, 2019).

5. Neuroplasticity

New connections can be made to existing circuits in the brain to create new neural pathways. The environment, learner experiences and responses impact the brain’s prefrontal cortex, which is still developing. This revolutionary discovery is known as neuroplasticity. Students who are engaged in the material are more adaptable to change. A new brain network will develop due to divergent thinking (Foisy et al., 2020; Whitman & Kelleher, 2016). Neurons, neural pathways, dendrites, axons and synapses are all related to neuroplasticity and rewiring of the brain. Making neurons, establishing established routes, developing new pathways and removing useless ones are a few examples of neuroplasticity mechanisms. These are the building blocks of memory formation (Whitman & Kelleher, 2016).

Neurons

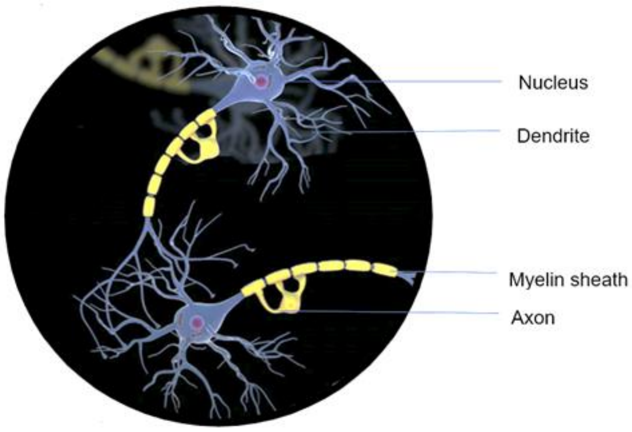


Figure 2.11: Structure of a neuron (Van der Walt & Neurozone, 2019)

Permission granted by the Head of Science and Research at Neurozone (Appendix B1)

According to the theory of learning of Richland et al. (2014), new information makes sense when related to prior understanding. Myelin is a fatty coating that surrounds the trunks of neurons in a whitish insulating sheath. It is made up of a combination of proteins and phospholipids. The learning process known as myelination makes the myelin thicker and speeds up the direction of impulses. There are several connections between each neuron (Figure 2.11). Throughout our lifetimes, this arrangement is continually shifting. Due to various environmental exposures, every brain undergoes diverse changes, which are more pronounced when pupils study. The average human is born with approximately 100 billion neurons. A neural network forms when new information is learnt, forming connections that will last a lifetime (Brown et al., 2014). These adjustments can result in students who are more assertive, content, driven and high achievers (Whitman & Kelleher, 2016).

6. Memory and attention

Understanding how your memory works and how one can maximise one's learning ability can make a big difference. Interleaving, chunking and other techniques can help people remember things better (Bidshahri, 2017).

When learning, one must remain focused, sometimes for a long time. Students must usually concentrate continuously for five to six (one-hour) sessions at school without repetition. This causes homework to represent new learning, not a review. On the contrary, Medina (2011) stated that the mind could simultaneously hold seven pieces of information for only about 30 seconds. Data will disappear after 30 seconds if one does not repeat it. The brain will store the information for one to two hours if one repeats it within 30 seconds. If it is not repeated, it will eventually disappear from memory. To remember memories, one must repeat them (Medina, 2011).

According to neuroscience, attention is the mental process that enables us to focus on some elements of our environment, while disregarding others (Ansari et al., 2012). Most memories vanish within a few minutes, but those that last past the short, brittle window get stronger with time. A two-way communication between the hippocampus and the cortex is necessary for long-term memory formation. This contact lasts until the hippocampus separates from the cortex and the memory is fixed, which can take years. Due to how our brains combine new knowledge with memories, it cannot give us an exact picture of reality. For long-term memory to be more reliable, further information must be incorporated gradually, and repeated in timed intervals (Medina, 2011). It is crucial to maintain the attention of one's students during class time. Boredom will make them lose interest. Culture is also influential.

Medina (2011) suggests a few factors that can keep learners' attention during instruction.

- Emotions get our attention. Emotionally arousing events tend to be better remembered than neutral events. In instruction, this does not have to be a dramatic or earth-shaking event. Instead, it can be a personal example in an engaging story, which might be less straightforward, but more relatable to students.
- Meaning before details. Studies show that emotional arousal focuses on the essence of an experience at the expense of peripheral elements.
- The brain cannot multitask. The brain naturally focuses on concepts sequentially, one at a time. Driving while talking on a cell phone is like driving drunk. The brain is a sequential processor, and large fractions of a second are consumed every time the brain switches tasks. Therefore, cell phone talkers are a half-second slower to hit the brakes and get in more wrecks. Research shows one's error rate goes up 50%, and it takes one twice as long to do things. When one is online, one is constantly distracted. So, the always online organisation is the always unproductive organisation.
- The brain needs a break. Loss of attention can be caused by relaying too much information and not leaving enough time to connect the dots – the 10-minute rule: Audience attention drops precipitously at about 10-minute intervals. The class structure naturally limits the amount of material that can be presented in one class. Medina (2011) focuses on the gist of his content before the details. He tries to ensure that his students

do not have to multitask to understand where a concept fits into the rest of the session. The brain pays attention to patterns.

From the Delphi study by Tokuhama-Espinosa (2017), the 21 tenets of the discipline are discussed.

Tenets of MBE (Tokuhama-Espinosa, 2017)

A tenet is an opinion or belief that is very important to a group and characterised by wide individual variation. The Delphi panel identified 21 tenets concerning the brain and learning, which can vary from learner to learner (Table 2.7).

Table 2.7: Accepted tenets in MBE (Tokuhama-Espinosa & Nouri, 2020)

Percentage of the agreement after 2020		
1.	Motivation influences learning (however, what motivates one person may not inspire another in the same way).	97.70%
2.	Emotions and cognition are mutually influential. Not all stimuli result in the same affective state for all people.	98.18%
3.	Stress influences learning (but what stresses one person and how may not stress another in the same way).	95.45%
4.	Anxiety influences learning (but what causes anxiety in one person may not cause fear in another).	97.25%
5.	Depression influences learning (but what causes depression in one person may not cause depression in another).	93.64%
6.	Learning is influenced by both challenges and threats as perceived by the learner. (What people find challenging or threatening is highly individualised as their reactions to the stimuli).	88.99%
7.	Reactions to facial expressions are highly individualised – they reflect prior experiences – both personal and in response to cultural expectations (except for autism disorder spectrum).	74.55%
8.	The brain interprets the tone of voice unconsciously and almost immediately; however, the reactions to the style of voice are based on prior experiences, which are individualised.	73.39%
9.	Humans are social beings who learn from and with each other. Social interactions influence learning. Different people desire different amounts of social interaction around learning.	96.36%
10.	Attention is a complex phenomenon, comprised of multiple systems (supporting systems such as metacognition, self-reflection, mindfulness and meditation, as well as states of high alertness, selective attention and focused attention) that work to different degrees in different relationships with one another.	88.99%
11.	Most learning does not necessarily occur linearly, but instead advances and retracts during stages of growth, reflection and the amount of repetition to which one is exposed.	86.24%
12.	Learning involves conscious and unconscious processes, which may differ between individuals based on their training and other individual	92.66%

Percentage of the agreement after 2020		
	experiences. Education is also described as implicit (passive or unaware methods) and explicit (active and aware processes).	
13.	Learning is developmental (nature and nurture) and experimental (nurture): a person's age. The cognitive stage of development and past experiences contribute to understanding and do so differently for each person.	89.81%
14.	Learning engages the entire physiology: the body and the brain interact to play a role in the learning processes.	78.70%
15.	Sleep and dreaming influence learning differently: sufficient sleep permits the brain to pay attention during wakeful states, and dreaming contributes to memory consolidation. The amount of sleep and desires an individual needs can vary based on culture, circumstances, motivation, genetics and learnt sleep hygiene practices.	72.22%
16.	Nutrition influences learning. Basic nutritional needs are common to all humans, although there are variations in the frequency of food intake and some dietary needs unique to individuals.	90.74%
17.	Physical activity influences learning; however, different individuals need different amounts of physical activity to perform optimally. Interspersing physical and cognitive activity may improve learning.	87.16%
18.	Use it or lose it. Brains that remain active cognitively help development and can also stave off cognitive decline in the ageing brain; however, individual variations, including experiences and genetic predispositions, influence the outcomes of interventions.	83.49%
19.	Feedback about learning progress influences learning outcomes. The input itself can be a source of learning. The type, frequency and use of feedback can influence learning outcomes, which vary according to individual.	96.26%
20.	It is easier to retrieve memories when facts and skills have been embedded in individually relevant and meaningful contexts (however, what is appropriate or meaningful varies according to individual).	92.59%
21.	Brains detect novelty (however, what is novel to one individual may not be unknown to another).	93.52%

More information is provided on some important tenets as described by Tokuhama-Espinosa (2017) and Tokuhama-Espinosa and Nouri (2020).

Tenets 1 and 5: Motivation and depression

The hormone dopamine is a chemical transmitter that regulates motivational and emotional behaviour. When the result is worse than expected, dopamine is conditionally released to avoid making unwise decisions (Halber, 2018). Dopamine has many complicated pathways and is influenced by the type of neurons and the area where they enter and exit. The "mesolimbic pathway" is the term Brookshire (2013) used to describe the connection between dopamine and motivation. It originates in the brain's deep centre and communicates its predictions to the cortex (Brookshire, 2013).

The caudate, the region in the brain associated with due reward, is activated during curiosity (Kang et al., 2009). When people are curious, their level of uncertainty is higher, but as they look for answers or solutions, it becomes lower. Learners can increase their interest by implementing various learning strategies. People with higher levels of interest are better able to learn and remember new information (Gruber et al., 2014). Dopamine is linked to rewards and inspires people to accomplish goals. Motivating oneself requires persistence (Collins, 2019), which is challenging, but crucial. Among the two types of motivation for learning, intrinsic motivation can promote endurance, since it is a reason learners must learn (Pink, 2010). Rather than focusing on the rewards (being extrinsically motivated) learners will receive when finish a learning course, they should be encouraged to learn for their sanity and personal development. Learners who receive praise for their continued effort, not based on their success, become more intrinsically motivated.

Serotonin is a neurotransmitter involved in mood, appetite, sleep, sexual desire and other physiological functions (Lim et al., 2019). Neurotransmitters (or neural hormones) regulate the human brain's complex nervous system (Table 2.8). Certain hormones (like cortisol) influence the brain's functions associated with reasoning and learning (Jung et al., 2011). Low serotonin levels can cause an overproduction of dopamine, since serotonin can sometimes inhibit dopamine production. Dopamine enhances impulsivity, while serotonin hinders it. Serotonin suppresses appetite, while low dopamine levels stimulate it. Serotonin and dopamine levels in the body can cause several different medical conditions. Other types of imbalances can also cause diseases that affect various body functions. As with dopamine, abnormal serotonin levels have been linked to several medical conditions, including mood disorders such as depression and anxiety (Eske, 2019).

Table 2.8: Functions of neural hormones (Lim et al., 2019)

Hormones	**Roles and functions**
Adrenaline	Produced when fear or tension is encountered. Increases the heart rate and blood pressure. High levels may cause aggression.
Dopamine	Increases strength of the heart and improves blood flow to the kidneys. Controls movement and emotional responses.
Serotonin	Regulates anxiety, happiness, mood, social behaviour, appetite, digestion, sleep and memory. Low levels may cause depression.
Cortisol	Increases in stress situations. Reduces cognitive and memory functions.

Tenet 4: Anxiety

Academic performance would be lower for students from high-anxiety homes than for students from more caring homes. Students who live in hostile surroundings are more prone to experience psychological illnesses, including depression and anxiety. Students who have experienced childhood stress suffer from academic performance issues as adults. Such conditions can negatively affect the cognitive processes essential for achieving academic success. Although women are more likely to develop depression after puberty, females become more anxious (Medina, 2011). See the role of serotonin in the case of anxiety in the previous explanation.

Tenets 2 and 3: Emotion, stress

Emotions play an essential role in our lives. They affect our decisions and reactions. The author of “Emotional intelligence”, Daniel Coleman, suggests that emotional intelligence (EQ) is more predictive of happiness and success than intelligence quotient (IQ) (Coleman & O’Connor, 2019). The role of dopamine on emotions was discussed in the previous section.

Stress affects learning, although some levels of stress are necessary for learning. In contrast, toxic stress, which involves distress over an extended period, can impair an individual’s memory recall (Finsterwald & Alberini, 2014). A study by Yerkes and Dodson (1908) in the early 20th century demonstrated that optimal performance, including learning, occurs when stress levels are appropriately high. Lupien et al. (2007). Lupien et al. (2007) showed that chemicals released during negative stress could interrupt the connectivity of neurotransmitters needed to solidify new learning.

The amygdala is the limbic structure where emotional reactions occur. It activates a stress response when needed and functions as a station for transforming emotions. Because the amygdala transmits stress signals from your senses to the prefrontal brain, too much stress inhibits learning, which is the predisposed, reactionary fight, flight or freeze section of the brain, instead of to the reflective prefrontal cortex (Collins, 2019; Wang et al., 2016). The amygdala regulates emotions since emotional memories are the most overwhelming in the brain. The amygdala is heavily involved in processing emotional memories when experiencing intense emotion (Lim et al., 2019). Getting sensory information from the prefrontal cortex is essential for learning. Therefore, learning how to manage stress is crucial. The myelination process from the amygdala to the prefrontal cortex becomes simpler with time. According to research, brief, supportive situations with moderate stress levels can rewire the brain to make it more capable of coping with stress in the future (Kelly, 2021). The correct amount of stress under the right circumstances strengthens one. Excessive stress damages cognition, memory, executive function, creativity, motivation, productivity, immune system and sleep, and increases depression. The brain was not designed to handle long-term stress. Responses to stress are built to last for at least 10 seconds. Brains under pressure do not learn the same way as brains under calm conditions (Kelly, 2021; Medina, 2011).

The limbic system consists of the hypothalamus, amygdala, hippocampus and other higher-order structures that are richly interconnected and form connections with the prefrontal cortex (Sprenger, 2020).

Table 2.9 describes the functions of specific brain regions.

Table 2.9: Function of certain parts of the brain (Lim et al., 2019)

Brain parts	**Location**	**Function**
Amygdala	Limbic system	Attention, fear and emotions
Hippocampus	Limbic system	Spatial memory and long-term memory
Prefrontal cortex	Frontal lobe	Higher cognitive functions, executive functions and decision-making
Thalamus	Limbic system	Physical security, regulation of consciousness and sleep
Hypothalamus	Limbic system	Feelings of rage, aggression, hunger and thirst Relay of motor and sensory signals to the cerebral cortex
Basal ganglia	Subcortex	Voluntary motor control, procedural learning, cognitive and emotional functions
Insula	Subcortex	Control of body states, pain perception, social engagement, empathy, emotions

The hypothalamus, amygdala and hippocampus are richly interconnected, ensuring functional solid interrelatedness. In this way, these three structures form an operational system (Figure 2.12).

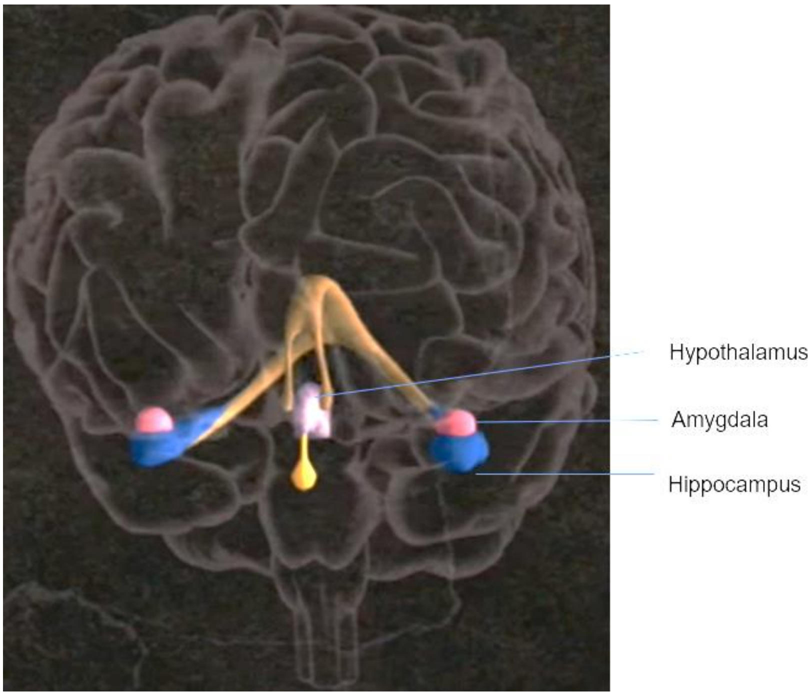


Figure 2.12: The gateway triad (limbic system) (Van der Walt & Neurozone, 2019)

Tenet 6: Challenge and threat

The gateway triad, called the limbic system (Figure 2.12), ensures more sophisticated survival. It moves us away from threats and moves towards rewards.

The hypothalamus is situated at the top of the brain stem. It is often called "the eye turned inward" because it significantly ensures that the body is synchronised with the external environment. If the external environment changes threateningly, it activates the appropriate system to move into a heightened physiological state. When the threat is removed, the hypothalamus deactivates the heightened state, and physiological relaxation is reinstated (Spagnola & Yagos, 2021). The hippocampus serves as a memory bank to accurately assess continuous threats and rewards the brain needs to deal with. The triad plays a significant role in brain performance (Oppezzo & Schwartz, 2014).

The hippocampus is highly susceptible to stress and serves, in part, as a relay centre to the rest of the brain. Because of the hippocampus's sensitivity, we lose access to some brain regions when there is an apparent threat. The challenge is to create a low-threat atmosphere (Medina, 2011). The hippocampus works closely with the long-term memory sites of the cortex, processing and appropriately distributing new memories to these sites where memories are made. It forms long-term relationships with different areas of the brain (Medina, 2011). For example, the visual elements of a new memory are distributed to long-term memory sites near the visual cortex. Memories are combinations of different neural circuits in other parts of the brain. Memory and three-dimensional learning are both facilitated by the hippocampus. The brain (synapses) strengthens connections through learning (Rahman et al., 2016).

The brain forms memories to learn and build new knowledge. The hippocampus plays an important role in this process. The brain’s long-term memory centres store learning. They serve as the foundation for creativity. Neuroplasticity enhances learning through the hippocampus (Rahman et al., 2016).

Tenets 7 and 8: Facial expressions and tone of voice (non-verbal communication)

According to Butt and Iqbal (2011), facial expressions are integral to teaching and learning to improve effectiveness and engage students. Teachers can leverage non-verbal communication (gestures and facial expressions) in the classroom to enhance learning and help students get more out of their learning experience. A teacher’s facial expression, such as anger or a smile, could be a communication tool that helps students understand the teacher’s messages and change their behaviour to accommodate the teacher’s needs. With their facial expressions, the teachers clarify many concepts and contents to the students, and the students become interested in the teaching-learning process. Students’ facial expressions in class activities may help the teacher improve their teaching style and methodology (Butt & Iqbal, 2011).

Facial expressions are not the only way to identify people’s emotions. The sense of hearing may be even more potent than sight when detecting emotions (Kraus, 2017). Kraus (2017) found that we are more accurate in identifying people’s emotions when hearing someone’s voice than just seeing their face. One can even know how someone feels better while talking to them on the phone than in person. For instance, during phone talks, one might pick up on a person’s quick breathing and uneasy demeanour, as well as their monotone speech and fatigued or bored tones. Speaking at high levels and quickly can signify passion and enthusiasm, especially in a classroom setting.

Tenet 9: Social interactions (social safety)

Socio-neuroscience is a branch of neuroscience that seeks to understand how biological processes affect social interactions. Depending on the learning goals, neuroscience can help determine the best approach to learning (Bidshahri, 2017). Because students must become more sensitive to the feelings of others, they have to recognise and manage their emotions before interaction can take place in an emotionally intelligent way (Sprenger, 2020).

A sense of belonging and bonding is not the same, but both play essential roles in human social and emotional wellbeing.

Bonding refers to the formation of emotional connections or attachments between individuals. These emotional connections can be based on various factors, including shared experiences, trust, affection and mutual understanding. Bonding is essential for building and maintaining healthy relationships. It contributes to feelings of security, trust and intimacy in relationships. Bonding develops through the ongoing secretion of a neurotransmitter called oxytocin that facilitates the need for friends (Norman et al., 2015).

Belonging is the sense of being part of a group, community or social network. It involves social safety, inclusion and value within that group. The sense of belonging arises from neural pathways that use dopamine as a rewarding transmitter. Belonging is a fundamental human need. It gives individuals a sense of identity, social support and emotional wellbeing. People who feel they belong tend to have better mental health and overall life satisfaction (Norman et al., 2015). A sense of belonging in education is crucial for creating a supportive and effective learning environment. When students feel like they belong, they are more likely to be motivated, engaged and successful in their academic pursuits. It also contributes to their overall wellbeing and development.

An unconscious activity that precedes every action is value tagging, contextualised as the brain-body system's need for social safety.

In response to every sensory cue, it asks three fundamental questions:

- Do I belong here (sense of belonging)?
- Is this me (sense of identity)?
- Does this give me meaning (a sense of meaningfulness)?"

Tenet 10: Attention compromised by multiple systems (multisensory approach)

Success depends on a student's capacity for concentration in the classroom. Students who pay attention can shut out their thoughts, background noise, visual distractions and irrelevant information. Students can focus on the crucial knowledge their lecturers impart (Keller et al., 2020).

Essential insights into sensory development begin in early childhood. Brain development occurs when different sensory inputs are internalised as increasingly accurate representations of the outside world (Vollbrecht et al., 2019). As the brain develops through further integration and sophistication, we start to make sense of the world and respond appropriately to ensure survival. Sensory integration is a highly nuanced and sophisticated process in which we continuously process massive amounts of data through all our senses.

Medina (2011) found that attention starts to wander after ten minutes. Students who do not pay enough attention may have trouble focusing and memorising what they learn. In response to external stimuli, the body releases adrenaline, which alerts the brain (Lim et al., 2019). Cortisol, in particular, undermines brain performance and can even kill brain cells in the hippocampus, where memories are made (Table 2.8 for hormones and their functions). When learning takes place, neurons are activated. While other neuron connections are made, and these routes become more robust, those not used frequently weaken or are eventually removed over time. A two-minute brain break at the end of the learning session, a good sense of belonging and optimised goal-directedness ensure that the brain is ready to leverage the valuable new knowledge the neuroscience of learning offers (Rahman et al., 2016).

The brain needs rich sensory input to learn (Figure 2.13). The human senses receive information that enhances the capacity for people to learn and memorise what they know in the long run (Collins, 2019). McTighe and Willis (2019) claimed that all learning begins with sensory information. The brain is continuously blasted with input from the body's sensory receptors. Data is constantly sent from the sensory systems and nerve endings in our muscles, joints and internal organs. Of the millions of sensory data available each second, only about 1% is admitted to the brain (Medina, 2011).

Vision alone processes about 25 billion bits of information every second (Saleh & Mazlan, 2019). Visual, auditory, tactile, smell and taste inputs continuously inform and shape brain behaviour and performance. This continuous process of multiple sensory integration occurs almost exclusively in the unconscious. This is especially true of smell, a sense with a remarkable capacity to drive behaviour by triggering memories embedded in the unconscious. A working understanding of multiple sensory integration creates an exciting opportunity to manage the external environment for optimum performance (Di Domenico & Ryan, 2017).

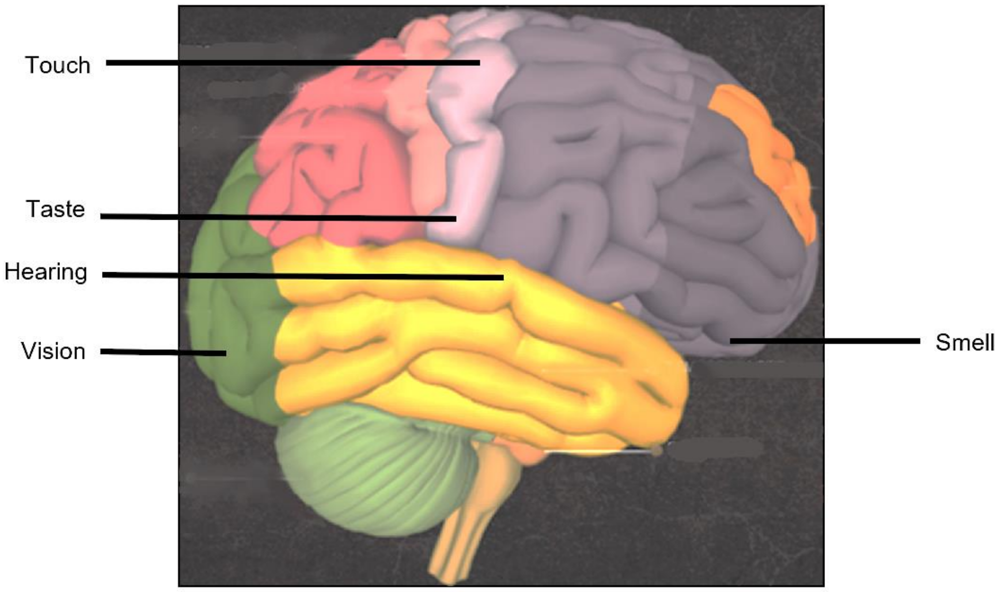


Figure 2.13: Senses in the brain (Van der Walt & Neurozone, 2019)

Multisensory stimuli should, therefore, be used in the learning design process (Lim et al., 2019). Each sense has an individual input in this process, as discussed below.

Smell

The sense of smell is potent at recalling memories, perhaps since it bypasses the thalamus and goes directly to the amygdala, which governs emotion and memory (Medina, 2011). In contrast to the other senses, smell perceptions are connected directly to the limbic system. The smell can thus trigger strong memories because of this direct connection with our emotions. Smell affects blood pressure and heart rate (Collins, 2019). Students generally are more creative and responsive when they are in a better emotional mood.

Vision

A person's most vital sense is usually their vision. Drawing something can help learners improve their ability to learn and absorb information, according to Schmeck et al. (2014). The ability to learn improves when learners combine text with visuals or pictures. Similarly, colours influence attention, and better attention translates to better learning. Red increases testosterone levels and boosts self-confidence (Farrelly et al., 2013).

Sound

Few studies have been found on the subject of auditory learning (Collins, 2019). Sound can improve learning by allowing learners to read a text aloud (think-aloud method). Learning materials can also be memorised and retained long term by creating poems, songs or raps about the learnt content. Major and minor keys can change learners' emotional states because they can sound pleasing or sad (Lim et al., 2019).

Touch

The brain needs oxygen and functions better through physical activity (Medina, 2011). Cognitive skills are enhanced by using hand activities. Because brain chemistry changes, a higher level of brain function is needed (Spagnola & Yagos, 2021). A way to teach learners is to create mental models of essential concepts and let them walk around or allow them to walk during a break (Lim et al., 2019).

The visual, auditory and tactile long-term memory sites are situated towards the back of the neocortex (Figure 2.14). Auditory and visual processes inspire different fragments of one's brain. More pathways are designed to improve memory if all these other senses are used simultaneously (Medina 2014). "Our senses are intended to work together, so when combined, the brain pays more attention and encodes the memory more strongly" (Medina 2014).

Mindfulness

Well-studied mindfulness methods consist of either learning to concentrate attention (focus attention) or developing a capacity to monitor experiences without reacting to them (open monitoring). The first method requires focusing on an object or thought while rejecting conflicts. The second method requires an open mind (Cullen et al., 2021). A valuable way of silencing the mind is to identify a quiet time and space, and be uninterrupted for at least 15 to 20 minutes in a comfortable and well-balanced position. Breathing in deeply and focusing on a stationary object is essential. Intrusive thoughts must pass the mind for at least ten minutes. Like exercise, silencing the mind is a powerful and effective way to reduce chronic stress. Deep breathing moves one into a relaxed physiological state, reducing blood pressure, lowering the heart rate, and building better coping capacities. Continued focused attention and open monitoring place us in the present and reduce anxieties about the past and the future (O'Hare & Gemelli, 2023) (Figure 2.14). According to the brain model, silencing the mind is associated with creativity. The neural axis connects the brain stem and hypothalamus at their most basic level, and the prefrontal cortex at its most sophisticated level.

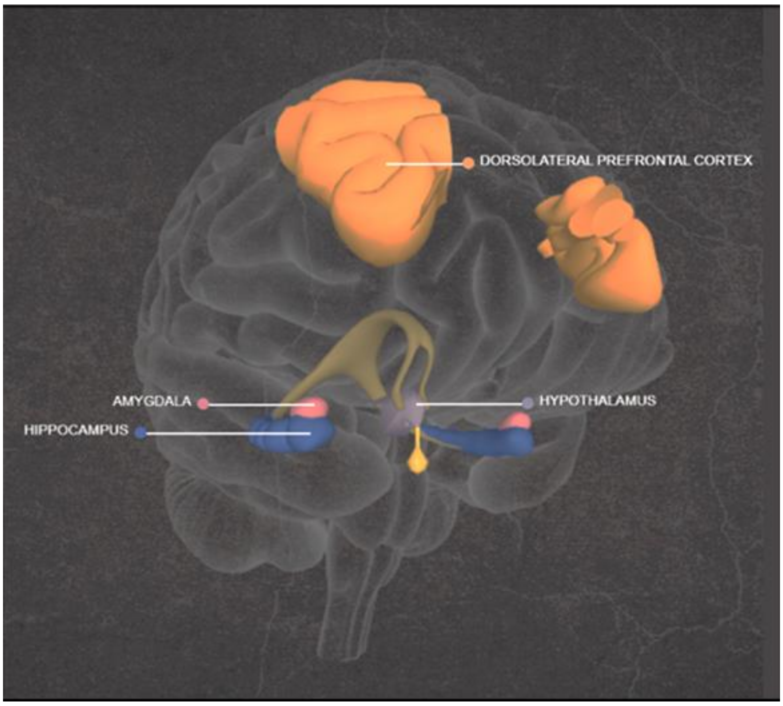


Figure 2.14: Silencing the mind (Van der Walt & Neurozone, 2019)

Everyday meditation for 15 minutes positively impacts the brain-body system. The hypothalamus and amygdala gain advantages from prolonged meditation, including restoring a calm physiological state. It improves the dorsolateral prefrontal cortex's capacity to concentrate and pay attention. As a result, the amygdala calms down, and the hippocampus creates more brain cells, promoting an overall feeling of clarity and tranquillity (Figure 2.14).

Tenet 11: Growth with repetition

Growth with repetition is a fundamental concept that underscores the importance of practice, feedback and the brain's ability to adapt and grow through learning experiences. Educators can use this knowledge to design effective teaching strategies and learning experiences that harness the power of repetition to support students' cognitive and neural development, and strengthen neural connections associated with specific skills or knowledge (Goodwin, 2018). Repeated exposure to and practice of specific learning materials or skills can lead to cognitive and neural growth, ultimately resulting in improved learning outcomes and encoding that information into long-term memory. This concept draws from the principles of neuroplasticity, which is the brain's ability to adapt and change in response to experiences and learning (Medina, 2011).

Tenets 12 and 15: Learning involves conscious and unconscious processes, sleep

Most brain activity occurs in the unconscious (less than 1% of the brain is believed to be conscious). An unconscious activity that precedes every action is value tagging, contextualised as the brain-body system's need for social safety. Therefore, the brain values every sensory input (Steffens et al., 2017). Just as significantly, value tagging precedes and shapes all thoughts and behaviour. It occurs in the amygdala and through its connections with the ventromedial prefrontal cortex (Figure 2.15). Value tagging precedes and shapes all thoughts and behaviour in the amygdala and through its connections with the ventromedial prefrontal cortex.

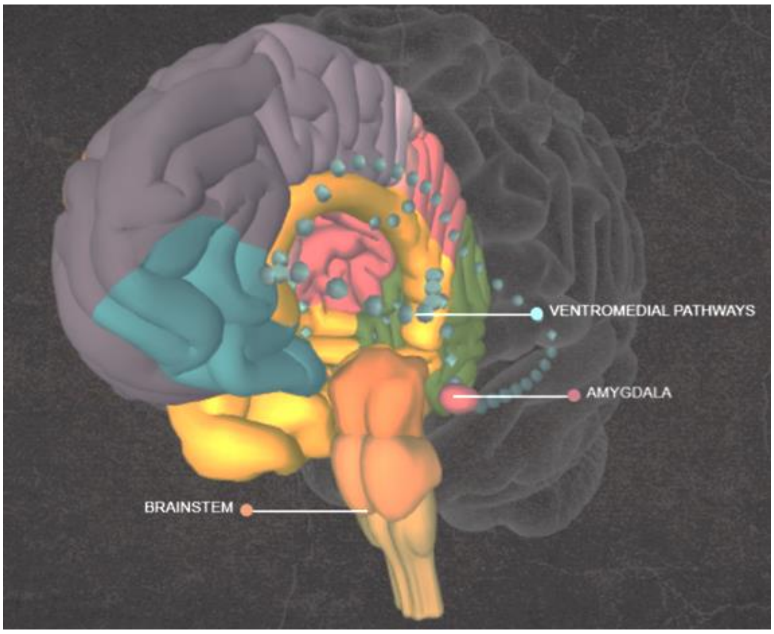


Figure 2.15: Neural systems (Van der Walt & Neurozone, 2019)

The human brain can store and retrieve an infinite amount of information. Creative problem-solving and innovation take place in the unconscious, especially during sleep. Knowing that the brain never stops performing, even while we sleep, is essential. The brain continuously forms new memories, builds new knowledge, addresses contemporary problems and fashions solutions. Most of this occurs in the unconscious (Hirshkowitz et al., 2015).

The brain stem regulates the sleep-wake cycle and brain performance (Figure 2.16). Sleep is a rhythm of seven to nine hours a day. It is as essential as breathing. The hypothalamus and brain stem regulate sleep and wake cycles. Sleep is not only to rest – the hippocampus shapes and merges memories during sleep (Nota and Coles, 2015).

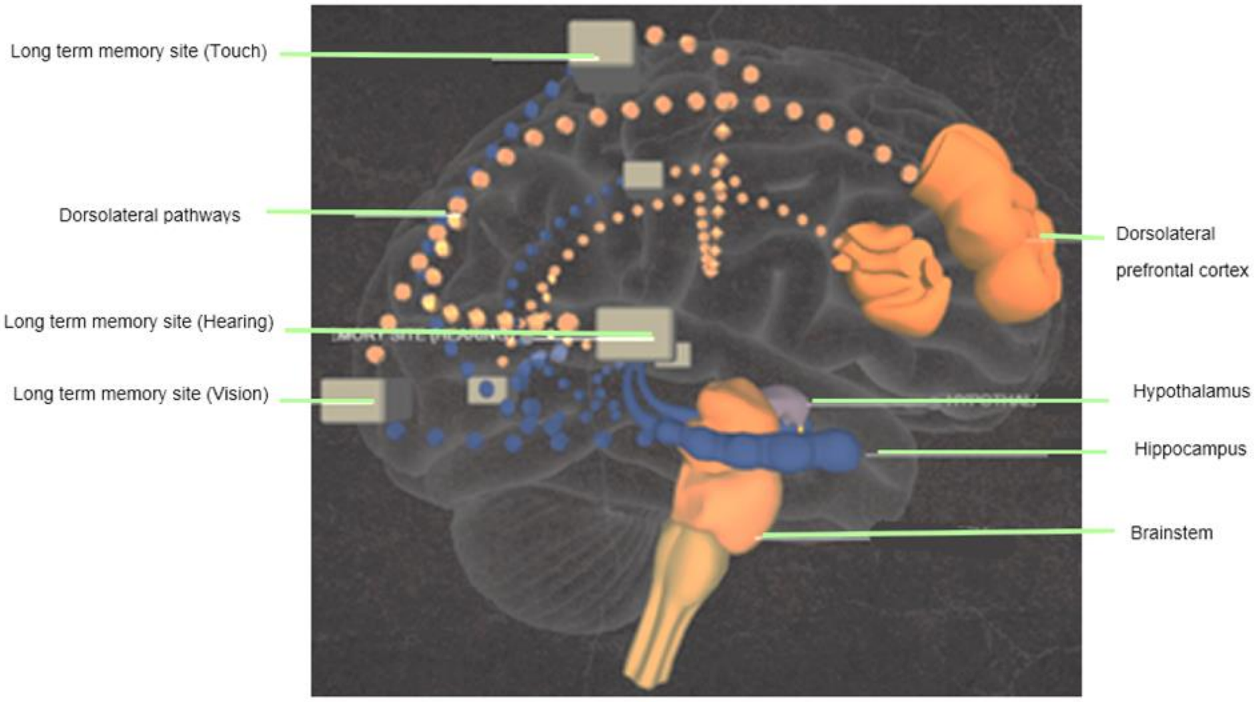


Figure 2.16: Sleep-wake cycle (Van der Walt & Neurozone, 2019)

Pratiwi and Pratama (2020) stated that students' sleep patterns and environment might affect their concentration. They found that students' learning ability and sleep time were related. Students lose concentration in class when they do not sleep enough (Apriana et al., 2016). Melatonin levels will be high when sleep quality and sleep cycles are disturbed, and slow the body and the brain (Apriana et al., 2016). Consistently lacking sleep can negatively impact sleeping patterns and, subsequently, cognitive function, primarily focus (attention) and memory if this continues (Alhola & Polo-Kantola, 2007). Scullin and Bliwise (2015) state that sleeping eight hours daily can improve cognitive capacities.

In a relaxed physiological state, we take a breath about every four seconds. For most people, the heart beats 60 to 80 times a minute. The brain continues to perform significant functions while we sleep. Adults need at least seven to nine hours of restful sleep (Nota & Coles, 2015). A vast and damaging misconception is that some of us can get away with two to three hours less sleep than the body requires. The brain is highly active during sleep and wake cycles – essential rhythms of life. We need rest to replenish the brain and body, build memory and solve problems. During sleep, the brain sorts and consolidates important information and removes useless information. Because problem-solving and creative thought processes take place during and especially during the latter part of the night, ensuring adequate sleep with an optimal sleep architecture (the pattern of non-REM and

REM sleep alternations) is critical for brain performance (De Mendonça et al., 2023). The brain develops to perform throughout a sleep-wake cycle.

Nevertheless, the brain also cycles through periods of higher and lower metabolic states. Typically, our metabolic brain activity peaks in the morning between 06:00 and 12:00, dips in the early afternoon and rises again in the early evening between 16:00 and 19:00. It has been demonstrated that cognitive performance peaks in the mornings, especially between 08:00 and 13:00 (Hirshkowitz et al., 2015). Awareness and observing one's essential biological rhythms as they innately occur in the sleep-wake cycle is a foundation for optimal brain performance.

Tenet 13: Learning is developmental (nature and nurture)

Learning is developmental and influenced by both nature and nurture. This is a fundamental principle in psychology, education and developmental science. This perspective acknowledges that learning is not solely determined by genetic factors (nature) or environmental influences (nurture), but rather emerges from the dynamic interplay between these two factors.

Nature (biological factors)

Some individuals may have genetic predispositions that make specific learning or cognitive abilities more accessible. Genetic factors can influence the brain development of sensory and perceptual systems, which are crucial for information processing and learning (Boyce et al., 2020; Nofsinger & Shank, 2020).

Nurture (environmental factors)

The social context in which an individual grows up considerably influences learning. Family, peers, teachers and cultural norms shape a person's educational experiences and opportunities. Access to quality education and educational resources, as well as the quality of teaching, can profoundly impact learning outcomes. Socioeconomic status can affect the availability of resources, access to educational opportunities and the overall learning environment. Research shows an increase in anxiety, depression, sleep disturbances, aggression, withdrawal and classroom performance in students living in urban areas (Quan et al., 2023).

Tenet 14: Learning engages the entire physiology

Although some people believe they are more "right" and others are more "left" brained, it is a neuromyth. Learning is a whole-brain process from the most basic to the most sophisticated.

Current science demonstrates simultaneous and integrated problem solving from the brain stem to the prefrontal cortex, constantly engaging the left and right brain. The left hemisphere is generally dominant for logical-mathematical and communication processing. It is set to identify already known challenges and implement effective previously developed responses. The right hemisphere is usually dominant for constructing accurate internal representations of the external environment (Handayani & Corebima, 2017). It allows us to interpret new challenges creatively and effectively (Sylvester et al., 2016).

The corpus callosum connects the cerebellum's two left and two right hemispheres in the human brain, which includes four pairs of lobes (Akyurek & Afacan, 2013; Jensen, 2008) (Figure 2.17). Neurons comprise hundreds of systems and subsystems that communicate and process information in the brain. The brain is responsible for planning, organising and predicting the correct action in a given situation.

Tenet 16: Nutrition

Like the rest of the body, the brain needs food to maintain its structure and fuel its performance. The brain stem regulates these processes through appropriate and specific feedback and feed-forward systems. Nutrition is not just about satisfying hunger or thirst. If one optimises the nutrients for one's brain, one simultaneously optimises the nutrients for one's body (Dubinsky, 2010). It is probably true that the highest physical performance levels are only achievable when brain performance is also optimised. The brain and body are unique and wonderfully complex systems (Jensen, 2005). The brain is a fussy eater. It is susceptible to the foods one eats. It performs best when we ingest the right mix of nutrients. Glucose is at the top of the list because glucose fuels neurons that fire in a continuous symphony of billions of connecting cells. The machinery of the brain (vesicles, neurotransmitters and other transport systems) is properly maintained when there is an optimum mix of nutrients. These include complex carbohydrates, proteins, the right fats, vitamins, minerals, etc. All these nutrients are first processed in the gut. Even though the brain makes up only 2% of body mass, it uses 20% of the energy produced by our foods. It is worth knowing that, when cognitively challenged (as often happens in the workplace), the brain demands even more of the body's energy resources (Stranges et al., 2014).

The brain model (Figure 2.17) illustrates an essential part of creative problem-solving (Bernardi et al., 2020).

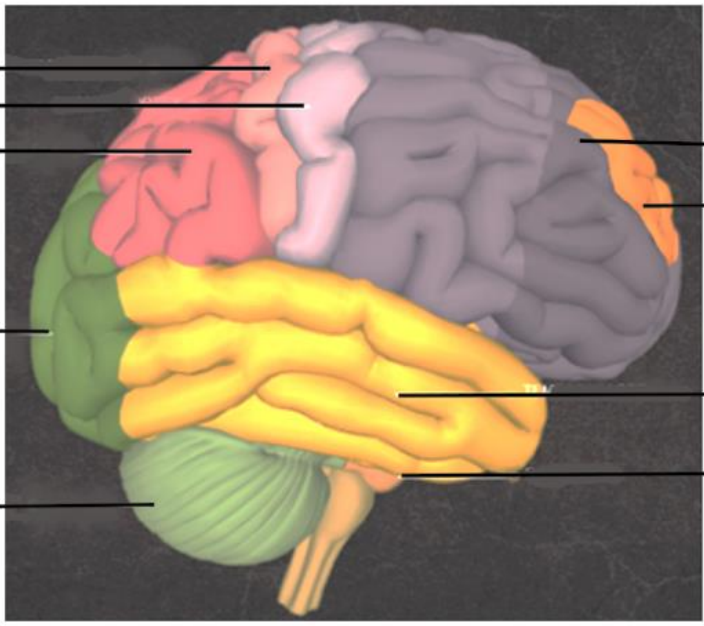


Figure 2.17: Different areas of the brain (Van der Walt & Neurozone, 2019)

Tenet 17: Exercise

The hippocampus develops new brain cells when exercised regularly. Training facilitates the release of growth factors in different regions of the brain. New brain cells can be formed throughout life in the hippocampus (Klein et al., 2023). A common misconception is that exercise is only for physical health. Inadequate exercise will always result in suboptimal brain performance. Different forms of exercise positively affect other functional brain structures, including the hippocampus for memory, the hypothalamus for brain balance and the prefrontal cortex for creativity.

It is well proven that moderate, regular exercise profoundly reduces the effects of chronic stress – a continuously activated physiological state that leads to the ongoing release of cortisol and adrenaline (Pratiwi & Pratama, 2020). Exercise enhances resilience by reducing chronic stress, anxiety, depression and loss of self-worth. Resilience is the ability to bounce back after a traumatic event or an incredibly stressful time.

The effect of exercise on the brain, one of the most widely researched fields in brain science, is given below (Medina, 2011).

- Exercise increases the concentrations of brain-derived neurotrophic factor (BDNF) at synapses (brain cell connections) in the hippocampus.
- Exercise stimulates the formation of mitochondria (the fuel stations in cells) in both the muscles and the brain.

- Submaximal exercise for one to two minutes leads to a spike of the human growth hormone in the pituitary gland – increases brain volume, stimulates the growth of brain cells in the hippocampus and increases muscle fibre.
- Short, high-intensity training increases the availability of growth factors that, in turn, enhance cognitive flexibility (a feature of creative thinking) in the prefrontal cortex.
- During exercises like running and cycling, repetitive motor patterns enhance the rhythm centres in the brain (basal ganglia, cerebellum and brain stem) that may improve pattern recognition abilities.
- Complex motor patterns during activities enhance the circuitry in the cerebellum and prefrontal cortex (crucial for sophisticated cognitive function).
- Cardiorespiratory fitness facilitates volumetric integrity in the dorsolateral prefrontal cortex grey matter, supporting spatial working memory tasks.
- Exercising in a heavily polluted environment does not seem to enhance the release of BDNF in the hippocampus and cortex (Holzel et al., 2011).

McNerney and Radvansky (2015) emphasised that simple exercises before, during and immediately after the learning process have improved students' memory for a relatively long period.

Tenet 18: Brains help development by remaining cognitively active

Individuals' ability to see, process information and interpret the world is influenced by both genetic and learnt variables. Cognitive development includes acquiring memory, linguistic skills, logic and information processing. Between the ages of 6 and 12, children start to develop solid thinking abilities. Teenagers between 12 and 18 engage in more sophisticated formal logical procedures. Their thinking shifts from concrete to logical (Fischer et al., 2018).

Electroencephalography (EEG) and functional magnetic resonance imaging (fMRI) are used to evaluate brain activity. The EEG technique employs a better sequential solution, while the fMRI technique uses an exceptional longitudinal resolution. These methods allow us to focus on the learning process rather than the learning results (Ng, 2018). Researchers Mangels et al. (2006) and Moser et al. (2011) used fMRI or EEG to assess the amplitude of brain waves to determine the effects of these waves on behaviour. Neuroscientific approaches are employed to understand how learning is affected by a growth mindset and intrinsic motivation and how the brain functions in learning (Decety et al., 2004; Ng, 2018).

Tenet 19: Feedback

Feedback needs to be succinct for effective learning, meaningful, compatible with prior knowledge and comprise logical networks (Betts et al., 2019; Hattie & Timperley, 2007). It must be pertinent, concrete, precise, differentiated and valuable.

Feedback is a critical approach to encourage pupils who make mistakes. Error-related negativity (ERN), which occurs shortly after cognitive mistakes, is the cause of many responses. The amplitude of the ERN indicates a focus on the given error messages. Positive learners have a bigger amplitude in ERN. These learners are also called students with a growth mindset.

Negative learners react negatively to error warnings when the amplitude is low. These learners are referred to as students with a fixed mindset. They had significant feedback-related negativity (FRN) (Klein et al., 2017; Schroder et al., 2017). The graphs from the study by Frank et al. (2007) illustrate the distinction between the event-related potential (ERP) of negative and positive learners in Figure 2.18.

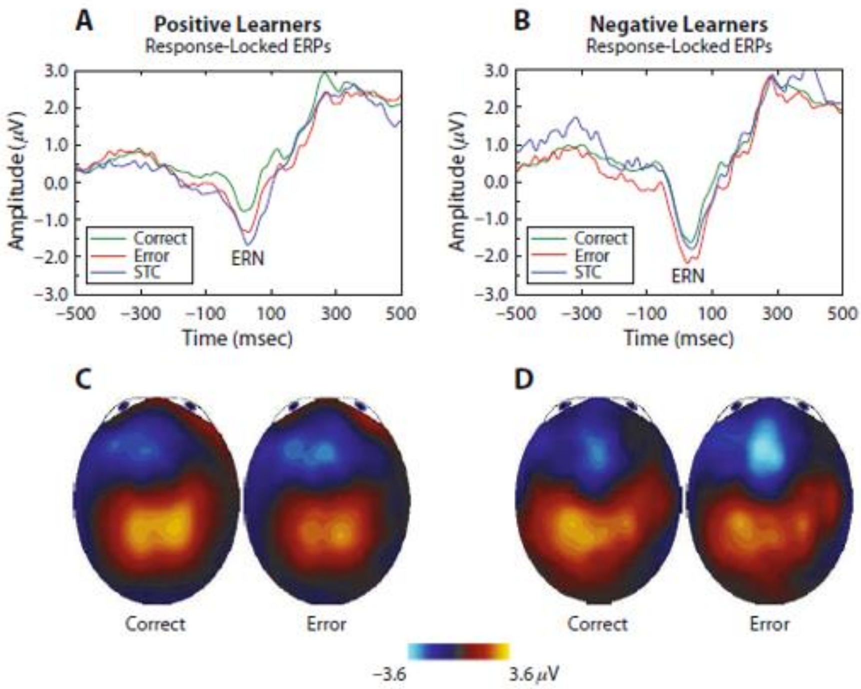


Figure 2.18: ERP response-locking during recognition memory (Frank et al., 2007) – permission granted by the author (Appendix B2)

The response-locked and error-corrected ERPs are displayed in the graphs. According to Frank et al. (2007) and Schroder et al. (2015), positive learners show more prominent ERN amplitude than negative learners. The level of learning that students achieve depends largely on their expectations and ideas about intelligence. Based on the probabilistic learning problem, the average wave forms are provided individually for positive (A) and negative (B) learners. The greater ERN, independent of the error circumstance, was seen. The topographic images were displayed throughout the corrected (C) and negative (D) learners, as well as the correct, uncorrected and switch-to-correct circumstances 32 msec post-response (the ERN peak).

Tenet 20: Relevant and meaningful contexts

For the brain's natural learning processes to function fully in brain-based learning, relevant and meaningful educational contexts must be created. To assist students in understanding the usefulness of learning, instructors might link classroom courses to practical applications.

Real-world issues or situations help develop critical thinking and problem-solving skills. Content can become more personally relevant by incorporating personal interests and experiences. Learning is reinforced using several senses, such as visual aids, hands-on exercises and interactive dialogues. The content becomes more memorable and impactful thanks to this multimodal approach, as described in Tenet 10. Narrative courses' context can help students grasp and retain the material. Understanding and retention can both be improved via collaborative learning. It promotes critical thinking and deepens comprehension to present various points of view and opinions on a topic. Emotionally intense experiences are frequently better remembered (Jennings, 2013).

Tenet 21: Novelty

The human brain is prone to seeking novelty and often detecting it quickly.

Incorporating novelty into brain-based learning is essential to provide a dynamic and exciting learning environment. Curiosity is sparked, and the reward system in the brain is activated when something novel and unexpected is introduced into the learning environment (Helgesen & Kelly, 2016). The likelihood of new experiences or knowledge retained in long-term memory keeps pupils engaged and motivated by breaking up the routine of conventional teaching techniques. The brain is wired to notice different things (Medina, 2014).

Students are forced to use their problem-solving abilities when confronted with new ideas or challenges, which fosters cognitive development. This can assist pupils to stay alert and cognitively engaged while reducing the stress related to ordinary learning. Their comprehension may be expanded, and holistic thinking may be encouraged by this multidisciplinary approach.

All the principles and tenets from MBE are discussed, including the brain-based learning principles – as described in the following section.

2.10.3 Principles of brain-based learning according to Caine et al. (2005) and Caine and Caine (1991)

Apart from Tokuhama-Espinosa (2017), Caine et al. (2005) and Caine and Caine (1991) defined 12 principles that served as the basis for brain-based learning's initial foundation (Table 2.10). Some of these principles overlap with the principles of MBE, discussed in section 2.11.2.

Table 2.10: Principles of brain-based learning (Caine et al., 2005)

1.	The brain is a parallel processor.
2.	Learning engages the entire physiology.
3.	The search for meaning is innate.
4.	The search for meaning occurs through patterning.
5.	Emotions are critical to patterning.
6.	Every brain simultaneously perceives and creates parts and wholes.
7	Learning involves both focused attention and peripheral attention.
8.	Learning always involves conscious and unconscious processes.
9.	We have at least two types of memory systems: spatial and rote learning.
10.	The brain understands and remembers best when facts and skills are embedded in the natural spatial memory.
11.	Learning is enhanced by challenge and inhibited by threat.
12.	Every brain is unique.

In addition to the above principles, Caine et al. (2005) also noted the three elements of brain-based learning. These elements are relaxed alertness, immersion in complex experience and active processing. The following section gives an overview of these three elements.

2.10.3.1 Elements of learning (Caine et al., 2005)

These three elements of brain-based learning underscore the significance of creating a learning environment that is conducive to cognitive engagement and growth. By promoting relaxed alertness, immersion in complex experiences and active processing, educators can optimise the learning process and enhance students' understanding and retention of information (Caine et al., 2005). These elements mirror the distinct phases of the flow of a lesson within the classroom.

Relaxed alertness

Relaxed alertness refers to a mental state in which learners are calm and attentive, creating an ideal setting for effective learning and information processing. In this state, students are comfortably challenged. Learning tasks hold personal significance, and daily practices like meditation and focus training counteract the harmful effects of stress, while bolstering the immune system. These elements help students maintain an appropriate level of attention for successful learning.

Orchestrated immersion

Orchestrated immersion is a method that leverages immersive and captivating experiences to enrich the learning process and maximise cognitive function. This approach enables individuals to recognise novel patterns and connections, making the learning material more significant. It offers learners intrinsic and multifaceted experiences that encompass choices and a feeling of completeness. This involves creating an environment where learners actively engage and fully experience the learning process. Educators play a pivotal role in immersing students in challenging, dynamic, substantial and authentic experiences.

Active processing

Active processing is crucial in the classroom. It is the learner's consolidation and internalisation of knowledge in a conceptually sound and personally meaningful way. It is the route towards comprehension as opposed to simple memory. Students who actively process information can control the type and pace of change. The principal goal is to concentrate on our educational process and to draw out and explain what has been learnt and what it implies. It is essential to recognise the chances for students to learn about the subject at hand and themselves as individuals to increase intrinsic motivation.

Figure 2.19 shows how the principles of brain-based learning are merged with the three elements. It takes extensive analysis of the various approaches to a subject and of learning in general for a learner to develop an understanding of it.

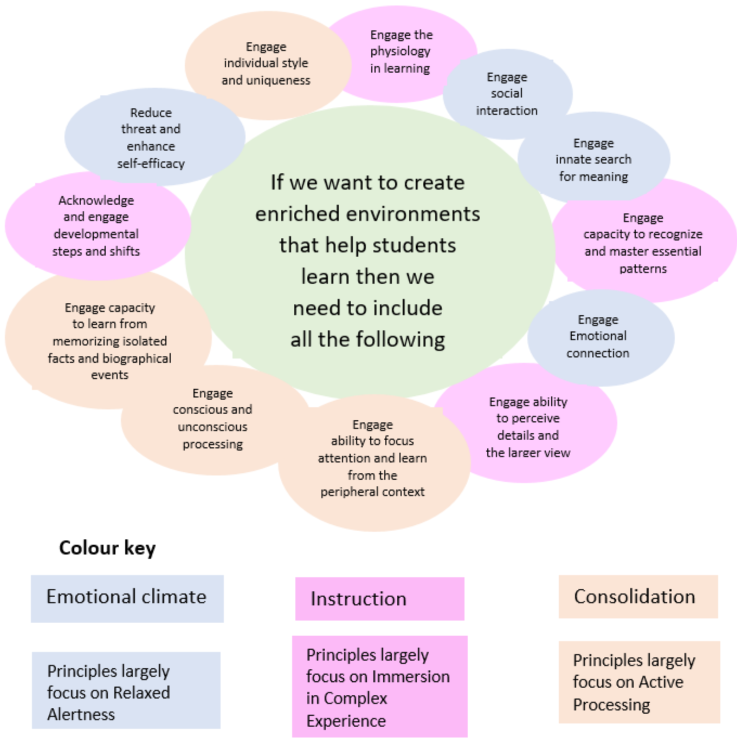


Figure 2.19: Principles of brain-based learning merged into the three elements (Caine et al., 2005)

2.10.4 Principles of brain-based learning according to Schachl (2013)

Schachl (2013) proposed another set of brain-based learning principles, as seen in Table 2.11. Again, there are similarities between the different sets of principles, as explained in sections 2.11.2 and 2.11.3.

Table 2.11: The basic principles of brain-based learning (Schachl, 2013)

1.	Present an overview before details.
2.	Use a multisensory approach.
3.	Take previous knowledge into consideration.
4.	Initiate contextual learning and show the interdependence of knowledge areas.
5.	Stimulate interests and curiosity.
6.	Arouse interest and teach attractively and in varieties.
7.	Teach with enthusiasm (enthusiastic teachers fill learners with enthusiasm).
8.	Take care of conscious attention.
9.	Take care of feelings and foster positive emotions.
10.	Involve breaks (in particular for physical exercises) in the teaching sessions.
11.	Avoid anxiety and advise on coping with stress.
12.	Initiate repetition.
13.	Give feedback as soon as possible.
14.	Link ideas and topics into structures.

All the brain-based learning principles mentioned by Caine et al. (2005) and Schachl (2013) are discussed by Tokuhama-Espinosa (2017) in section 2.11.2.

2.10.5 The application of brain-based learning in the classroom

Several studies illustrate how brain-based learning can be applied in the classroom. The section below discusses some of these methods.

2.10.5.1 The application of mindfulness in the classroom

Mindfulness-based clinical interventions can reduce anxiety and depression and improve the quality of education. Whether internal or external, memory and language processing are significantly affected by life stress (Holmes, 2019). Language barriers increase stress and affect the educational trinity of cognitive, emotional and social contexts. Practising mindfulness may help manage this type of trauma. A child's genetic potential is essential, but genetics alone cannot teach them to speak (Boyce et al., 2020). A more detailed explanation is given in section 2.11.2.

Continuous focused attention and open monitoring keep us in the current moment and reduce anxiety about the past and future (O'Hare & Gemelli, 2023).

Attention or cognition needs to focus on an object, while dismissing conflicts. It is critical to focus on a stationary object. For at least ten minutes, intrusive thoughts must travel through the mind.

Open monitoring requires an open mind (O'Hare & Gemelli, 2023). The ability to observe events without reacting to them must be developed. Silencing the mind by meditating for 15 minutes positively impacts the brain-body system. Identifying a quiet time and area, and being uninterrupted for at least 15 to 20 minutes is an excellent technique to calm the mind. A comfortable and well-balanced position is required. Take a long breath in. Silencing the mind, like exercise, is a powerful and effective strategy to relieve chronic stress. Deep breathing induces a relaxed physiological state, lowering blood pressure and heart rate, and enhancing coping abilities.

2.10.5.2 The application of mind moves in the classroom

The next mind moves can be practised often (De Jager, 2019):

- Confidence booster

  This mind move aims to ensure more stable and even brain waves**.** Mental and emotional resources are maximised when in this state.

  Cross the feet and arms in a hugging motion. Place the tongue against the palate in the sucking position to calm and boost the immune system. Take slow deep breaths. Keeping the eyes closed will help avoid visual distractions.

- Leg workout

  This mind move improves concentration, listening and comprehension skills, allowing one to complete tasks and become more confident.

  While sitting on a chair, place both feet on the floor, while straightening both legs forward. Lift both legs off the ground. Try flexing and pointing both feet and feel whether the calves are tight. Flex the right foot while resting the left leg on the floor. While holding the foot in the flexed position, count to eight. Relax the foot. Repeat the move three times. Flex the left foot while resting the right leg on the floor for eight counts. Relax. Repeat three times before stopping. Lift both legs off the ground. Feel the tightness in the calf muscles by flexing and pointing both feet.

- Mouse pad

  This mind move integrates the left and right visual fields when the body and the brain cross the midline. Visual, auditory and kinaesthetic wiring will improve. By performing this activity, eye-hand coordination and visual integration can be developed.

  The eyes are doing to the brain what a mouse does to a computer. If the eye turns up, down, horizontally, left, and right, it accesses different brain regions. Concentrate on the thumb and hold it at an elbow distance from the eyes. By using the thumb, make an infinity sign by moving it up and around the left, and then around the right eyes. Do this five times. Repeat this exercise with the other hand. Always start with the left eye.

- Bilateral walk

  This mind move aims to improve reading, listening, writing and communication skills by crossing the visual, auditory and kinaesthetic midline. While crossing the midline, this move integrates the brain and body's left and right sides. Eye movements that cross all three midlines include visual, auditory and kinaesthetic exercises.

Touch the left knee with the right hand by twisting the trunk, bringing the opposite shoulder and hip towards each other, and extending the other arm and leg. Extend the other arm and leg while touching the right knee with the left hand. It is best to perform this movement lying down, and then stand up, crossing the lateral midline to stimulate left-right integration. Repeat this at least ten times. Exercises like this can also be done while singing or learning rote facts.

- Antennae adjuster

This mind move aims to strengthen ability and memory, and improves abstract reasoning to become more aware of the importance of listening actively and attentively before responding.

Using circular movements, massage both earlobes simultaneously. As a result of this exercise, the near senses, the auditory system, auditory perception and receptive language capacity are developed.

- Temporal toner

This mind move stimulates the sense of balance in the inner ear and listening, organisational, mathematical and critical thinking abilities. It encourages verbal and written communication.

Start behind the ears and tap upwards around them using two hands simultaneously.

- Focus adjuster

This mind move aims to improve near-to-far vision, focus in the midfield, eye-hand coordination, and vision perception.

The face should be facing forward while holding the thumb at an elbow's distance. Keeping focus, bring the thumb slowly to the tip of the nose, then out to arm's length. Consider the thumb first, followed by a point further away, and then the thumb again. Focus on the thumb while bringing the thumb back to the tip of the nose. Do this ten times. Then, rub the hands together and place them over the eyes.

- Arm workout

  This mind move aims to stimulate the muscle tone in the back, shoulders and hands to improve posture, eye-hand coordination and communication skills.

  Intertwine the fingers and turn the palms outward. Extend the arms forward to lengthen the arm and shoulder muscles by keeping the body in the "string of beads" position. Count to eight while maintaining the extended position. With the hands above the head, repeat the process. Put both hands against the body, palms facing downward, and repeat the step. Move the hands behind the back after unclasping them. By clapping the palms together and pushing them downward, stretch and relax the shoulder muscles.

2.10.5.3 Multisensory approach

Edgar Dale, a pioneer in multisensory learning, asserted in 1969 that individuals acquire knowledge more effectively when exposed to visual and auditory stimuli, such as seeing images and hearing words simultaneously (Dale, 1969). Willingham et al. (2015) and Lynn (2015) support this notion, emphasising that the key to effective learning lies in understanding the cognitive processes within the learner's brain rather than just the information delivery method.

It is acknowledged that our brains have distinct processing mechanisms for visual, text, audio and sound inputs. Consequently, in the context of comprehending vast amounts of data, multisensory learning has gained significance (Whitman & Kelleher, 2016). Medina (2014) supported the idea that individuals who receive information through multiple senses tend to have superior memory retention compared to those who rely solely on visual or auditory input. He noted that when information is presented using only auditory cues, just 10% will likely be remembered after three days. However, when visual elements, such as images, are introduced, approximately 65% of the information is retained. Medina (2014) and Newell et al. (2003) demonstrated a significant increase, ranging from 50 to 75%, in the likelihood of creative problem solving in individuals exposed to information through multiple sensory modalities. Collins (2019) and Lim et al. (2019) agreed that learning is a multisensory endeavour, and integrating various senses can enhance comprehension, retention and practical application of knowledge.

By engaging multiple senses simultaneously through multimedia modes, learners can reinforce their understanding of concepts and connect more effectively (section 2.11.2).

The application of multisensory approaches in education

Conducting hands-on experiments allows students to actively engage with scientific concepts and principles (Lathan, 2018). They can perform experiments, collect data, analyse results and draw conclusions, fostering a deeper understanding of scientific principles (Aghaei & Gouglani, 2016; Caine et al., 2005; Dale, 1969; Lim et al., 2019) and engaging students in practical, experiential learning through projects, experiments or simulations.

Teachers can use demonstrations to showcase scientific phenomena or experiments that might be challenging to replicate individually. Demonstrations provide a visual and interactive experience, enhancing student comprehension and engagement (Jaipal, 2010) and showing or illustrating concepts through practical examples or visual aids.

Taking students on field trips to museums, science centres, nature reserves or research institutes provides real-world experiences and opportunities to observe and explore scientific phenomena in their natural contexts. It promotes curiosity, observation skills and hands-on learning (Kolb, 2011).

Using multiple modalities, teachers can incorporate visuals, videos and animations to illustrate scientific concepts, processes and models (Armbruster et al., 2009). Multimedia presentations provide a dynamic and engaging learning experience, aiding the comprehension and retention of scientific information (Francique, 2021). They use audio, video and interactive digital resources to enhance learning. According to Whitman and Kelleher (2016), multimedia learning environments promote students' desire to learn, help them hone their critical thinking and decision-making skills, and boost brain activity.

Encouraging group learning activities, such as group projects, discussions and debates, allows students to interact with their peers and engage in scientific inquiry (Esteves et al., 2017).

Virtual simulations and computer-based models enable students to explore scientific phenomena and conduct experiments in a virtual environment. They provide interactive and immersive experiences that enhance understanding of complex scientific concepts (Puentedura, 2010). Moving images or visual sequences illustrate dynamic processes, concepts or interactions (Francique, 2021; Haşiloğlu et al., 2020; Jackman & Roberts, 2014; Joseph et al., 2013).

Discussions can be applied where students participate in conversations and share ideas. Incorporating communication activities, such as creating scientific posters, giving presentations or writing reports, helps students develop their communication skills and effectively convey scientific concepts to others (Gashi Shatri, 2020; Kraus, 2017; Whitman & Kelleher, 2016; Wichadee, 2015).

Data visualisation software or online tools can create interactive visual representations of scientific data. Students can manipulate and analyse data sets, create graphs and charts, and explore patterns and relationships visually (Adams et al., 2020; Yeo & Nielsen, 2020).

Encoding refers to the initial processing and transformation of information into a format that can be stored in memory. When capturing knowledge, individuals encode by acquiring and representing new information or concepts in their memory system. It involves reading, listening, observing, taking notes, summarising, discussing or reflecting on the information. These actions help individuals engage with the content, understand its meaning, and make connections to their prior knowledge, which aids in the encoding process.

Willingham et al. (2015) declared that learning is more effective using multiple approaches and contended that the most important is what is happening inside the learner's brain rather than how information is delivered. People retain information better when they actively consider it, work through challenges, or speculate about what might happen if certain circumstances change. This approach emphasises using multiple sensory stimuli to create a more comprehensive learning experience. Because our brains are wired to process visual, text, audio and sound input very differently, multisensory learning has become increasingly crucial when understanding large volumes of data (Whitman & Kelleher, 2016).

Researchers have confirmed the existence of a dual coding system in which visual and textual information are processed separately by fMRI scans. Stevenson et al. (2014) found that students who combined visuals and text learned more than those who only used text. Therefore, using multiple methods to assist and support the development of memory alliance is recommended. Jubbal (2019) stated that multiple brain regions and neural pathways must be employed to maximise learning. Medina (2014) agreed that learners who receive information via multiple senses could remember far better than learners who only obtain information through visual or auditory senses. He stated that by hearing, only 10% of the information would be recognised after three days, and by adding an image, 65% would be remembered (Medina, 2014). Newell et al. (2003) revealed that creative problem solving is 50 to 75% more likely in people who receive information via multiple senses. Collins (2019) and Lim et al. (2019) approved that multisensory stimulus is critical in designing learning activities and improving memory.

By engaging multiple senses simultaneously through multimedia modes, learners can reinforce their understanding of concepts and connect more effectively.

2.10.5.4 Metacognition

Vos and De Graaff (2004) defined metacognition as the ability to know about cognition. They argued that metacognition is the base for active learning, concerned with the mental processes associated with awareness. Based on Vos and De Graaff (2004), the learning objective is to understand the metacognitive level formulated by the teacher and the mental states and procedures related to it.

Lim (2016) describes metacognition as the interaction between brain function's cognitive, affective and psychomotor aspects. By explicitly teaching and practising metacognitive strategies across content and social settings, students can "drive their brains" (Wilson, 2014). Consequently, self-regulation is enhanced to manage motivation, increase ability and achieve more independence.

Blakey and Spence (1990) describe the metacognitive process as enabling students to recognise their thinking and discover what they know and do not know about themselves. Through metacognition, students gain knowledge and expertise from life experiences (Price-Mitchell, 2015).

The metacognition component plays a critical role in solving a problem.

Strategies for developing metacognitive behaviour

- At the beginning of the activity, students must be encouraged to identify what they do not understand (Li & Bates, 2019). This promotes metacognition and creates a classroom culture that recognises the confusion inherent in learning (Price-Mitchell, 2015).
- Students need to talk about thinking to discuss their thinking through modelling and discussion (Nisnisan, 2014).
- Students can keep a journal to describe their handling of ambition, comment on how they dealt with difficult situations, and share their thoughts about real-world problems (Hartman, 2001; Price-Mitchell, 2015).
- During the debriefing of activities, students discuss strategies they can apply to other learning situations to develop their awareness of thinking techniques. Students must reflect on their coursework using paired problem-solving (Blakey & Spence, 1990).

Their biases are challenged, and they learn to think more flexibly and adaptively (Price-Mitchell, 2015).

- The use of essays or multiple-choice questions must be considered when assessing performance. For multiple-choice tests, students employ lower-level thinking skills, but for essays, they use higher-level metacognitive skills (Price-Mitchell, 2015).
- A short intervention integrating a metacognitive practice into an existing activity can promote student monitoring. Students can be motivated to share their experiences to enhance learning skills and metacognitive monitoring (Price-Mitchell, 2015). If students learn how their brains grow by studying metacognition, their performance will be affected. The research shows that learners with a growth mindset consider their learning and growth more often (Dweck, 2015). A good starting point is to assess their students' mindsets (Dweck, 2015) (sections 2.4 and 2.5).
- The awareness of neuroplasticity can significantly impact classroom learning when it is explicitly taught to students. Studying how the brain changes during learning has positively influenced lecturers' expectations and abilities of their students (Sowell, 2015; Tokuhama-Espinosa, 2017). Using these strategies, students gain cognitively and academically, leading to further academic success and easing classroom management issues. It is vital to keep the concept of neuroplasticity at the forefront of professional practices when students struggle; it is not because they cannot learn, but because they need more training and instruction (Nisbett, 2009; Tokuhama-Espinosa, 2017) (section 2.11.2).

2.10.5.5 Summary of the application of brain-based learning

The application of how to use brain-based learning in education is summarised in Table 2.12.

Table 2.12: Summary of brain-based learning application

Brain-based learning application	Section	Activity
Mindfulness	2.11.5.1	Focus attention Open monitoring Silencing the mind
Mind moves	2.11.5.2	Confidence booster Leg workout Power on Mouse pad Bilateral walk Antennae adjuster Temporal toner Focus adjuster Arm workout
Multisensory approach	2.11.5.3	Hands-on experiments Demonstrations Field trips Multiple modalities Group learning activities Virtual simulations Discussions Data visualisations Encoding
Metacognition	2.11.5.4	Prior-knowledge awareness Talk about thinking Capture new knowledge Use real-world problems Feedback on real-world problems Mindset development Neuroplasticity teaching

2.11 BRAIN-BASED LEARNING IN SCIENCE EDUCATION

The impact of brain-based learning on science performance, motivation and mindset is covered in this section.

2.11.1 The effect of brain-based learning on science performance

Ozden and Gultekin (2008) investigated how educational neuroscience contributes to student achievement and knowledge retention among fifth-grade science students. During the 11-day study, 18 hours of class time were devoted to analysing. Educational neuroscience was applied in the experimental group, while conventional teaching methods were employed in the control group. The experimental group's classroom offered a learning environment where the functions of the brain and their significance for learning were taken into account during the teaching process. In addition, the atmosphere was enriched with unique learning experiences that engaged learners in challenging activities. For the experimental group simulations, group discussions, role play and dramatisations were used to retain and organise acquired knowledge and communicate it to new situations. Classical music was played during these periods of "relaxed alertness" and "active processing" (section 2.11.3). The teacher's role for the conventional group was to acquire knowledge and skills and transmit them to the students. The students needed to pay attention to the teacher, make notes and do the assigned readings to reinforce and internalise the content. This approach was centred around the teacher. Both groups were tested for achievement after the intervention period ended. It was found that educational neuroscience techniques and approaches appear more effective in improving students' academic achievement than conventional methods in science courses (Ozden & Gultekin, 2008).

In another study, Achor and Gbadamosi (2020) examined how educational neuroscience affected secondary school pupils in Nigeria's Physics achievement and retention levels. Researchers discovered that using an educational neuroscience strategy significantly improved achievement and retention scores in Physics students compared to students using conventional learning methods. This finding confirmed that of Ozden and Gultekin (2008). From the initial results of this study, the educational neuroscience strategy is found to be more effective than conventional learning. Therefore, Achor and Gbadamosi (2020) recommended exposing Physics lecturers to educational neuroscience principles through seminars or training to improve their input during teaching and learning.

A study released by Lagoudakis et al. (2022) investigated the impact of brain-based learning on students' performance in a Biology course. They used a teaching strategy influenced by brain-based learning and assessed secondary students' performance in Biology courses. In a quasi-experimental study using pre- and post-tests, seventh graders from a public mainstream school in Athens, Greece, were split into experimental and control groups. The experimental and control groups each received seven 45-minute lessons on the curriculum. The control group was told to employ the traditional procedure, whereas the experimental team used the brain-based learning strategy. The students were exposed to the new information using properly developed audio-visual material, simulations, models and working sheet completion to try a balanced activation of the two hemispheres within the context of a whole-brain didactic approach. Questions, predictions, explanations and discussions spurred the students' participation in the present phase. There was a concentration slump for about 13 minutes. Before the course began, the students could unwind and chat peacefully as classical music played in the background. The layout and technique of teaching knowledge, which included a variety of tasks, exercises and practice methods to increase student memory capacity and provide more effective encoding and storage, were the main areas of focus for this time zone. The results revealed that the experimental group's students significantly outperformed those in the control group on an achievement test given as a post-test, demonstrating that the suggested teaching strategy positively impacted the students' improvement in academic performance.

Saleh and Subramaniam (2019) examined the differences in Physics accomplishment between students exposed to brain-based learning and those who employed the traditional teaching method. In a quasi-experimental study, 90 students from two normal schools in Penang, Malaysia, participated. The experimental group was instructed to utilise brain-based learning techniques by activating, clarifying outcomes, painting a broad picture, generating connections, developing meaning, and participating in learning activities and demonstrations. In contrast, the control group received instructions using conventional methods, including demonstration, lab activities and discussions, without considering brain-compatible strategies. According to the findings, pupils who made use of brain-based learning techniques had higher mean test scores than those who received conventional education.

The systematic review of Bada and Jita (2022) on incorporating brain-based learning in science classes was published in 2022. They examined and debated the findings of 25 peer-reviewed studies and highlighted the methods and approaches utilised to enhance the integration of brain-based learning in science classrooms. They systematically assessed the effectiveness of such learning in science classrooms and the various integration strategies utilised in primary and secondary institutions. Studies on using brain-based learning in the classroom demonstrate an improvement in science performance.

Alanazi (2020), Al-Balushi and Al-Balushi (2018), Saleh and Subramaniam (2019), Sani et al. (2019) and Willis (2007) confirmed that such learning increased students' performance in Chemistry and Physics courses taught in primary and secondary schools.

Kress et al. (2006) included an article examining the multimodal environment of a science classroom for Grade 8 students in their book "Multimodal teaching and learning: The rhetoric of the science classroom" (Kress et al., 2006). In the first part of the lesson, the teacher explained how blood moves in a cycle. The teacher's voice, images, gestures and other actions were necessary during the presentation. The teacher's narrative and motion created a series of representations of the body. In the second part, a picture of the lesson was drawn on the whiteboard. The teacher described the flooding through gestures, which were then transposed onto images. He used a model to demonstrate how the blood flows and the heart contracts. Students needed to follow a picture in their textbook as they traced their fingers over the blood circulation process. Students completed a series of activities based on their textbooks as a final task. Students were optimistic about the presentation method of the first part of the class (Kress et al., 2006).

Jaipal (2010) utilised a "multimodal semiotics discourse analysis framework" that considered all modes equally, as essential to illustrate the potential of deep learning, while teaching science notions in a multimodal context. The study was carried out for eight months at a high school in a Canadian city. By using multimodal learning, lecturers have gained a deeper understanding of how various modalities create meaning and highlight the essential characteristics of semiotic modalities to consider. The teacher used verbal language, written text, motions, writing and diagrams. The teacher asked students to recall, visualise and imagine these demonstrations. The research findings support the efficacy and usefulness of the multimodal semiotics framework for science learning.

Sarac and Tarhan (2017) used multimedia-supported instructional materials in the experimental group, including the 7E model (elicit, engage, explore, explain, elaborate, evaluate and extend). The materials included stage pictures, drawings of experimental activities, animations based on computer simulations, video filming and presentation files. In the control group, the teacher was responsible for giving an oral presentation about the unit and conducting conventional teaching methods. Various materials were used, including textbooks, study guides and teacher's guides. The study's findings suggest that multimedia-based learning materials, supported by the 7E model, can assist academic achievement and help make learnt materials in science more memorable.

Iravani and Delfechresh (2011) added that learning through animation provides a broader range of stimuli.

Mirza and Khurshid (2020), from a university in Pakistan, studied the impact of the VARK learning model on tertiary students from the medical, engineering, social and basic sciences disciplines. It was proven that learning styles could not be related to tertiary education and that there is no evidence connecting performance to learning styles. Arbabisarjou et al. (2016) confirmed no relation between learning styles.

Adadan (2013) investigated aspects of the particle theory with two groups of Grade 11 students in the USA. A study was conducted to determine whether multimodal representations in science help students understand the material more effectively. Control and experimental groups were randomly selected for the study. In the experimental group, communication was performed during the session via verbal and visual methods. For the control groups, only oral and written presentations were given. Then, both groups discussed their understandings with their peers. Based on their study, the experimental group showed a better understanding of the particle theory compared with the control group. They concluded that using multiple representations to deliver instruction can positively affect the development and maintenance of students' scientific understanding.

Givry and Pantidos (2012) examined how a Greek Physics teacher teaches the concept of potential energy to students in Grade 9 using various modalities. To illustrate the storage and conversion of various forms of energy into potential energy, the teacher simultaneously uses aspects of scenery and technical objects. As the teacher described situations from everyday life, body movements were employed to show how potential energy is transformed. They found that using semiotic resources like signals, body displacements, material objects, drawings and co-text was valuable for introducing or addressing aspects of a concept that may be "hidden". Thorough preparation is essential when using multiple modalities in a lesson.

2.11.2 The effect of brain-based learning on motivation

A study by Sani et al. (2019) examined how brain-based learning affected students' motivation to learn electric circuits. The participants were students from an international school in Indonesia. A quasi-experiment was conducted with 26 pupils in the experimental group and 23 in the control group. While the control class learnt through lectures, the experimental class used brain-based learning. Both groups of students shared similar socioeconomic and educational backgrounds. They were between the ages of 13 and 14. The study examined the effect of brain-based learning on students' desire to comprehend the electric circuit. Both groups' levels of motivation were assessed before and after the tests. They found that brain-based learning increased pupils' motivation.

Mejías et al. (2021) conducted a study based on the idea that insights from neuroscience can be applied in science education. They implemented a workshop-based intervention designed for young adult students to influence their self-perception as learners. They hypothesised that educating participants about the structure and function of the brain and the principles of learning could alter how students view themselves and foster a positive mindset towards learning situations. The primary objective of this research was to transform students' self-concept, boost their motivation and equip them with valuable tools to lever educational challenges throughout their lives. The researchers utilised the MSLQ at three distinct time points: before, immediately, and ten months after the intervention, to gather data for their study. Their findings indicate that a programme focusing on neuro-education and learning strategies directly and positively impacted student motivation.

2.11.3 The effect of broad-based learning on mindset

Fitzakerley et al. (2013) launched a programme in 2013 to boost students' enthusiasm for science. They invited scientists to visit classrooms and serve as inspirational figures for students. The programme incorporated training in neuroscience to enhance science performance and shift students' fixed mindsets towards a growth mindset, according to Blackwell et al. (2007). The programme's primary goals were to deepen students' understanding of crucial brain functions and instil an appreciation of their learning capabilities. As part of the programme, lecturers and students engaged in one-hour brain awareness sessions, likely involving discussions and activities centred around the brain and neuroscience. Students were surveyed to assess their attitudes towards science and their comprehension of neuroscience to gauge the programme's effectiveness. The results showed that the brain awareness presentations successfully encouraged growth mindsets and fostered positive attitudes towards science among the students. Educators involved in the programme also expressed their endorsement, noting that the classroom visits by scientists ignited students' interest in science. Notably, the intervention proved particularly beneficial for schools in less affluent areas, indicating that it positively impacted students who may have had fewer opportunities for exposure to science and neuroscience.

2.11.4 Summary

Numerous investigations have determined that employing educational neuroscience techniques and strategies yields more favourable outcomes in enhancing students' academic performance than traditional methods in science courses. Arbabisarjou et al. (2016) and Mirza and Khurshid (2020) reported a lack of evidence linking performance to learning styles.

The results of studies showed that implementing a programme centred on neuro-education and learning strategies directly and positively influenced student motivation.

The incorporation of brain awareness presentations effectively promoted growth mindsets and cultivated positive attitudes towards science among students.

In science classes, it was discovered that brain-based learning strategies and approaches seem more effective than conventional ones at raising students' academic achievement. A brain-based, learning-focused curriculum directly and favourably improved student motivation. According to the literature, brain-based learning benefitted schools in less affluent areas since it affected the mindsets of students who may not have had as much exposure to science and neuroscience.

Therefore, this research suggests that such learning should be appropriately and consistently incorporated into science lessons.

In the following section, neuromyths and possible misconceptions are discussed.

2.12 NEUROMYTHS

The word “neuromyth” combines neuro (cells associated with the nervous system) and myth (a widely held, but false belief or idea) (Dekker et al., 2012). According to a neurosurgeon, neuromyths are misconceptions, misinterpretations or errors of facts that have been scientifically proven to encourage the use of brain knowledge in education (Torrijos-Muelas et al., 2021). According to Betts et al. (2019), a neuromyth is a misconception about brain function.

Recent studies have highlighted the widespread prevalence and persistence of neuromyths, particularly among those involved in education (Dekker et al., 2012; Düvel et al., 2017; Howard-Jones, 2014).

The Welcome Trust conducted the most comprehensive study on neuromyths among 1 200 lecturers in the UK (Simmonds, 2014). According to Simmonds (2014), 76% of lecturers use the learning style neuromyth in their practice, similar to the findings of Dekker et al. (2012). The left-right brain learning neuromyth was the most commonly endorsed notion, with 18% of lecturers reporting that it is practised in their classrooms (Simmonds, 2014).

The following section contains further details on the origins of neuromyths.

The learning style theory

A learning style theory hypothesis tries to classify and define how people like to learn and process information. It suggests that people have unique learning styles or preferences that influence acquiring and understanding new knowledge. This paper will discuss a few of these.

In the 1990s, a classroom inspector in New Zealand, Neil Fleming, launched the concept of “learning styles”, arguing that different students excelled more in school if they used their preferred learning modes (Fleming & Mills, 1992). Fleming tried to solve the learning puzzle after observing excellent lecturers who failed to reach some learners and poor lecturers who did. In his observations, a preferred mode of learning held some explanatory power. As a result of Fleming’s model and inventory, Barbe and colleagues (Barbe et al., 1979) created and developed a new notion of sensory modalities (VAK) in 1979. The visual dimension (V) was divided into the visual (V) and texts as reading or writing (R). It is named the “VARK” model (Table 2.13). These dimensions are explained in more detail in section 2.11 on brain-based learning.

Table 2.13: VARK learning styles with examples (Mirza & Khurshid, 2020)

Learning styles	Non-technical example	Technical examples
V (Visual)	Charts, graphs, symbolic figures, maps, pictorial representations, posters	Videos, spreadsheets, data visualisers, mind maps
A (Aural/auditive)	Lectures, group discussions, self-talk and talking out, interviews, stories, discussion topics, ideas	Radio, webinars
R (Reading/writing)	Text-based input: books, notes, quotations, lists, diaries, journals, reflections, essays, manuals	PowerPoint presentations, research articles, blogs, e-news
K (Kinaesthetic)	Working on a project, practical demonstrations, case studies, performance, role-playing	Programming, computer-aided design

Fleming and Mills (1992) concluded that individuals use four different channels for receiving and processing information using this technique. Depending on the type of presentation, some students learn better. Fleming believed that changing an individual's learning preferences was nearly impossible. For example, for students who claim to be visual learners, lecturers should determine their students' preferred learning styles and provide new material that suits their preferences.

Critique of the learning style model

Each of us prefers several things that others do not, be it food, music or learning styles. According to Kirschner (2017), the concept of learning styles has several flaws.

- A significant disparity exists between a person's preferred learning style and what promotes effective and efficient learning.
- A preference for how one learns does not depend on one's preferred learning method, but on the type of person one is, as differentiated according to different social categories.
- The use of learning styles has no valid scientific basis.

The learning style theory of Fleming requires lecturers to place students into four boxes, although the way they learn best may differ from project to project (Kirschner, 2017).

The learning style neuromyth

Neuromyths are perceived as misunderstandings, misreading, and misquotations of scientific facts to investigate the importance of brain knowledge (OECD, 2002).

In most cases, neuromyths are only based on some degree of truth, with no scientific evidence for their validity available (Dekker et al., 2012; Grospietsch & Mayer, 2018; Newton, 2015; Rohrer & Pashler, 2012). Recent studies have debunked the assumption that people retain information more effectively when it is presented to them in their preferred learning style (Papadatou-Pastou et al., 2017; Varas-Genestier & Ferreira, 2017; Zhang et al., 2019).

Newton (2015) and Newton and Miah (2017) add to studies that do not support learning styles. Their point is that it may harm the learner. The acknowledged preference can insist on unrealistic expectations for the lecturers to match. They argue that students' learning ability can even be reduced if categorising or biasing them to pursue a career.

The significant problem is that students are subjected to simplistic techniques that do not help them learn more effectively (Lawrence et al., 2020). According to a comprehensive study by Willingham et al. (2015), preferences in learning styles do not reflect actual abilities, but only how information is processed. A survey of nearly 400 lecturers, 93% in the UK and 96% in The Netherlands, confirmed these findings. Research in Taiwan has shown that focusing on students' learning styles can encourage them to reflect on their abilities (Hsieh et al., 2011). An Auburn university professor found that teaching concepts to individuals according to their learning styles can enhance information recall (Davis, 2007).

Even though students may have preferences regarding learning, there is no scientific evidence that it will enhance learning. Many scientists found that this popular neuromyth can harm students (Lawrence et al., 2020). Instead, lecturers should meet this requirement by providing information relevant to the content, students' level of knowledge, ability and interests, not learning styles (Riener & Willingham, 2010; Tokuhama-Espinosa, 2014; Whitman & Kelleher, 2016).

Riener and Willingham (2010) argue that prior knowledge is more critical than learning styles. This is confirmed by Tokuhama-Espinosa (2017), who claimed that first-class assessment could significantly be used to test how well students remembered the prerequisite course material.

A study conducted at the University of Indiana in 2018 by Husmann and O'Loughlin (2019) asked hundreds of undergraduate students to complete one of the most popular online learning surveys, the VARK. Their study found that a subject-oriented teaching style was more important than focusing on student learning styles. To determine if the students used methods following their dominant learning style, the researchers surveyed them later in the term about how they studied outside of class. According to Husmann and O'Loughlin (2019), the researchers examined students' end-of-year grades to discover if there was an association between grades and dominant learning styles and/or studying outside of class in a way consistent with dominant learning styles. Based on these results, student performance was not significantly correlated with their dominant chosen learning style(s).

Furthermore, 67% of the students failed to study according to their preferred learning style. No significant difference in grades could be found. Husmann and O'Loughlin (2019) said that categorised learning styles could "stress lecturers and crutch students". They referred to learning preferences rather than learning styles. More accessibility is not always better to learn something new. Getting things in a preferred style may not be challenging to process and understand. We must refocus the conversation on how people learn and not put them into boxes (Husmann & O'Loughlin, 2019).

One of the reasons many people think learning styles are so convincing is that they already believe them to be valid. If students feel like visual learners, they start living in that way (Riener & Willingham, 2010). Several studies on education and learning conducted by scientists have established that matching instruction to the specific learning style of a particular student is not as simple as it seems (Lawrence et al., 2020). Although everyone is unique, the best way to learn is by the nature of the curriculum and not by individual preferences (Lawrence et al., 2020).

Although many evidence-based teaching models improve learning, learning styles are not such a model. It makes learning worse. It gives lecturers unnecessary things to worry about, making some students reluctant to engage with certain types of instruction (Willingham et al., 2015). The money and time spent on learning styles could be better used on scientifically proven interventions. Leaners are not visual, auditory, reading/writing or kinaesthetic, but all these in one (Whitman & Kelleher, 2016).

Tokuhama-Espinosa (2018) listed neuromyths in categories in her book "Debunking neuromyths" (Table 2.14).

Table 2.14: Neuromyths listed in categories

Category	Neuromyth
Intelligence	Intelligence is fixed at birth and cannot be modified. Mental capacity is inherited and cannot be affected by environment or experience.
Brain architecture	The average person only uses 10% of their brain. While some people are more "right" brained, others are more "left" brained. Brain sections function independently of one another. Your brain will shrink if you do not consume six to eight glasses of water daily. Our brain records and stores everything we perceive, similar to the way a video camera does. Using drugs damages your brain.
Teaching and learning	The information delivered to people in their preferred learning styles improves learning. Neuroscience research supports the theory of multiple intelligences. "Drill and kill" encourages education. High-stakes exams are a reliable indicator of a student's knowledge.
Development and the environment	Humans have a "blank slate" at birth, and they will learn if knowledge is given. By age three, the brain has developed to its full potential. Playing violent video games has little impact on behaviour. Internet use can make you more intelligent or stupid. Pre-school-aged children's brains require additional stimulation. The learner's past does not affect their ability to learn. Differences in brain function that arise from developmental inequities cannot be resolved by education alone. Variances in brain function related to developmental variances in individuals are not their fault. Teenagers lack maturity and "act out" because the pre-frontal brain does not fully develop until their mid-20s.
Brain activity	People can multitask; however, women are better at it than men. Your brain shuts down while you are sleeping. Those who are considered "brain dead" can still be awake.
Brain plasticity	Only at specific "critical periods" is the brain plastic for particular types of information. Neurons cannot be replaced because new brain cells cannot be created. Brain injury is invariably irreversible. Learning is optimised by neurogenesis. Sound pedagogy contributes to neural plasticity. New brain cells were generated by learning.

Category	Neuromyth
Memory	Memory is like a factual recording of an event; everyone abstractly perceives reality. The amount of memory in the brain is infinite. Memorisation is undesirable in contemporary education and not necessary for learning. The brain remembers every event it has ever had; forgetting results from incorrect encoding.
Emotions and learning	The social and emotional context can be separated from learning. Emotion and feeling can be separated from reasoning and decision making, which enhances one's ability to think clearly.
Language, bilingualism and multilingualism	Languages are found in the left hemisphere of the brain. Acquiring a second language comes after a child has mastered their mother tongue. Children easily pick up new languages since they are like sponges.

2.12.1 Summary

Neuromyths are incorrect beliefs or misconceptions about how the brain works. Popular culture, educational methods or well-meaning teachers frequently spread it. Neuromyths can be problematic because they can result in inadequate teaching strategies, misconceptions about brain development, and poor educational practices. When making decisions regarding teaching and learning, it is critical for parents, educators and the general public to be informed about these fallacies and rely on practices and studies that are supported by the available evidence.

2.13 SUMMARY OF CHAPTER 2

In this chapter, a thorough exploration of prior research was conducted to address the research questions, with a specific focus on education and science education. The examination involved a detailed analysis of various factors such as science performance, mindset, motivation, technologies, pedagogies and brain-based learning. Consequently, the integration of technology and aspects of brain-based learning was undertaken to ascertain their impact on performance, mindset and motivation within the realm of science education. The primary objective of this research was to present a comprehensive overview of the current state of knowledge in these domains and identify areas that necessitate further investigation.

The literature review aimed to provide critical insights and pinpoint gaps in the existing body of knowledge pertaining to education and science education. The following chapter discusses teaching and learning frameworks used in science education.

CHAPTER 3: TEACHING AND LEARNING FRAMEWORKS USED IN SCIENCE EDUCATION

3.1 INTRODUCTION

This chapter examines existing teaching and learning frameworks to draw upon in developing the TBBaSK Framework. Frameworks for teaching and learning help lecturers integrate assessment into lessons, align learning goals with classroom activities, and create a comprehensive classroom atmosphere (Hwang et al., 2012).

The Substitution, Augmentation, Modification, Redefinition (SAMR), Universal Design for Learning (UDL), Triple E and Technological Pedagogical Content Knowledge (TPACK) frameworks with variations used in science education are discussed below.

3.2 FRAMEWORKS USED IN SCIENCE EDUCATION

Research papers and articles addressing the implementation and efficacy of science education frameworks that incorporate technology were examined. Google Scholar facilitated access to relevant literature, contributing to a more thorough topic comprehension. The following section covers discussions on several of these frameworks.

3.2.1 Substitution, Augmentation, Modification, Redefinition Framework

Educators and instructional designers often use the SAMR model developed by Puentedura (2010) to guide technology integration in the classroom. The idea is to aim for higher levels of technology integration, moving from substitution to redefinition, to promote more meaningful and impactful learning experiences.

As shown in Figure 3.1, the SAMR Framework evaluates technology integration from various angles. Educators need to be motivated to use the top two classroom applications (redefinition and modification), according to Drugova et al. (2021). Although using technology may save lecturers time, it alone is not a compelling incentive.

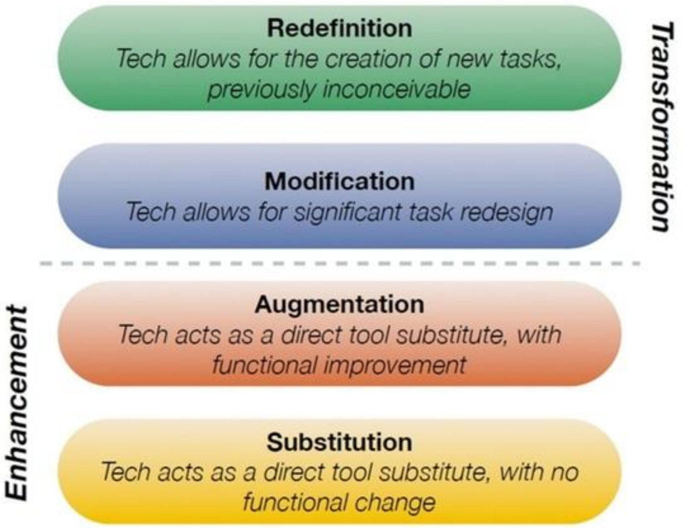


Figure 3.1: The SAMR Framework (Puentedura, 2010)

Puentedura (2010) explains the levels of the framework as follows:

- **Substitution:** Without making any major changes to the task, technology is utilised as a direct replacement for a non-technological task.
- **Augmentation:** Technology is used to enhance a non-technological task, such as adding multimedia elements to a presentation or providing instant feedback to students.
- **Modification:** Technology is used to significantly redesign a task, allowing for new possibilities that were not previously possible without the technology.
- **Redefinition:** Technology creates previously impossible and entirely new tasks, such as collaborating with peers worldwide or creating virtual simulations.

The SAMR Framework in science education

An education framework based on the SAMR approach was developed by Tsybulsky and Levin (2016). They established their conceptual framework on examining and assessing lecturers' worldviews about technology and its role in education, and examining and analysing the integration of information and communication technology (ICT) in science education. Their newly proposed matrix model, which represents the ontology of ICT integration in education, was used to map lecturers' worldviews during a particular teacher training course. Several lecturers reached the most advanced level of technology understanding, known as the redefinition level.

Flores and Adlaon (2022) examined science instructors' use of ICT using the SAMR Framework. Their findings show that the SAMR Framework's augmentation level, or second stage, makes precise use of ICT by science instructors. Science teachers substituted more functional technology for conventional tools. ICTs are now in the improvement stage; however, Flores and Adlaon (2022) suggested they need to be upgraded to the redefinition level to improve students' learning. They added that the level of education and experience of scientific lecturers affects their capacity to integrate ICT into science instruction. The curriculum, grade level and school influence their opinions.

3.2.2 The Universal Design for Learning Framework

The UDL educational framework was created by Rose and Meyer (2002) based on learning and cognitive neuroscience research (Figure 3.2). Using the UDL paradigm, educational curricula and teaching may be created that are effective for all students, including those with disabilities and various learning requirements.

There is no one "right" way to teach, learn or display knowledge, according to the UDL paradigm. Instead, the paradigm prioritises providing a range of representational, expressive and participation modes to aid all learners. In practical terms, this means that UDL encourages educators to do the following:

- Provide multiple ways of presenting information through text, images, videos and audio.
- Offer multiple ways for students to express their knowledge, such as writing, speaking, creating videos or drawing.
- Create various opportunities for students to participate in the topic, such as interactive exercises, group projects or games.

The UDL Framework strives to increase the accessibility and effectiveness of education for all students, regardless of their skills, backgrounds or learning preferences, by providing various learning options.

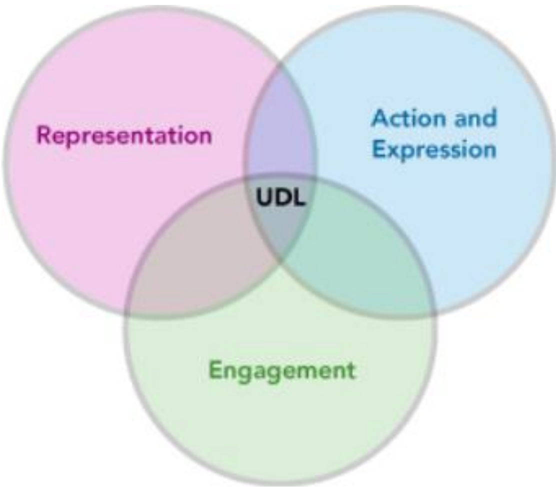


Figure 3.2: The UDL Framework (Rose & Meyer, 2002)

To eliminate any obstacles to learning, the UDL Framework employs a variety of instructional strategies. Flexibility must be built in while considering each learner's requirements and skills. The UDL Framework is thus advantageous to all learners. The curriculum comprises the following elements:

- **Engagement** of learners who are motivated and purposeful to stimulate interest and motivation.
- **Representation** of information and content in a variety of ways.
- **Differentiating** students' expressions to allow them to express themselves and take action.

The UDL Framework in science education

Kurtts et al. (2009) applied the UDL Framework in a Physical Science lesson on solutions. This tool was created to make it simpler for students with learning disabilities to comprehend the important ideas covered in class. Students with disabilities may find it challenging to comprehend science material in science classrooms nationwide because of their slow reading pace and an inability to understand writing. The instructors organise classroom instruction to ensure that all students can access and succeed with the curriculum. According to Kurtts et al. (2009), children with impairments might gain the most from the UDL Framework in science instruction.

A study by Miller and Lang (2016) demonstrates how universal design for learning concepts can be used in scientific labs to help students under stress due to the demanding nature of the labs. They discovered that the UDL approach focuses on four elements in the lab: open-mindedness, encouraging communication, curriculum analysis and adaptation. A strategy for encouraging all students – including those with mental health issues – to benefit from laboratory experiences was created based on the research's findings. It is possible to reduce stressful situations in the lab by using a supportive communication style and a lab curriculum that has been examined and modified to enhance involvement, delivery and assessment. A lab instructor's encouraging attitude might be very helpful to the students. The UDL philosophy aims to maximise learning and engagement for all students with different learning styles and requirements.

3.2.3 The Triple E Framework

The Triple E practical framework was developed by Kolb (2011) as a valuable resource for assessing the success of technology integration in the classroom. It offers a simple framework for determining the advantages and potential disadvantages of various technological tools and methodologies. Figure 3.3 depicts the Triple E Framework.

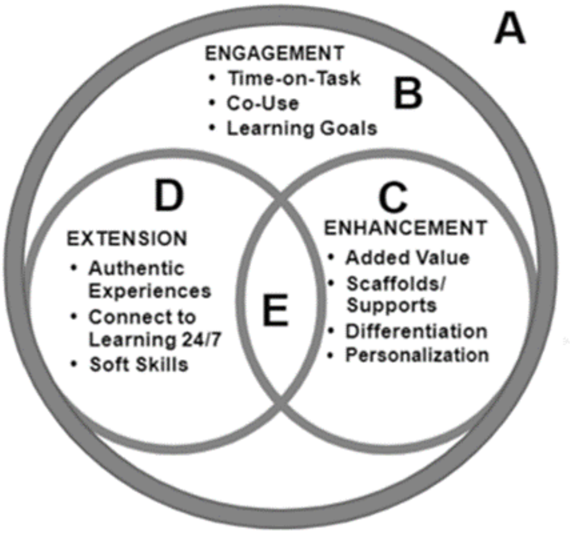


Figure 3.3: The Triple E Framework (Kolb, 2011)

The Triple E Framework is a model for evaluating technology use in education. The framework consists of three components, each of which begins with the letter "E":

- **Engage:** The first "E" focuses on how technology can engage and motivate students in their learning. This involves using technology to make learning more interactive, immersive and personalised. Employing technology includes virtual field trips, game-based learning and social media tools.
- **Enhance:** The second "E" concerns how technology can improve education by giving students access to more resources and chances for practice and feedback. This entails leveraging technology to provide students with access to educational materials whenever and wherever they want and to extend learning outside the classroom. Digital textbooks, instructional apps and online tutorials are examples of improving technology.
- **Extend:** The third "E" focuses on how technology may broaden learning by letting students employ their skills and knowledge in fresh, real-world situations. This involves using technology to connect students with real-world problems and challenges, allowing them to use their learning to make a difference in their communities. Examples

of extending technology include online collaboration tools, community service projects and digital portfolios.

The Triple E Framework in science education

The Triple E Framework can be applied to science education in various ways (Kolb, 2020).

Engage: By offering immersive and interactive experiences, technology can help students become more interested in learning about science. For example, virtual and augmented reality tools allow students to explore scientific concepts and phenomena more engagingly and memorably. Online simulations and games can also engage students in scientific inquiry and experimentation.

Enhance: Technology can enhance science learning by giving students additional resources and opportunities for practice and feedback. For example, online science labs and virtual dissection tools can allow students to explore scientific concepts and practice lab skills in a safe and controlled environment. Digital textbooks and educational videos can give students additional explanations and examples to help them understand complex scientific concepts.

Extend: Enabling students to apply their learning in real-world circumstances, technology can be used to enhance science education. Citizen science projects, for example, can allow students to participate in scientific research and contribute to scientific knowledge. Online collaboration tools can enable students to connect with scientists and experts in different fields, providing them with opportunities to learn from and work with professionals.

Middle school students researched hurricanes together in groups of four and created plans to stop them from wreaking havoc (Kolb, 2020). Students anticipate where the hurricane will land using software, websites for internet searches and Microsoft Excel. This lesson covers all three levels of the Triple E Framework. Technology enables students to concentrate (engage) on tasks or activities without interruptions, to demonstrate their knowledge of the learning objectives (enhance) and to extend their capacity to improve as learners over time.

Pratama (2022) studied 14 high school lecturers to determine their association between technology level and using the Triple E Framework as the primary tool. Students perform better and are more engaged with connected lecturers. Even though students only spent a short time utilising technology in the classroom, they appeared to pay attention to its use.

3.2.4 The Technological Pedagogical Content Knowledge Framework

The 1980s work of Shulman (1986) is the foundation for the TPACK Framework. It is a theoretical framework that can act as a compass for educators, curriculum designers and teachers as they consider how and when to incorporate technology into successful teaching and learning. This paradigm can also be used to direct research on the use of technology in education. It is an adaptable model that may be used in many educational settings and at different grade levels.

Research suggests that professional development initiatives to enhance teachers' TPACK knowledge and abilities may favour using technology in the classroom and student learning outcomes. Ertmer et al. (2012) did a meta-analysis using data from 15 studies. They found that TPACK-focused professional development programmes significantly improved teachers' technology integration skills and students' learning outcomes. Other studies have also found positive impacts of TPACK-focused professional development on teacher attitudes towards technology, classroom practices and student engagement (Koh et al., 2010; Thompson et al., 2013). These findings suggest that TPACK-focused professional development programmes can effectively support teachers using technology to enhance student learning in various subject areas.

TPACK brings a very different approach to the way education technology is conceptualised. The TPACK Framework identifies three knowledge areas: technological, pedagogical and content knowledge – arranged in a Venn diagram (Figure 3.4). In the early 2000s, Koehler and Mishra (2009) realised that keeping the technological knowledge (TK) component isolated from pedagogical knowledge (PK) and content knowledge (CK) in the TPACK Framework was ineffective. After several revisions, in 2005, they published their well-known framework. The flexibility of the TPACK Framework allows lecturers and curriculum designers to weave these three factors together.

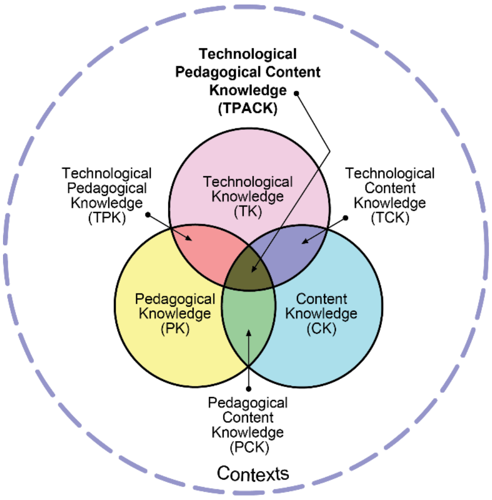


Figure 3.4: The TPACK Framework (Mishra & Koehler, 2006)

Understanding the connection between these diverse knowledge components in different contexts is essential for integrating technology effectively into pedagogy. Mishra and Koehler (2006) argued that it is impossible to find a single combination of content, technology and pedagogy that applies to all lecturers, courses and education views because every situation is unique.

Mishra and Koehler (2006) developed the TPACK Framework as a lens through which lecturers examine the compound challenges modelled by lecturers' pedagogical integration of technology. The elements and characteristics of the framework are established before connections between core components can be discussed.

Technological knowledge is an integral part of the TPACK Framework, which incorporates lecturers' understanding of various technologies. Mishra and Kereluik (2011) warn that these can include conventional and more innovative technologies. To effectively process information, communicate and solve problems, lecturers must understand and master information technology. Mishra and Koehler (2006) observe that lecturers who better understand technological knowledge can successfully use technology at work and home by recognising when technology can either support or delay the accomplishment of a goal.

Lecturers give students subject material based on their content knowledge. Content knowledge is defined as a teacher's knowledge of the subject matter, including the concepts, facts and skills pupils need to learn, according to the observations of Shulman (1986). This includes knowledge of critical concepts, theories and procedures within the field and understanding how this knowledge is organised and connected. The more teachers understand and can communicate their subject matter, the better equipped they will be to help students learn and succeed in their studies (Mishra & Koehler, 2006).

The concluding section of the TPACK Framework is pedagogical knowledge (PK). According to Mishra and Koehler (2006), pedagogical knowledge relates to the understanding of teaching methods. It involves all education issues, classroom management, lesson plan progress, implementation and student evaluation. The purpose of pedagogical knowledge is to understand how to teach (Graham, 2011).

Lecturers' technology integration decisions can be influenced by the three core components of the TPACK model. The three circles represent these three pillars of knowledge (Figure 3.9). Mishra and Koehler (2006) explain the equal importance of considering this framework's intersections (Graham, 2011). A deeper understanding of lecturers' pedagogical integration of technology can be gained after thoroughly examining these intersections and components.

The TPACK Framework begins with pedagogical content knowledge (PCK) as the first connection between pedagogy and content knowledge. Different disciplines are essential in the relationship between pedagogy and content (Mishra and Koehler, 2006). Pedagogical content knowledge refers to teachers' knowledge about how to teach specific content to their students. Pedagogical content knowledge refers to effectively teaching a particular content area, considering students' prior knowledge and misconceptions. This includes organising and scaffolding learning activities, making challenging ideas understandable to students, gauging students' material comprehension and adapting instruction to fit the requirements of different types of students.

Lecturers must understand the impact of technology in applying a specific discipline when evolving technological tools for educational purposes (Mishra and Koehler, 2006). Technological content knowledge (TCK) describes how technology and content impact each other (Graham, 2011). These representations are similarly flexible because technology provides the structure for their flexibility. Thus, education requires more than subject knowledge, and lecturers must know how technology can change the presentation of a subject (Graham, 2011). Teachers who are well-versed in pedagogy know how pupils learn and how technology might support that learning. This requires a broader understanding of how it can be meaningfully integrated into teaching and learning. Effective technology integration requires ongoing knowledge, experimentation and a willingness to collaborate with other teachers and seek new ideas and approaches.

Technological pedagogical knowledge (TPK) involves understanding the technologies used in a teaching and learning context and how those technologies can support particular learning goals and pedagogical approaches (Mishra and Koehler, 2006). Integrating technology effectively into pedagogical practices requires a unique blend of subject matter expertise, technical proficiency and pedagogical knowledge. Technological pedagogical knowledge cannot be acquired quickly, though. It necessitates constant professional growth and a readiness to try novel tools and instructional strategies. The advantages, however, are substantial and include better learning outcomes, higher student motivation and engagement, and more instructional flexibility.

The TPACK Framework seeks to provide a more comprehensive understanding of effective technology integration in education by considering the interdependence of these three fields of knowledge. Technology, pedagogy and content exist in a dynamic equilibrium that must be understood in their intricate interrelationships and appropriate, context-specific techniques and representations (Mishra and Koehler, 2006). The dynamic relationship between technology, pedagogy and subject knowledge in teaching and learning using technology can be better understood by educators and researchers using a framework like the TPACK Framework. Instead of looking at these three elements separately, we can better grasp how they interact to help or obstruct successful teaching and learning by looking at them together.

It is crucial to remember that professional development programmes' conception and execution can differ significantly, and not all initiatives emphasising TPACK are equally successful. According to specific research (Harris & Hofer, 2011; Schmidt et al., 2009), the programme's efficacy can be influenced by its length, rigour and the quality of assistance given to teachers. Consideration must be given to both their design and implementation to improve teachers' knowledge and skills. Unfortunately, there is confusion surrounding the TPACK Framework's many construction limits (Cox, 2008). While definitions have been provided for each construct, there is still some ambiguity around how they interact (Koehler and Mishra, 2009; Mishra and Koehler, 2006). This can make categorising cases that fall between the defined constructs difficult, which can be a barrier to effectively applying the framework in practice.

The TPACK Framework needs more clarification, according to Angeli and Valanides (2009), to properly comprehend the intricate relationships between technology, pedagogy and content knowledge. The framework must be improved and continually developed to ensure that it is based on solid educational ideas (Voogt et al., 2013).

The TPACK Framework may help promote teacher preparation and professional growth. It may be necessary to develop more precise methods for implementing and evaluating the framework to address these challenges and continue refining its theoretical underpinnings to understand the relations between its different components. Further study and improvement may be required to refine the TPACK Framework and provide a more precise understanding of its components and their interactions. This may involve identifying the differences between the elements or expanding the framework to include new elements that may impact how well technology is used in teaching and learning.

Teachers can build exciting and successful learning experiences that support students in comprehending scientific ideas more deeply and enhance learning outcomes by incorporating all three components. The following section will concentrate on science as specific content knowledge, even if the objective is to develop a holistic approach to teaching and learning that integrates content, pedagogy and technology to improve student results.

Radical neuroconstructivism

A recent framework was presented by Tokuhama-Espinosa and Borja (2023) to integrate the "how" and "what" of teaching and learning. This theory is based on radical neuroconstructivism, which stresses how other people's opinions can affect how someone thinks (Figure 3.5). Radical neuroconstructivism recognises the crucial influence of social relationships and interactions on how an individual understands the world.

Within the radical neuroconstructivism framework, the TPACK Framework developed by Mishra and Koehler (2006) is considered. These authors contend that the framework can help promote an all-encompassing approach to education by combining neuroscientific insights into pedagogy and curriculum design.

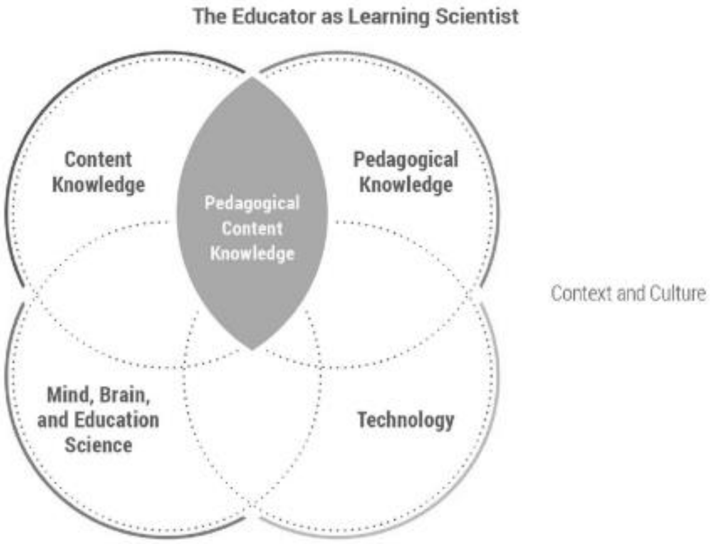


Figure 3.5: Radical neuroconstructivism (Tokuhama-Espinosa & Borja, 2023)

This theoretical framework has not yet been tested.

TPACK in science education

The TPACK Framework can be applied to science education by emphasising the importance of integrating technology in teaching science. The TPACK Framework suggests that effective science teaching with technology requires teachers to have a deep understanding of three types of knowledge: technological knowledge, pedagogical knowledge and content knowledge (knowledge of science).

In their 2015 paper, Sheffield et al. (2015) emphasise the value of TPACK in pre-service teacher preparation. The TPACK Framework provides a helpful lens for examining the interplay between the components and their impact on pre-service teachers' professional development. As a framework, science inquiry offers hands-on experience and helps pre-service teachers understand science concepts (content knowledge) and inquiry processes. Integrating technology (technological knowledge) and pedagogy (pedagogical knowledge) supports the development of the TPACK Framework and prepares pre-service teachers for the classroom. Koehler and Mishra (2009) state that offering authentic learning experiences to integrate technology, pedagogy and content knowledge is crucial in teacher training. Providing them with practical and relevant knowledge can equip them to use this knowledge in their future classrooms.

A study by Niess (2005) emphasised the importance of TPACK in teacher education. The study found that a technology course that offered opportunities for students to design lessons around specific curriculum objectives helped pre-service teachers develop their knowledge of

TPACK. The study's results showed that this approach effectively assisted them in integrating technology, pedagogy and content knowledge in teaching, particularly in Mathematics and Science. The study (Niess, 2011; Niess et al., 2009) also emphasised the collaboration between subject-area lecturers in identifying areas for integration, and discovered that a professional development programme for science teachers focused on TPACK significantly improved teachers' knowledge and skills, and students' learning outcomes.

The research of McCrory (2014) supports the importance of the TPACK Framework in science education. According to the study, effective scientific instruction requires teachers to have a solid grounding in pedagogy and science concepts (content and pedagogical knowledge). Teachers with deep knowledge of student learning and effective teaching strategies can address students' specific needs and design well-planned lessons. The study emphasised the need for lecturers to integrate technology (technological knowledge) meaningfully and purposefully. Technology should enhance student learning, support multiple learning styles, and provide collaboration and critical thinking opportunities. The TPACK Framework emphasises the importance of considering how technology, pedagogy and content knowledge are interconnected with technology to learn effectively. It highlights the idea that simply understanding technology or content is not enough. It must be combined with pedagogical knowledge to be effectively used in the classroom. The TPACK Framework helps science lecturers understand the complex relationships between these three areas of expertise and how they can use technology to support student learning in meaningful and impactful ways.

Chang et al. (2014) found that the technological, pedagogical and content knowledge of secondary science teachers in Taiwan and in the Shaanxi Province in China varied significantly. In Taiwan, the results showed that using different types of ICT (technological knowledge) was a significant factor in determining the technological, pedagogical and content knowledge of science teachers. Teachers who used multimedia showed the essential differences in technological, pedagogical and content knowledge based on gender and teaching experience. In Shaanxi, the results showed that using PowerPoint (the most used ICT) did not significantly impact technological, pedagogical and content knowledge by gender. However, it showed significant differences based on teaching experience (pedagogical knowledge). These findings suggest that cultural and regional differences affect the type of ICT science lecturers use. These results emphasise the importance of considering different types of ICT and the need to understand cultural and regional differences. Thus, science lecturers can be better prepared by teacher preparation programmes to include technology, pedagogy and topic knowledge in their instruction to improve student learning.

A study by Hechter (2012) found that teachers' perceptions of training to use technology in the class changed significantly due to their participation in a science methods course. This transformation in the pre-service teachers' pedagogical perceptions demonstrates the importance of designing teacher education programmes that explicitly address the TPACK Framework and its principles. According to research, incorporating technology into the classroom can increase student motivation and engagement, enhance their problem-solving and critical thinking abilities, and encourage the growth of 21st-century skills like teamwork and communication. The study emphasises the importance of providing science methods courses (content knowledge) that specifically cover the tenets of the TPACK Framework. The TPACK Framework aids pre-service teachers in comprehending the connections between technological, pedagogical and subject-matter expertise, and how they might collaborate to design productive learning environments for students.

A study by Trautmann and MaKinster (2010) emphasises the importance of professional development courses on technological, pedagogical and content knowledge. Case studies showed that, by enhancing teachers' technological literacy and helping them integrate their technological knowledge with their pedagogical and content knowledge, they could effectively use the TPACK Framework in their teaching practices. The results showed that the teachers became more confident in their technological capabilities and sought to integrate geospatial technology in science into a broader range of topics throughout the school year. This illustrates the potential for professional development programmes focusing on the TPACK Framework to significantly impact lecturers' capacity to effectively incorporate technology into their teaching methods.

Jimoyiannis (2010) states that the TPACK Framework can help direct professional development. To assist science teachers to successfully incorporating ICT into their teaching practices for science education, he created a TPACK Framework. The framework emphasises the significance of considering the unique knowledge and abilities that science teachers require to incorporate technology into science teaching effectively. The rationale behind the creation of the Technological Pedagogical Science Knowledge (TPASK) Framework is that science teachers need a particular type of knowledge distinct from that of disciplinary specialists, technological experts and general pedagogical knowledge.

Teachers of science must be able to bridge the gap between their knowledge of science topics and their use of technology in the classroom.

He emphasised how using technology may help students prepare for the challenges of the contemporary workforce, where the ability to solve problems and think critically is highly prized. Students can acquire the knowledge and mindset necessary to thrive in the 21st-century industry by using technology to solve issues and develop new solutions. Science teachers can build a strategy to increase their knowledge and skills in integrating technology into science instruction using the TPASK Framework, which offers a structure for doing so (Jimoyiannis, 2010) (Figure 3.6).

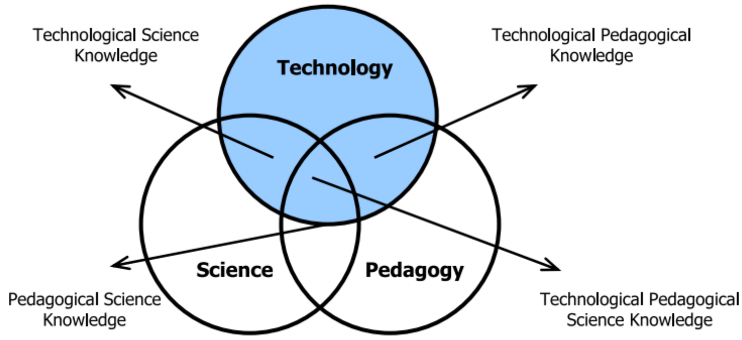


Figure 3.6: The TPASK Framework (Jimoyiannis, 2010)

A study by Mugot and Fajardo (2021) emphasises the significance of the TPASK Framework in science education and its influence on science lecturers' instructional strategies. The study results found that, although science lecturers have a good understanding of science knowledge and pedagogy, their competence in using technology for teaching science is relatively low. The study emphasises the importance of integrating technology, pedagogy and science knowledge rather than solely on the technology itself. By developing the TPASK Framework, science lecturers can better align their teaching practices with their students' learning needs and improve their ability to use technology to support science education.

To assist pre-service Chemistry teachers in developing their technological science knowledge and technological, pedagogical and science knowledge abilities, Rodríguez-Becerra et al. (2020) created a learning module using the TPASK Framework and educational computational chemistry technologies. The study's findings showed that Chemistry teachers appreciated being trained to integrate technology and pedagogy in the instructional module and thought it supported their knowledge acquisition (science knowledge). This emphasises the value of including technology in science teacher education programmes so that graduates may more effectively use technology in their classrooms and promote student learning.

Thohir et al. (2022) claim that technological pedagogical content knowledge is a talent that pre-service science teachers must have in the 21st century of education. They found that using technology to improve teachers' practice is seriously understudied in Indonesia. Therefore, this study aimed to determine how well-equipped pre-service teachers were to integrate technology into science classes. For their investigation, 30 scientists participated in three Delphi method rounds. The results showed that four dimensions of the TPACK Framework – knowledge, skill, character and meta-learning – were supported by the agreement of the experts. These findings conclude that the Four Dimensions of TPACK (4D-TPACK) Framework must be used by the institution that teaches scientific professors to use technology (Figure 3.7).

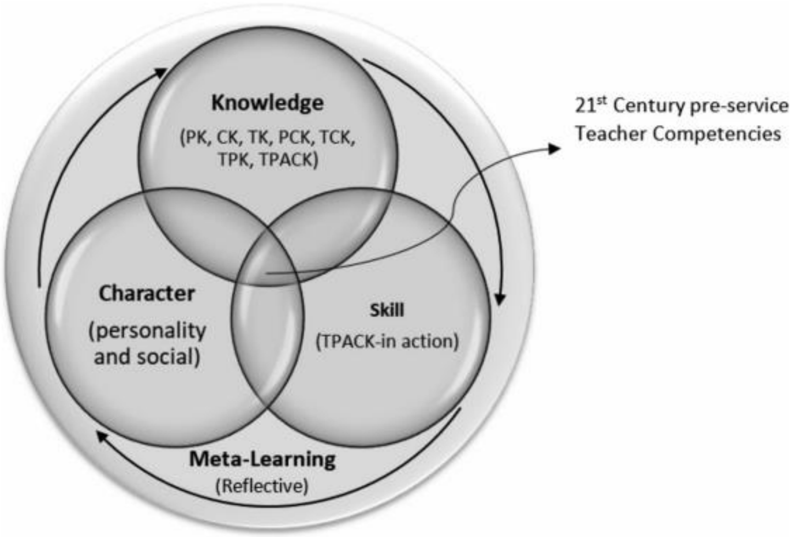


Figure 3.7: The 4D-TPACK Framework (Thohir et al., 2022)

Thohir et al. (2022) provided the consensus on domain competencies and indicator items from their Delphi research in Table 3.1. This table is adapted later in the study in section 3.3.

Table 3.1: Domain competencies and indicator item consensus (Thohir et al., 2022)

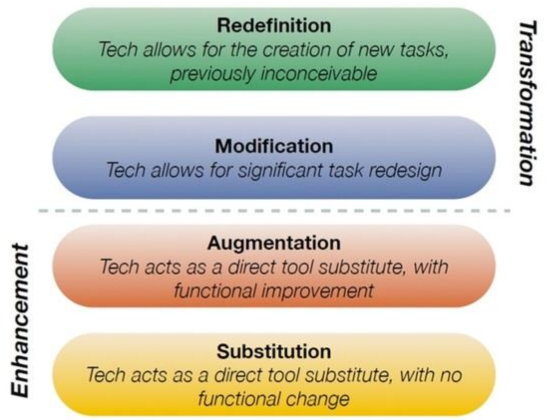
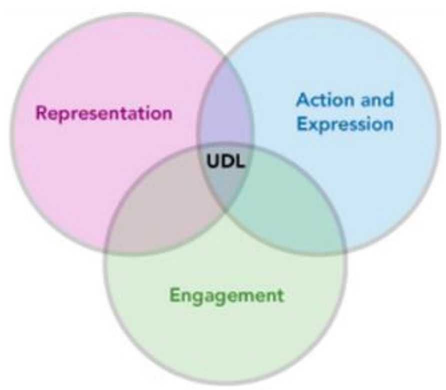
Competencies	75% or more experts' agreement
General pedagogical knowledge	Knowledge of student characteristics in cognitive, social, socio-emotional, economy and culture Knowledge of curriculum development Theory of learning knowledge Models of teaching and learning knowledge Knowledge of teaching management in the classroom Knowledge of procedure assessment
Content knowledge	Content knowledge of science in specific Physics, Chemistry and Biology courses Integrating science knowledge into any part of the curriculum
Technological knowledge	Knowledge of general technology Knowledge of specific technology in using, accepting, adapting and exploring, and advancing this knowledge
Pedagogical content knowledge	Knowledge of student difficulty and misconception of science content Knowledge of selecting the appropriate learning strategy with science knowledge Structuring science learning material with the curriculum
Technological content knowledge	Knowledge of using, accepting, adapting, exploring and advancing technology in learning science material
Technological pedagogical knowledge	Knowledge of using, accepting, adapting, exploring and advancing technology in student management Knowledge of using, accepting, adapting, exploring and advancing technology to select the appropriate learning strategy Knowledge of using, accepting, adapting, exploring and advancing technology to evaluate learning
Technological pedagogical content knowledge	Knowledge of using, accepting, adapting, exploring and advancing technology to facilitate science learning and remediate misconception Integrating a specific technology and learning strategy to facilitate science learning
Character	Self-efficacy Personality Social collaboration in the whole school and science community
Skills	Skills in specific technology Communication skills Skills in planning, design, implementation and assessment
Reflection	Self-regulated learning Less than 75% of experts' agreement
General pedagogical knowledge	Knowledge of pedagogical courses (e.g. psychological education, social education, history of education and philosophy of education knowledge)

Competencies	75% or more experts' agreement
Technological content knowledge	Finding out what is right and wrong with scientific statements from the internet
Technological pedagogical content knowledge	Arrange classes during technological-based science learning Adapt the preferred technology to design science learning material Expert recommends removing
Technological pedagogical knowledge	Designing the preferred technology
Technological content knowledge	Technology is preferred in understanding concepts and science material structures, and applying them

3.2.5 Summary of science teaching and learning frameworks

A summary of the technology educational frameworks discussed above that are used in science education is given in Table 3.2. In the following section, the development of the proposed framework is discussed.

Table 3.2: Summary of some of the existing frameworks

Substitution, Augmentation, Modification, Redefinition (SAMR) Framework The SAMR Framework examines the integration of technology from multiple perspectives, from a simple substitution at the lowest level to more transformative uses of technology at the highest level (Hilton, 2016).	 *The SAMR Framework (Puentedura, 2010)*
Universal Design for Learning (UDL) Framework A foundational educational model based on the evidence that students deserve an education that ensures that they are purposeful, motivated, practical, informed, planned and goal-directed (Rose & Meyer, 2002).	 *The UDL Framework (Rose & Meyer, 2006)*

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Triple-E Framework

This framework evaluates whether and how incorporating technology into lessons enables students to participate in, improve and extend their learning (Kolb, 2011).

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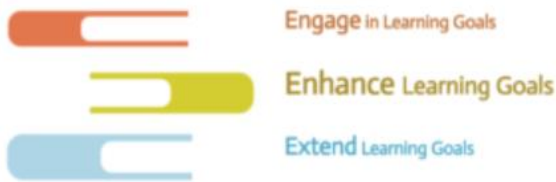

The Triple-E Framework (Kolb, 2011)

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Technological, Pedagogical Content Knowledge (TPACK) Framework

The TPACK Framework allows lecturers and students to understand how educational technology, teaching practices and learning outcomes intersect with context (Koehler et al., 2013).

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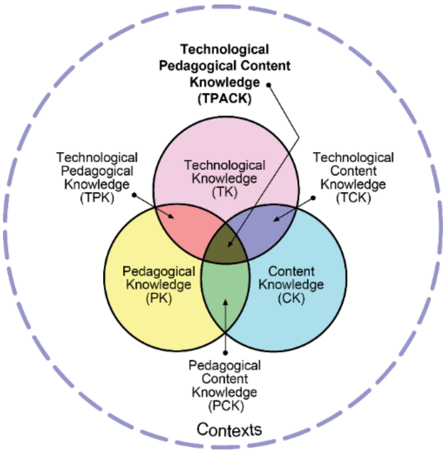

The TPACK Framework (Mishra & Koehler, 2006)

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Four dimensions of TPACK (4D-TPACK) Framework

Teachers' skills, character and meta-learning are added to TPACK dimensions (Thohir et al., 2022).

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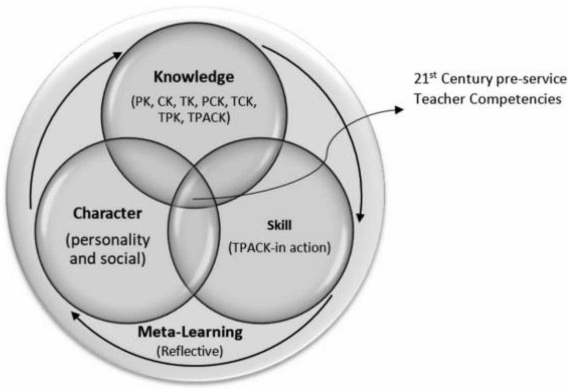

The 4D-TPACK Framework (Thohir et al., 2022)

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3.3 THE TBBaSK FRAMEWORK – ADAPTED FROM THE TPACK FRAMEWORK

In the context of science education in tertiary education, the Technology-enhanced, Brain-based and Science Knowledge (TBBaSK) Framework for science education proposes the design of meaningful learning environments that integrate brain-based learning with technology and science knowledge (Figure 3.8).

While this study drew its foundation from the well-established TPACK Framework, the domain competencies of Thohir et al. (2022) were adapted, as illustrated in Figure 3.7 and detailed in Table 3.3. In their work, Thohir et al. (2022) assert that technological pedagogical content knowledge is an essential skill for pre-service science teachers in 21st-century education. Their research aimed to assess the preparedness of pre-service teachers to integrate technology into science classes. The study's results indicated that the agreement among experts supported four dimensions of the TPACK Framework: knowledge, skill, character and meta-learning. These findings led to the formulation of the Four Dimensions of TPACK (4D-TPACK). The study of Thohir et al. (2022) served as inspiration for the current research, with all TPACK constructs being incorporated into the knowledge component of Figure 3.7.

Figure 3.8 shows the integration of three domains: technology, brain-based learning and science knowledge, and the domains' intersections conceptually.

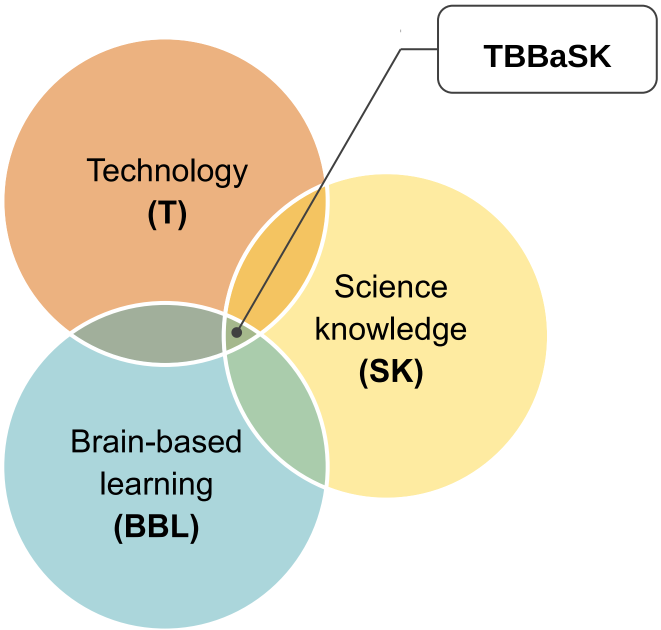

Figure 3.8: The TBBaSK Framework

The domain competencies of the TBBaSK Framework, based on the work of Thohir et al. (2022), are listed in Table 3.3 (section 3.2.4).

Table 3.3: Domain competencies and knowledge needed for the TBBaSK Framework – adapted from Thohir et al. (2022)

The TBBaSK Framework	
Competencies	**Knowledge**
Brain-based learning	Knowledge of student characteristics in the cognitive, social, socio-emotional, economic and culture domains Knowledge of curriculum development Theory of learning knowledge Knowledge of teaching management in the classroom Knowledge of procedure assessment Knowledge and application of brain-based learning principles Application of brain-based learning in the classroom Brain-based learning principles
Science knowledge	Content knowledge of science in specific Physics and Chemistry courses integrating science knowledge
Technological knowledge	Knowledge of general technology Knowledge of specific technology in using, accepting, adapting and exploring, and advancing this knowledge
Brain-based science knowledge	Knowledge of student difficulty and misconception of science content Knowledge of selecting the appropriate learning strategy with science knowledge Structuring science learning materials with the curriculum Knowledge to apply brain-based learning in the science classroom
Technological science knowledge	Knowledge of using, accepting, adapting, exploring and advancing technology in learning science material Knowledge to integrate technology into science
Technological brain-based knowledge	Knowledge of using, accepting, adapting, exploring and advancing technology in student management Knowledge of using, accepting, adapting, exploring and advancing technology to select the appropriate learning strategy Knowledge of using, accepting, adapting, exploring and advancing technology to evaluate learning Knowledge to integrate technology with brain-based learning
Technological brain-based science knowledge	Knowledge of using, accepting, adapting, exploring and advancing technology to facilitate science learning and remediate misconceptions using brain-based learning Integrating specific technology and brain-based learning strategies to facilitate science learning.

After conducting an extensive examination of mind-brain education (MBE) principles, as presented in the work of Tokuhama-Espinosa (2017) (Table 2.6 and Table 2.7), brain-based learning principles, as outlined by Caine et al. (2005) (Table 2.9), and brain-based learning principles, as expressed by Schachl (2013) (Table 2.11), the researcher formulated principles for the present thesis.

These derived principles are documented in Table 3.4, with explicit references to the respective researchers whose work served as a foundation. The numerical values in the last three columns correspond to the specific principle or tenets from tables 2.6 and 2.7, 2.10 and 2.11.

Table 3.4: Brain-based principles for this study[1]

Element (Caine et al., 2005)	**Principle**	**Mind-brain education** (Tokuhama-Espinosa, 2017) Table 2.6 and 2.7	**Brain-based learning** (Caine et al., 2005) Table 2.10	**Brain-based learning** (Schachl, 2013) Table 2.11
Relaxed alertness	1. Learning is developmental and experimental (nature and nurture).	T13	3	
	2. Learning is improved by challenge and inhibited by depression, stress, threats and anxiety.	T3, T4	11	11
	3. Social safety	T9		
	4. Engages entire physiology	T14	2	
	5. Physical activity and nutrition influence learning	T16 and 17		10
	6. Involves breaks in teaching sessions	T10		10
Orchestrated immersion	7. Patterns give meaning.	T10, 15 and 17	4 and 5	
	8. Multisensory approach	T10	1	2
Active processing	9. Learning involves conscious and unconscious processes, sleep.	T12	8	
	10. Neuroplasticity	P5		
	11. Feedback and repetition	T11 and 19		12 and 13
	12. Memory	P6	9 and10	
	13. Attention	P6 and T10	7	8
	14. Prior knowledge	T7		1 and 3

[1] The numerical values in the columns correspond to either T for Tenet, e.g. T13 for Tenet 13, P for Principle, e.g. P5 for Principle 5, or simply the number of the principle in the referenced table.

However, it should be stressed that a teacher's daily planning and organisation of brain-based learning lessons constitutes a time-consuming procedure.

The following section explains the guidelines for implementing these principles in more detail.

3.3.1 Guidelines to implement the TBBaSK Framework

- The framework can be implemented using the domain competencies (Table 3.3). The implementation of brain-based learning elements (Caine et al., 2005) from Table 3.4 for this study is discussed below:

  Relaxed alertness ensures a low threat and high challenge for the brain to achieve optimal learning. Varghese and Pandya (2016) define an environment of relaxed alertness as one in which children have no fear of repercussions, even if they are wrong. It deals with a brain state that is highly challenged, yet free from threats or negative stress, allowing learners to internalise information as best as they can (Saleh & Subramaniam, 2019).

  Orchestrated immersion involves immersing students in the learning environment, which will help them absorb the material more thoroughly than simply through a lecture or book (Varghese & Pandya, 2016). According to Saleh and Subramaniam (2019), orchestrated immersion is a phase of education comprising various teaching and learning activities connected to actual events that create a favourable learning environment.

  Active processing entails analysing situations in various ways (Varghese & Pandya, 2016). It is described as a constant process of strengthening for increased comprehension (Saleh & Subramaniam, 2019).

  Adding mind moves, mindfulness and metacognition can contribute to technological pedagogical content knowledge (Chapter 2.11.3). It applies vital ideas from brain-based learning theory to address the drawbacks of conventional teaching strategies and accomplish learning goals and objectives in the classroom. This study did not incorporate any neuromyths, as indicated in Chapter 2.13.

- As the literature shows that most studies using brain-based learning were performed with secondary school learners, the researcher wants to stress the importance of university application by applying this framework to previously disadvantaged university students.

- It is crucially important for a lesson to be designed and arranged so that each instructional strategy and learning activity is included in distinct, sequential steps that are synchronised with the brain's natural speeds. All brain functions involved in learning are supported and made as practicable by the state, as mentioned above.

Lecturers can choose from the following tables to obtain the necessary skills for a brain-based learning science lecture.

Technology

Knowledge of specific technology in using, accepting, adapting, exploring and advancing science knowledge can be obtained from Table 2.4 in Chapter 2.9. This work is based on the overview provided by Lai and Bower (2019).

Science curriculum

Content knowledge of science as defined by the Faculty.

Brain-based learning elements

Knowledge of student difficulty and misconception of science content, selecting the appropriate learning strategy, structuring science learning materials with the curriculum and knowledge to apply the elements and principles of brain-based learning in the science classroom are discussed in Chapter 2.11.3 (Caine et al., 2005).

Activities

Knowledge of student characteristics in cognitive, social, socio-emotional, economic and cultural domains, the development of the curriculum, theory of learning knowledge, teaching management in the classroom, assessment procedure and application of brain-based learning principles in the classroom are discussed in Chapter 2.11.5 and summarised in Table 2.12.

Figure 3.9 shows the mapping of the TBBaSK components and suggests how such a mapping can be implemented using the curriculum of a BSc Extended Programme in Physical Science (Table 3.5).

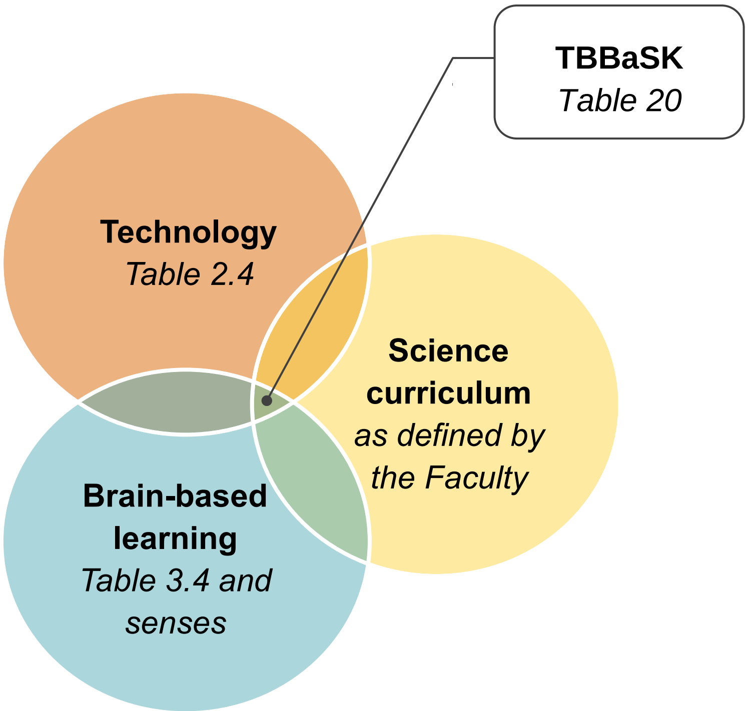

Figure 3.9: Mapping of the TBBaSK Framework

Table 3.5: Mapping suggestions

Science curriculum component https://www.up.ac.za/yearbooks/2021/pdf/programme/02130015		**Brain-based learning** (Table 3.4)	**Technology** (Table 2.4)	**TBBaSK activity** (Table 2.12)	**Senses**
Physics	**Chemistry**				
Mathematical concepts One-dimensional kinematics	Mathematical concepts Atomic theory	Orchestrated immersion	Mobile device: Laptop and data projector Web 2.0: YouTube	Video to explain: Working of the brain and mindset	Auditory Visual
		Relaxed alertness	Mobile device: Laptop and data projector Web 2.0: YouTube	Brain exercise: mindfulness Brain exercise: mind moves	Auditory Visual Kinaesthetic
		Orchestrated immersion	Mobile device: Laptop and data projector, whiteboard Slideshow presentation: PowerPoint Student response system: Quizzes on cell phones Social media: WhatsApp	Slideshow for revision Discussing concepts from slideshow Quizzes with cell phones for encoding WhatsApp recording of lesson for encoding	Auditory Visual Kinaesthetic
		Active processing	Mobile device: Laptop and data projector, whiteboard Learning management system: Any	Multiple-choice questions to revise prior knowledge Brain exercise: feedback	Auditory Visual Kinaesthetic

Science curriculum component https://www.up.ac.za/yearbooks/2021/pdf/programme/02130015		Brain-based learning (Table 3.4)	Technology (Table 2.4)	TBBaSK activity (Table 2.12)	Senses
Physics	**Chemistry**				
Projectile Circular motion Rotation	Bonding and Molecular Geometry	Orchestrated immersion	Mobile device: Laptop and data projector Web 2.0: YouTube	Video to explain: Working of the brain, neuroplasticity	Auditory Visual
		Relaxed alertness	Mobile device: Laptop and data projector Web 2.0: YouTube	Brain exercise: mindfulness Brain exercise: mind moves	Auditory Visual Kinaesthetic
		Orchestrated immersion	Mobile device: Laptop and data projector, whiteboard Animation: PNET simulations Social media: WhatsApp Slideshow presentation: PowerPoint	Video to explain new concepts Discussion of new concepts Put recording on WhatsApp for capturing	Auditory Visual Kinaesthetic
		Active processing	Mobile device: Laptop and data projector, whiteboard Web 2.0: YouTube Learning management system: Any	Revise prior knowledge Examples of new concepts Do problems to capture new knowledge Answer questions individually and give feedback Multiple-choice questions to revise prior knowledge Brain exercise: feedback	Auditory Visual Kinaesthetic

Science curriculum component https://www.up.ac.za/yearbooks/2021/pdf/programme/02130015		Brain-based learning (Table 3.4)	Technology (Table 2.4)	TBBaSK activity (Table 2.12)	Senses
Physics	**Chemistry**				
Newton's laws of motion Work, energy and power	Principles of reactivity	Orchestrated immersion	Mobile device: Laptop and data projector Web 2.0: YouTube	Videos to explain: Working of the brain, threats	Auditory Visual
		Relaxed alertness	Mobile device: Laptop and data projector Web 2.0: YouTube	Brain exercise: mindfulness Brain exercise: mind moves	Auditory Visual Kinaesthetic
		Orchestrated immersion	Mobile device: Laptop and data projector, whiteboard Animation: PNET simulations Social media: WhatsApp Student response system: Kahoot! Virtual and augmented realities	Video to explain new concepts: Discussing concepts shown on video Kahoot! with cell phones for capturing WhatsApp recording of lesson for capturing	Auditory Visual Kinaesthetic
		Active processing	Mobile device: Laptop and data projector, whiteboard Learning management system: Any Slide show presentation: PowerPoint	Revise prior knowledge Examples of new concepts Do problems to capture new knowledge Answer questions individually and give feedback Example on whiteboard and save to web Multiple-choice questions in class and complete online at home	Auditory Visual Kinaesthetic

Science curriculum component https://www.up.ac.za/yearbooks/2021/pdf/programme/02130015		Brain-based learning (Table 3.4)	Technology (Table 2.4)	TBBaSK activity (Table 2.12)	Senses
Physics	**Chemistry**				
Temperature and heat Hydrostatics and dynamics *Used in the intervention of this study*	Rate of reactions	Orchestrated immersion	Mobile device: Laptop and data projector Web 2.0: YouTube	Videos to explain: Working of the brain, sleep/wake cycle	Auditory Visual
		Relaxed alertness	Mobile device: Laptop and data projector Web 2.0: YouTube	Brain exercise: mindfulness Brain exercise: mind moves	Auditory Visual Kinaesthetic
		Orchestrated immersion	Mobile device: Laptop and data projector, whiteboard Animation: PNET simulations Social media: WhatsApp Virtual and augmented realities Student response system: Mentimeter	Video to demonstrate practical Do practical in groups Put recording on the web for capturing Mentimeter with cell phones for capturing	Auditory Visual Kinaesthetic
		Active processing	Mobile device: Laptop and data projector, whiteboard Learning management system: Blackboard Slide show presentation: PowerPoint	Revise prior knowledge Examples of new concepts Do problems to capture new knowledge Answer questions individually and give feedback Example on whiteboard and save to web Multiple-choice questions in class and complete online at home	Auditory Visual Kinaesthetic

Science curriculum component https://www.up.ac.za/yearbooks/2021/pdf/programme/02130015		Brain-based learning (Table 3.4)	Technology (Table 2.4)	TBBaSK activity (Table 2.12)	Senses
Physics	**Chemistry**				
Physical optics	Introduction to Organic Chemistry	Orchestrated immersion	Mobile device: Laptop and data projector Web 2.0: YouTube	Videos to explain: Working of the brain	Auditory Visual
		Relaxed alertness	Mobile device: Laptop and data projector Web 2.0: YouTube	Brain exercise: mindfulness Brain exercise: mind moves	Auditory Visual Kinaesthetic
		Orchestrated immersion	Mobile device: Laptop and data projector, whiteboard Animation: PNET simulations Social media: WhatsApp Student response system: Kahoot!	Video to demonstrate practical Do practicals in groups or demonstrate Discussing concepts shown on video WhatsApp recording of lesson for capturing Kahoot! with cell phones for capturing	Auditory Visual Kinaesthetic
		Active processing	Mobile device: Laptop and data projector, whiteboard Learning management system: Any	Revise prior knowledge Do problems to capture new knowledge Answer questions individually and give feedback Example on whiteboard and save to web Multiple-choice questions in class and complete online at home	Auditory Visual Kinaesthetic

Science curriculum component https://www.up.ac.za/yearbooks/2021/pdf/programme/02130015		Brain-based learning (Table 3.4)	Technology (Table 2.4)	TBBaSK activity (Table 2.12)	Senses
Physics	**Chemistry**				
Revision	Revision	Orchestrated immersion	Mobile device: Laptop and data projector Web 2.0: YouTube	Revise the video of the working of the brain	Auditory Visual Kinaesthetic
		Orchestrated immersion	Mobile device: Laptop and data projector	Play Kahoot! of the brain	Auditory Visual Kinaesthetic
		Orchestrated immersion	Mobile device: Laptop and data projector Web 2.0: YouTube	Revise the importance of multiple senses Play Kahoot! of senses Do brain puzzle	Auditory Visual Kinaesthetic
		Active processing		Assessment of module	Auditory Visual Kinaesthetic

3.3.2 Example of implementation of the TBBaSK Framework

An example of how the TBBaSK Framework can be implemented is demonstrated in Table 3.6.

The brain-based learning principles correlate with the numbers given in Table 3.4.

See Appendix F for details of the intervention.

Table 3.6: Example of implementing the TBBaSK Framework

Example of implementing the TBBaSK Framework					
Curriculum (Fluids)	**Brain-based learning element**	**Brain-based learning principles** (Table 3.4)	**Technology** (Table 2.4)	**TBBaSK activity** (Table 2.12)	**Senses**
Density Pascal Archimedes Bernoulli	Orchestrated immersion	7. Patterns give meaning 8. Multisensory approach	Web 2.0: YouTube Mobile device: Laptop and data projector	Brain knowledge videos on: The influence of threats on the brain Foundational drivers Brain and learning Stress response	Auditory Visual
	Orchestrated immersion	8. Multisensory approach	Mobile device: Laptop and data projector, whiteboard Animation: PNET simulations Social media: WhatsApp	Demonstrate practical experiment	Auditory Visual Kinaesthetic
	Active processing	10. Neuroplasticity 11. Feedback and repetition 12. Memory 13. Attention 14. Prior knowledge	PowerPoint slide show presentation Mobile device: Laptop and data projector	Do experiment (in groups while others are doing exercise)	Auditory Visual Kinaesthetic
	Active processing	10. Neuroplasticity 11. Feedback and repetition 12. Memory 13. Attention 14. Prior knowledge	Mobile device: Laptop and data projector, whiteboard Learning management system: Schoology	Explain new knowledge and do an example	Auditory Visual

Example of implementing the TBBaSK Framework					
Curriculum (Fluids)	**Brain-based learning element**	**Brain-based learning principles** (Table 3.4)	**Technology** (Table 2.4)	**TBBaSK activity** (Table 2.12)	**Senses**
			Slide show presentation: PowerPoint		
	Relaxed alertness	4. Engages entire physiology 5. Physical activity and nutrition influence learning 6. Involve breaks in teaching sessions	Web 2.0: YouTube Mobile device: Laptop and data projector	Brain exercises: Mind moves Leg workout Power on Bilateral walk Temporal toner	Auditory Visual Kinaesthetic
	Active processing	8. Multisensory approach 10. Neuroplasticity 11. Feedback and repetition 12. Memory 13. Attention 14. Prior knowledge	PowerPoint slide show presentation Mobile device: Laptop and data projector	Do experiment (in groups while others are doing exercise to capture new knowledge)	Auditory Visual Kinaesthetic
	Relaxed alertness	2. Learning is improved by challenge and inhibited by depression, stress, threats and anxiety. 4. Engages entire physiology 5. Physical activity and nutrition influence learning	Mobile device: Laptop and data projector Web 2.0: YouTube	Brain exercise: Mindfulness (deep breathing)	Auditory Visual Kinaesthetic

Example of implementing the TBBaSK Framework					
Curriculum (Fluids)	**Brain-based learning element**	**Brain-based learning principles** (Table 3.4)	**Technology** (Table 2.4)	**TBBaSK activity** (Table 2.12)	**Senses**
		6. Involve breaks in teaching sessions			
	Relaxed alertness	4. Engages entire physiology 5. Physical activity and nutrition influence learning 6. Involve breaks in teaching sessions	Web 2.0: YouTube Mobile device: Laptop and data projector	Brain exercises: Mind moves Antennae adjuster Temporal toner	Auditory Visual Kinaesthetic
	Active processing	9. Learning involves conscious and unconscious processes, sleep 10. Neuroplasticity 11. Feedback and repetition 12. Memory 13. Attention 14. Prior knowledge	Mobile device: Laptop and data projector, whiteboard Learning management systems: Blackboard, Schoology Slide show presentation: PowerPoint	Do multiple-choice questions online in class to capture new knowledge, discuss and give feedback	Auditory Visual Kinaesthetic
	Active processing	9. Learning involves conscious and unconscious processes, sleep 10. Neuroplasticity 11. Feedback and repetition	Mobile device: Laptop and data projector, whiteboard Learning management systems: Blackboard, Schoology	Do challenging problems in class, discuss and give feedback	Auditory Visual Kinaesthetic

Example of implementing the TBBaSK Framework					
Curriculum (Fluids)	**Brain-based learning element**	**Brain-based learning principles** (Table 3.4)	**Technology** (Table 2.4)	**TBBaSK activity** (Table 2.12)	**Senses**
		12. Memory 13. Attention 14. Prior knowledge	Slide show presentation: PowerPoint		
	Relaxed alertness	2. Learning is improved by challenge and inhibited by depression, stress, threats and anxiety. 4. Engages entire physiology 5. Physical activity and nutrition influence learning 6. Involve breaks in teaching sessions	Mobile device: Laptop and data projector Student response system: Kahoot!	Brain exercise: Play Kahoot! of Fluids to capture new knowledge	Auditory Visual Kinaesthetic
	Orchestrated immersion	7. Patterns give meaning 8. Multisensory approach	Web 2.0: YouTube Mobile device: Laptop and data projector	Brain knowledge: Explain senses in the brain Video on mindset and neuroplasticity	Auditory Visual
	Orchestrated immersion	7. Patterns give meaning 8. Multisensory approach	Mobile device: Laptop and data projector, whiteboard	Capture new knowledge Put recording lessons on the web for experimental purposes	Auditory Visual

Example of implementing the TBBaSK Framework					
Curriculum (Fluids)	**Brain-based learning element**	**Brain-based learning principles** (Table 3.4)	**Technology** (Table 2.4)	**TBBaSK activity** (Table 2.12)	**Senses**
			Learning management systems: Blackboard, Schoology	Put answers on the web for the control group	
	Relaxed alertness	1. Learning is developmental and experimental (nature and nurture) 2. Learning is improved by challenge and inhibited by depression, stress, threats and anxiety 3. Social safety 4. Engages entire physiology 5. Physical activity and nutrition influence learning 6. Involve breaks in teaching sessions	Mobile device: Laptop and data projector Student response system: Kahoot!	Brain exercise: Kahoot! of the brain to capture new knowledge	Auditory Visual Kinaesthetic
	Orchestrated immersion	7. Patterns give meaning 8. Multisensory approach	Web 2.0: YouTube Mobile device: Laptop and data projector	Video to explain new knowledge	Auditory Visual

Example of implementing the TBBaSK Framework					
Curriculum (Fluids)	**Brain-based learning element**	**Brain-based learning principles** (Table 3.4)	**Technology** (Table 2.4)	**TBBaSK activity** (Table 2.12)	**Senses**
	Orchestrated immersion	7. Patterns give meaning 8. Multisensory approach	Mobile device: Laptop and data projector PowerPoint as a slideshow presentation	Revise senses to capture brain knowledge	Auditory Visual Kinaesthetic
	Active processing	9. Learning involves conscious and unconscious processes, sleep 10. Neuroplasticity 11. Feedback and repetition 12. Memory 13. Attention 14. Prior knowledge	Learning management systems: Blackboard, Schoology Social media: WhatsApp	Extra information	Visual

3.4 SUMMARY

In this chapter, an exploration was conducted of the frameworks employed in the realm of science education. The TBBaSK Framework, derived from the TPACK Framework, was investigated and adapted for the context of this research. Reference was made to the foundational brain-based learning principles that underpinned this theoretical framework. The evolution and creation of the TBBaSK Framework were expounded upon, and the core principles derived from this framework were explained to illustrate the development process. Furthermore, comprehensive guidelines for implementing the TBBaSK Framework were provided, and an illustrative example was included to demonstrate the application of this framework in various subjects and themes.

The research methodology employed is discussed in the following chapter.

CHAPTER 4: RESEARCH METHODOLOGY

This chapter covers the approach and techniques of this study to plan, conduct and analyse the research. It encompasses the methods, processes and tools employed to gather, interpret and draw conclusions from data or information to address the research question. The research design of this study is given in Figure 4.1. The rest of the chapter will explain the design in more detail.

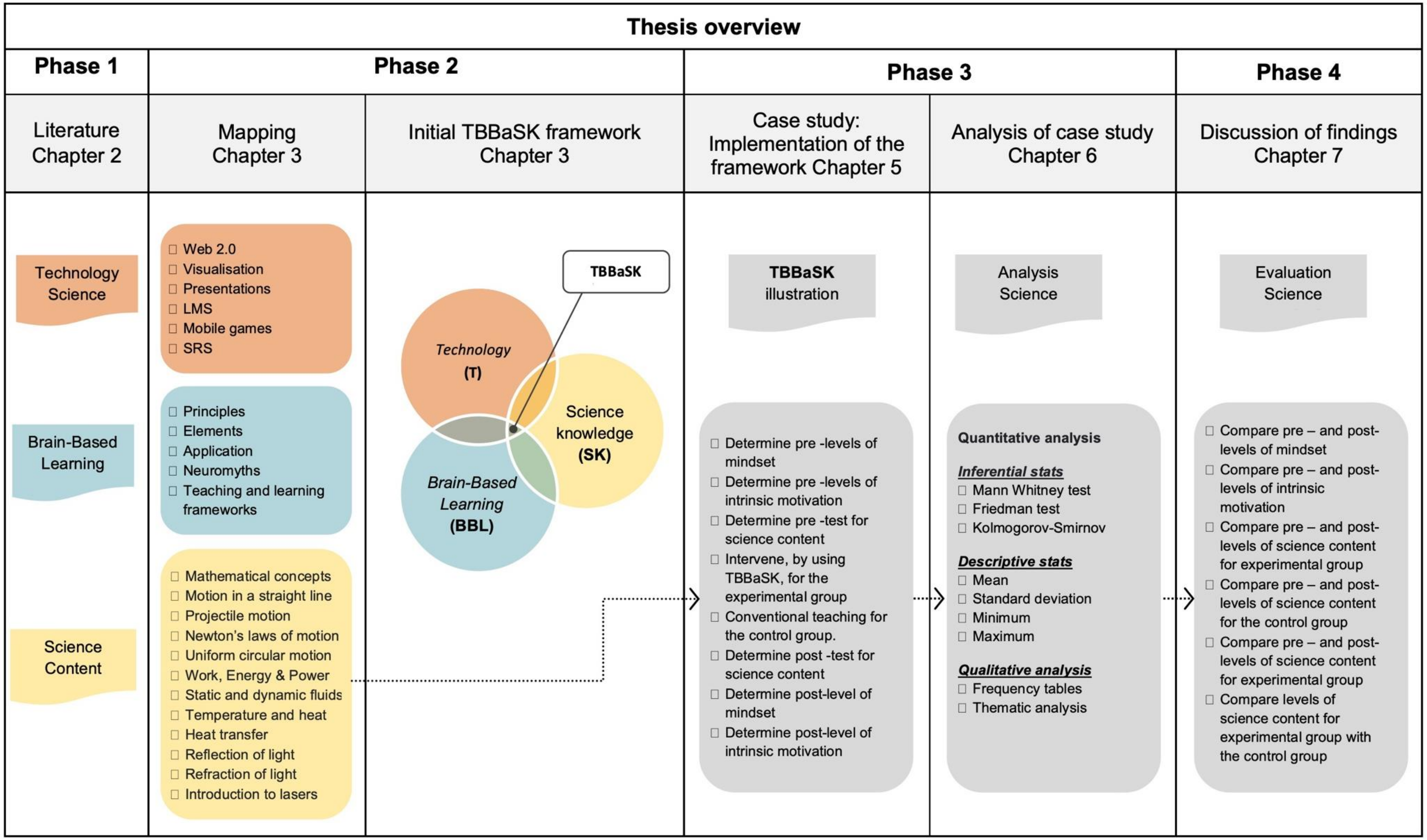

Figure 4.1: Overview of the thesis

4.1 INTRODUCTION

The research plan is the road map that shows how the researcher moved from the beginning to the end of the project. The study's contribution, by developing a brain-based learning framework to enhance students' mindsets, intrinsic motivation and science performance, was considered in Chapter 1. Chapter 2 provided an overview of research of the currently available literature. In Chapter 3, existing science teaching frameworks were discussed, and the TBBaSK Framework was developed. The research design, approach, strategy and scientific rigour of this research study are covered in this current chapter. Ethical considerations are discussed in the final section of the chapter.

Research design is a thorough plan to guarantee that the right tools and methodologies are employed to gather, analyse and interpret the data, and answer the research questions (Creswell, 2009). The study aims to assess what constitutes a science education teaching framework (TBBaSK), focusing on technology and brain-based learning.

4.1.1 Philosophical perspective

As this research uses technology to teach science studies, research practices can be borrowed from the information systems (socio-technical) view (Beynon-Davies, 2009). Research in this field aims to understand human aspects apart from technological aspects. For research in such environments to be successful, these presumptions or belief systems must be stated clearly from the outset. The data collection and analysis techniques needed for a particular study were determined depending on the research paradigm and research question. This allows researchers to choose the most appropriate data collection and analysis method.

Worldviews reflect researchers' understandings of ontology (reality) and epistemology (knowledge) (Morgan, 2007). Epistemological assumptions about knowledge validity are based on these ontological perspectives on the social world. They influence the type of knowledge sought (Cohen et al., 2000). This section defines the paradigms of positivism, interpretivism, critical thinking and pragmatism.

Positivists believe that the nature of reality can be objectively observed and described without interfering with the observed phenomena (Saunders et al., 2012). Collins (2010) defines interpretivism as a philosophical paradigm in which people understand the world based on experience and reflection. In contrast, critical researchers criticise and justify the existing status quo in society and provide alternative information to produce a better social order (Bhattacherjee, 2012).

It has been argued that paradigms are incommensurable, meaning that radically different assumptions regarding reality and knowledge make it impossible to translate and reinterpret research between them (Morgan, 2007). Consequently, researchers who adhere to one paradigm reject other paradigms (Morgan, 2007). However, an argument has been made against the perspectives of these different paradigms. Embracing a singular paradigm could lead to a misrepresented perception of its value in research, leaving such a paradigm incapable of engaging pragmatically with those aspects it cannot address by its nature (Brannen, 2004). Therefore, multiparadigm approaches are based on pragmatism, asserting that researchers should select the philosophical or methodological approach that is most appropriate for their specific topic (Goles & Hirschheim, 2000). Another aspect of pragmatism is that researchers should employ mixed methods to effectively study social and educational issues (Onwuegbuzie et al., 2011). A researcher can gain a deeper understanding of a problem when applying more than one method to a specific phenomenon (Goles & Hirschheim, 2000). Mitchell and Education (2018), echoes this sentiment, concluding that a better answer is obtained when numerical reasoning is combined with cognitive knowledge than when using either approach individually. This study's pragmatic paradigm addresses how students experience the science classroom. The research methods best suited to the research questions were chosen. Structured questionnaires and pre- and post-tests were used to obtain accurate statistics to evaluate. Open questions were used to collect qualitative data.

4.1.2 Research approach

Researchers must make a critical methodological choice between qualitative, quantitative and mixed methods to fit the study's structure and choose the most appropriate way to solve the research problem.

Qualitative research focuses on methods based on multiple meanings of individual experiences to develop a theory or pattern (Bhattacherjee, 2012). A statistical, mathematical or numerical analysis of the survey, poll and questionnaire data is essential to quantitative research. It can also involve manipulating pre-existing statistical data using computational methods (Oates, 2005)**.**

Mixed methods research is sometimes considered a new methodology (Creswell & Creswell, 2005). Mixed methods combine analysis elements of quantitative and qualitative methods. In 1959, Campbell and Fiske (1959) introduced mixed techniques to study the validity of psychological traits (Johnson & Gray, 2010). As a result, the researchers encouraged each other to use their multimethod framework to explore multiple approaches for data collection (Bryman & Cramer, 2012; Green et al., 2007).

In mixed-method research, qualitative and quantitative analysis insights are balanced, while looking for a practical middle ground between the two (Onwuegbuzie et al., 2011). Quantitative (closed-ended) and qualitative (open-ended) data are combined to obtain a complete understanding of a research problem (Bryman, 2006; Creswell, 2014). However, attention is paid to how and when the results are combined, using two data-gathering approaches to get richer data than using only one approach (Bryman, 2006). Morse (2009) suggests several places where integration points can be located during the integration process.

The vital aspects of using mixed methods minimised the limitations of a study (Creswell, 2003; Creswell et al., 2011).

Concurrent and sequential designs are available among the mixed methods strategies that can be divided into triangulation and nested designs. The two concurrent collection types are explained in Figure 4.2 (Creswell, 2003). As part of the triangulation design, qualitative and quantitative data are collected simultaneously so that the investigator can compare qualitative data to more normative quantitative data, while simultaneously collecting both qualitative and quantitative data (Creswell, 2003). This design is used when researchers compare or validate quantitative data with qualitative data. In a nested design, data is collected in parallel within the same study, and one approach dominates, while the other is embedded within the research or "nested".

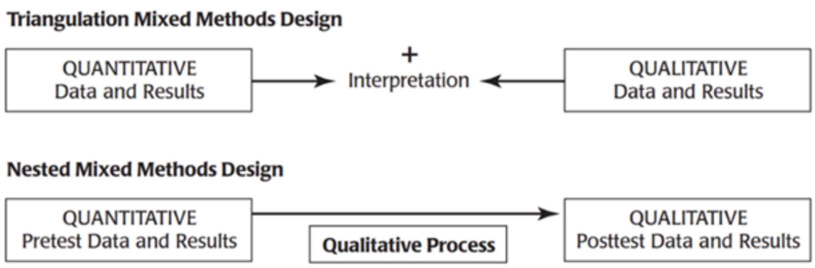

Figure 4.2: Two types of concurrent design (Creswell, 2003)

The concurrent triangulation design fit perfectly in this study because different kinds of questions – the structured data (quantitative) and unstructured data (qualitative) – were simultaneously addressed to answer the research question (Creswell & Creswell, 2005). Through this methodology, the complexity of social facts was reduced through observation, which improves understanding (Creswell & Creswell, 2018). After analysis, findings converged. The quantitative data collection weighed more than the qualitative data collection because more data instruments were used.

4.1.3 Research strategy

The objectives of a research study influence the choice of the research strategy. Action research, grounded theory, ethnography, narrative inquiry and case studies are among the most common research methodologies used in social science, particularly in information systems (Bhattacherjee, 2012). These strategies are discussed below.

Bhattacherjee (2012) describes action research as initialising an action in response to a real problem. The motion must be based on theory, explaining how and why the move would work. Ethnography is a research strategy that emphasises the study of the research phenomenon within the context of its culture (Auriacombe & Mouton, 2007). Inductive theories are grounded in empirical observations of social phenomena, as described by Bhattacherjee (2012). The use of narrative inquiry as a method describes researchers' experiences. It tries to extract a story with a plot from the analysed data (Bhattacherjee, 2012). Case studies examine underlying principles' causes by reviewing the grounds of a single individual, group or event in depth (Yin, 1984). Yin (2009) cited that by looking at a contemporary phenomenon in its real-world setting (e.g. a "case"), no clear distinctions are made between the phenomenon and the context.

A single case study chosen in this study is considered appropriate as it is judged by its ability to demonstrate and evaluate the use of the TBBaSK Framework to improve mindset, intrinsic motivation and science performance (Myers, 2019). The framework was assessed through the implementation of an experiment. Different aspects of the problem were addressed and evaluated (Creswell & Garrett, 2008). Bhattacherjee (2012) highlights the difficulties of generalising and transferring the findings when using a case study approach. A broader and more complete range of research questions was used in this study to overcome the weaknesses and exploit the strengths of the quantitative and qualitative methods (Hodkinson & Hodkinson, 2001).

The case study setting

In 2004, three technikons in South Africa merged to form a university of technology in South Africa. The Tshwane University of Technology (TUT) has nine campuses nationwide and seven faculties: Arts and Design, Economics and Finance, Engineering and the Built Environment, Humanities, Information and Communication Technology, Management Sciences, and Sciences.

It is the largest residential higher education institution in South Africa, with an annual enrolment of 60 000 students, a varied student body, and a gender distribution of 53.10% female and 46.90% male. Currently, TUT has 86.05% black students, 11.91% white students, and 2% Indian and coloured students. TUT offers housing for 10 200 students. Black and white students co-exist harmoniously in TUT's residences, where integration is visible (TUT, 2022a).

The university of technology was given an essential role in higher education because of its commitment to excellent instruction, research and community involvement. TUT was ranked among the top 15 scientific, technology, and engineering universities in South Africa in the Times Higher Education rankings for 2022–2023. It has also been acknowledged as the top technical university in the nation for these areas. The university of technology is essential in supporting education, research and innovation in South Africa because of its size, scope and commitment to excellence.

One of the qualifications offered is a National Diploma. To be considered for admission for the National Diploma, applicants must have an Admission Point Score (APS) of at least 28. The APS is calculated according to the matric results (final year at secondary school). (Chapter 5 explains the APS score.). The Extended Programme or the Higher Certificate was considered for those with an APS of between 20 and 27. Candidates must attain a specified level of achievement in several subjects. They must have at least an achievement level of 4 for English (home language or first additional language), 5 for Mathematics, and 5 for Physical Science to be eligible for the Engineering degree programme. For the Extended Programme or Higher Certificate, candidates must have an achievement level of 4 for English, 4 for Mathematics and 3 for Physical Science.

The TUT seeks to assist students from low-income and working-class families through financial aid offered by the National Student Financial Aid Scheme (NSFAS), with the restriction that the combined household income does not exceed R350 000 per year (TUT, 2022b). Most students at TUT study with NSFAS bursaries, demonstrating the university of technology's commitment to ensuring that people from underprivileged backgrounds have access to higher education.

Conducting the case study research

The case study was implemented using the TBBaSK Framework to apply science teaching interventions over six Saturdays.

Research methods such as experiments and quasi-experiments examine cause-and-effect relationships or test hypotheses. Researchers Fraenkel and Wallen (1990) defined this research design as the best way of explaining cause-and-effect relationships. The factors that are used in experiments can be significantly controlled by researchers. Participants are randomly divided into experimental and control groups after the independent variable(s) have been purposefully altered (Campbell, 1963). With the help of this control, researchers may more confidently determine a cause-and-effect connection. Randomisation is one approach to guarantee that participants are divided into groups to minimise bias and eliminate any confounding factors (Creswell, 2005). The ability to prove causation is frequently prioritised in experiments, but external validity – the capacity to extrapolate results to different populations or contexts – can also be constrained.

In quasi-experiments, researchers have little control over some variables (Cook et al., 2002). They can seldom divide individuals into random groups because of ethical, practical or other restrictions. As a result, it may be more difficult to prove causality because the groups may not be equivalent at the beginning of the study (Creswell, 2005). While quasi-experiments can suggest causal relationships, they are less effective at establishing causality due to the lack of randomisation and control over variables. This may induce bias and make linking observed effects to the independent variable more challenging. Because they frequently involve real-world circumstances and a variety of populations, quasi-experiments may have greater external validity, but may trade some internal validity.

This study experimented to determine the influence of applying the framework on mindset, motivation and academic performance.

Figure 4.3 summarises the data collection instruments used and the analysis techniques employed. These will be discussed in the sections below.

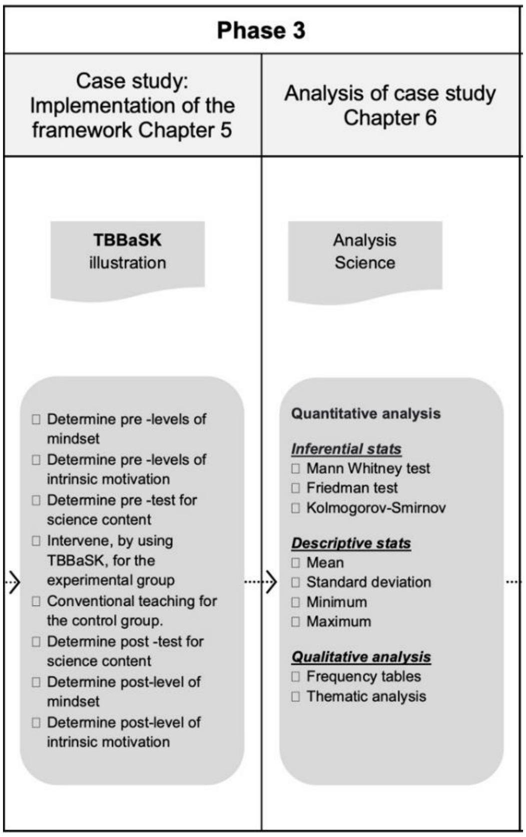

Figure 4.3: Data collection instruments and analysis techniques

4.1.3.1 Sampling

A sample of participants was selected to answer the research questions. The researcher's sample is drawn from the entire set of issues in the population. Due to limited time and resources, researchers must reduce the number of cases by applying a sampling technique (Taherdoost, 2016) (Figure 4.4). In this study, the total sample was used.

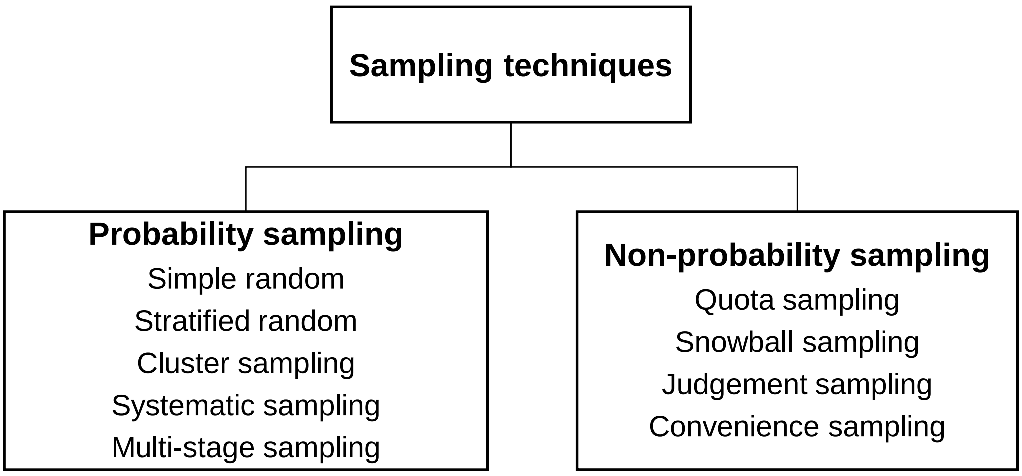

Figure 4.4: Sampling techniques (Taherdoost, 2016)

According to Zikmund (2000), the probability sample implies that all items in a population have a fair chance of being selected. A simple random sample ensures reliability by equally selecting participants from the population (Zikmund, 2000). If the population is divided into groups and samples are randomly selected from each group, it is called a stratified sample (Ackoff, 1953). Cluster sampling is used to separate the population into clusters or groups. This is followed by a random sample from these clusters (Wilson, 2014). The systematic sampling method involves picking every random number's case from an unexpected start, while multi-stage sampling moves from a wide-ranging to a biased sample once a general sample has been collected (Ackoff, 1953).

Non-probability sampling methods are often used in qualitative and case study research. For case studies, smaller samples are typically used. Rather than concluding that the larger population is affected by a real-life phenomenon, these studies examine a real-life phenomenon (Yin, 2009). According to Davis and Cosenza (2005), the total sample comprises the same proportion of appearances as the general population. The snowball sampling method increases the sample size by including other issues in the study. This method is best suited to small, hard-to-reach populations due to its closed nature (Brewerton & Millward, 2001). Maxwell (2012) defines judgmental sampling as selecting specific settings, individuals or events to obtain otherwise unavailable information (Maxwell, 2012). In convenience sampling, participants are chosen since they are often readily available and accessible to contact (Ackoff, 1953).

Random sampling fits perfectly into this study as it ensures that all participants had an equal chance of being allocated to the experimental or the control groups. The names of students who achieved between 30 and 60% for Engineering Science in their first written test were received from the lecturers who taught the subject. The researcher was not one of those lecturers. A total of 165 Higher Certificate in Engineering students (named the sample frame) from the target population of 454 adhered to the requirements for this study. A Microsoft Excel program randomly divided these names into a control and an experimental group. The program generated a unique number for each participant for statistical comparison purposes. It is confidential with no discrimination for or against any student because these numbers were not linked to any student's identity.

Out of the original 90 students who signed the consent form, 41 were dedicated to all the research rules, including attending all six research sessions. It was essential to do the intervention immediately after the different lecturers had completed the specific topic in their time slot for the investigation and exploration of this intervention to be done thoroughly and deeply.

4.1.3.2 Data collection instruments

Data is gathered, measured and analysed from various relevant sources so that researchers can answer questions, evaluate outcomes, and forecast trends and probabilities. The data in this study was collected using a concurrent triangular method to utilise the vital aspects of quantitative and qualitative research (Creswell, 2003; Creswell et al., 2011; Johnson & Christensen, 2019). This approach investigates cause (TBBaSK) and effect (mindset, intrinsic motivation and science performance) using a hypothesis that can be retained or rejected.

In the qualitative aspect of the research, feedback from the sample group was collected via open-ended questions.

This study aimed to develop a science teaching framework to contribute to current research concerning the factors that can facilitate the change from a fixed to a growth mindset, enhancing intrinsic motivation and science performance. The plan was executed as follows (Table 4.1):

Table 4.1: Data-collection

<table>
<tr><th>Group</th><th>Pre-intervention tests</th><th>Intervention</th><th>Post-intervention tests</th><th>Structured feedback</th><th>Open-ended questions</th></tr>
<tr><td>Experimental</td><td rowspan="2">Pre-structured questionnaire on mindset
Pre-structured questionnaire on intrinsic motivation
Pre-test on science knowledge</td><td>Implementation of the TBBaSK Framework</td><td rowspan="2">Post-structured questionnaire on mindset
Post-structured questionnaire on intrinsic motivation
Post-test on science knowledge</td><td>Structured questions to compare pre- and post-interventions</td><td rowspan="2">Students' overall experience after the intervention</td></tr>
<tr><td>Control</td><td>Conventional teaching methods</td><td></td></tr>
</table>

Data was collected for both groups in real-time using questionnaires and tests. Pre- and post-tests were written, and structured questionnaires were completed to analyse students' mindset, motivation and science performance. The researcher focused on a challenging part of the work (Fluids), which was not part of the matric syllabus. The same content was lectured to the experimental and control groups (Appendix F).

All participants wrote a science test before and after the intervention. A similar, but not identical test on the topic of Fluids was given after the intervention. Differences between the marks of the pre-test on the chosen topic by the control and experimental groups were compared with the post-test marks of both groups after the intervention. All information given to the experimental group was also given to the control group after the intervention to ensure that the control group did not miss out on any opportunity. Marks for this intervention were not part of their year marks.

The participants' feedback on their experience after the intervention on science understanding was analysed.

The pre- and post-test levels of mindset were compared. The Structured Questionnaire for Intelligence Scale for Adults (Appendix C) by Dweck (1999) was used. It consists of entity and incremental statements (Dweck, 1999). Students should rate these questions on a Likert-like scale from one to six. The average of the items indicates the students' mindset, with scores closest to six demonstrating a growth mindset (Myers et al., 2016).

The pre- and post-test levels of motivation were compared. The standardised Motivated Strategies of Learning Questionnaire (MSLQ) (Appendix C) by Pintrich et al. (1993) was used. It consists of value (intrinsic, exinitic and task), expectancy (control of learning belief, self-efficacy for learning and performance) and text anxiety. The complete questionnaire consists of 31 questions. Specific weights were allocated to each question, with the outcome statistically interpreted. The questionnaire may be partly used (Pintrich et al., 1993). Therefore, only questions 1, 16, 22 and 24 were used to test intrinsic motivation. Pre- and post-tests were written, and questionnaires were used to analyse students' intrinsic motivation. Students should rate these questions on a Likert scale from one to seven. The average score closest to seven demonstrates that students are more intrinsically motivated.

The experimental group members were required to express and provide reasons for the aspects they found most and least helpful about the intervention through an unstructured, open-ended questionnaire. They were also invited to share thoughts or feedback on their learning experience throughout the intervention.

The control group also had the chance to offer their perspectives; however, their input cannot be included in the report due to their non-participation in the intervention.

4.1.3.3 Pilot study

A pilot study was executed to examine the quality and feasibility of the intended approach. Science is an appropriate, challenging subject to activate the intrinsic motivational patterns needed for this research, especially where improvement relies on previously studied material (Grant & Dweck, 2003). The pilot study was executed on 33 first-year Engineering students who followed the same syllabus as the Higher Certificate students. Their circumstances were the same. Unfortunately, limited time was available, so only one of the four sections on Fluids (the intervention's topic) was done. All the students completed the unstructured questionnaire to answer yes or no to reveal their experience of the intervention. See Appendix D for the complete intervention plan and pilot study feedback.

4.1.3.4 Data analysis

Data analysis is a procedure that is used to interpret the collected data. This occurs when the information is taken apart, analysed and put together again (Creswell, 2013). The purpose of the analysis is to answer the research questions. Data analysis clarifies the purpose of the study (Patton, 2002).

It can be performed using various software tools and programming languages, such as Python, R, Excel and SQL, and specialised data analysis software like SPSS and SAS.

The quantitative and qualitative techniques used in this study are described in the following section.

4.1.3.5 Quantitative data analysis

Quantitative data analysis is a research technique that entails the systematic and mathematical study of numerical data to reach conclusions, spot trends, test hypotheses and infer information about a population or phenomenon.

Descriptive statistics

Descriptive statistics were used to analyse the experimental and control groups' data on motivation, mindset and science understanding (in questionnaires and tests). The data refers to pre- and post-intervention data collection. SPSS was used as a statistical software (Tyagi et al., 2021). Descriptive statistics for the participants' feedback after the intervention was used to strengthen the outcome.

Analysis of feedback via frequency tables was used to analyse the occurrence of specific values to assess the reliability of the research (Creswell & Clark, 2017). Several questionnaires reflected the feedback on the experience of the experimental group after participating in the intervention. The valid percentage column displayed the percentage of observations from that section's total number of responses. The cumulative percentage was expressed as the sum of the percentages by adding one period to the next. Combined percentages were calculated to express the summarised feedback of the participants' experiences.

Inferential statistics

Descriptive statistics summarises the characteristics of a data set, while inferential statistics provides conclusions and predictions based on data. The Shapiro-Wilk test was used to investigate the normality of the data in this study. The Spearman test was used to determine if mindset and motivation are correlated with science performance. The Mann-Whitney test was used to determine the distribution of the experimental and control groups. Friedman's tests were used to determine the statistical differences between the groups non-parametrically. All data sets were measured at a confidence interval of 95% and a p-value of 0.05.

A hypothesis test is a statistical analysis that uses inferential statistics. Statistical tests are used to test hypotheses or predictions. The testing of hypotheses began with an assumption that the null hypothesis is true among the population. Statistical hypotheses are formal ways of predicting the behaviour of a group of people. Every research prediction is rephrased into null and alternative hypotheses to test a hypothesis. Based on sample statistics, inferential statistics was gathered for this study to conclude the population's parameters (Lowry, 2014).

The objectives of the quantitative part of the study, formulated as a hypothesis, are provided below:

Hypothesis 1: Implementing the TBBaSK Framework will enhance the growth mindset of learners.

Hypothesis 2: Implementing the TBBaSK Framework will improve learners' intrinsic motivation.

Hypothesis 3: Implementing the TBBaSK Framework leads to the improved science performance of learners.

The TBBaSK Framework, using brain-based learning, was the independent variable that caused the change in the dependent variables (mindset, intrinsic motivation and science performance (Figure 4.5).

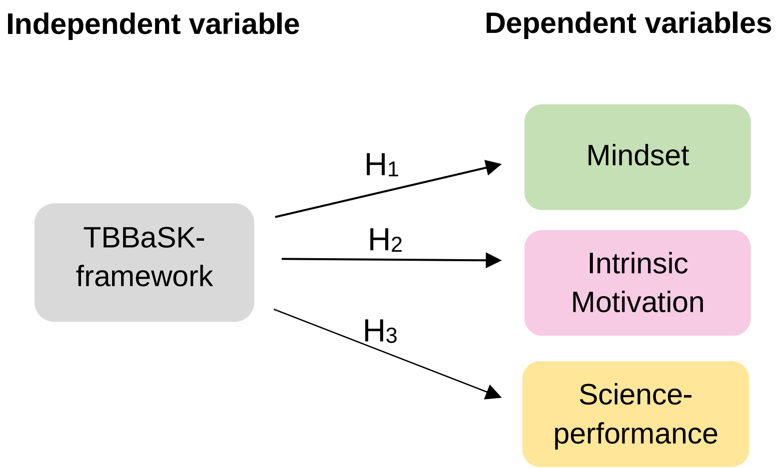

Figure 4.5: Variables used in this study

Statistical tests were executed to assess whether the null hypothesis could be rejected.

Correlation tests

Correlation tests evaluate the degree of association between two variables (Creswell et al., 2004). A Spearman non-parametric correlation test was executed in this study to measure the strength of association between the experimental and control groups, pre- and post-intervention. It was executed to determine the correlation between mindset and science performance, as well as the correlation between intrinsic motivation and science performance.

4.1.3.6 Qualitative data analysis

In qualitative data analysis, patterns and themes in textual data are identified, examined, interpreted and used to develop answers to research questions. The most common approaches are content, thematic, textual and discourse analysis.

Thematic analysis

Thematic analysis is an excellent research approach used when analysing qualitative data to uncover people's views, opinions, knowledge, experiences or values (Braun & Clarke, 2006). A thematic analysis fits in perfectly with the qualitative part of this mixed-method case study, as it analyses the participants' opinions from the experimental and control groups after the intervention. The findings from the thematic analysis are discussed to answer research questions 1 to 5, in addition to the descriptive statistical results.

The researcher analysed the feedback thoroughly as a first step to understanding the collected information. Braun and Clarke (2006) suggested that codes should be assigned to describe the content in the next step. The researcher then worked systematically through the entire data set to form the recommended themes from the assigned codes. A theme, as defined by DeSantis and Ugarriza (2000), is a holistic concept that unifies the essence or basis of an experience. With this condensed overview of the codes, it was possible to identify common meanings and main points throughout the data.

Data instruments are summarised in the matrix, where research questions were plotted against the research instruments (Table 4.2).

Table 4.2: Research instrument per research question

Research approach mixed methods	**Quantitative**				**Qualitative**
Research questions / **Research instruments**	**Literature**	**Pre- and post-tests**	**Structured standardised Likert-scale questionnaires**	**Structured Likert-scale questionnaires on feedback**	**Open-ended questionnaires**
RQ 1: What is the effect of using technology in science understanding?	✓			✓	✓
RQ 2: What is the effect of brain-based learning on science understanding?	✓			✓	✓
RQ 3: What is the effect of intrinsic motivation on science performance?	✓	✓	✓		
RQ 4: What is the effect of mindset on science performance?	✓	✓	✓		
RQ 5: What is the effect of the implementation of the TBBaSK Framework on mindset, intrinsic motivation and science performance?		✓	✓	✓	✓

4.2 THE SCIENTIFIC RIGOUR OF THE RESEARCH STUDY

The rigour of a research study refers to the degree of thoroughness, accuracy and validity of the research methods and processes used in the study.

Quantitative measures

The validity and reliability of procedures and measurements are essential in quantitative research. This shows how accurate a method, methodology or test is. Reliability is a measurement's consistency, whereas validity is a measurement's correctness (Lincoln & Guba, 1985).

Reliability

Reliability refers to the consistency, stability or repeatability of measurements or results in a research study (Bhattacherjee, 2012). To ensure internal consistency and dependability, the questionnaires used to collect the data in this study were structured, and the pre- and post-science test's Likert scale findings matched with those. No student in the experimental sample group was unfairly given the benefit of the doubt when it came to exposure to the intervention – all the materials used after the intervention were made available to the control group to establish external reliability.

Validity of measure

Validity measurements are required to guarantee the reliability of instruments and tests.

Internal validity

Reliability is crucial to research, indicating the consistency, stability or repeatability of measurements or results. Bhattacherjee (2012) notes that ensuring reliability is essential in research. In this study, several measures were taken to ensure internal consistency and dependability.

The questionnaires used in this study were structured, enhancing data collection reliability. Structured questionnaires typically use well-defined questions and response formats, reducing response variability. The study ensured that the findings of the two different scales from pre- and post-science tests were consistent. This matching of findings indicates stability in the measurements over time, contributing to reliability. Cronbach's Alpha values were calculated for specific parts of the questionnaires.

For the MSLQ used to assess intrinsic motivation, the calculated Cronbach's Alpha was 0.74, indicating moderate internal consistency (Duncan & McKeachie, 2005). The Structured Questionnaire for Intelligence Scale used to assess mindset had a high Cronbach's Alpha value of 0.94, suggesting internal solid consistency (Elliot et al., 2002). The structured feedback questionnaire on the implementation of the TBBaSK Framework used in the study produced a Cronbach's Alpha value of 0.88, which was considered extremely good. All values exceeded the acceptable value of 0.7 and contributed to the reliability of the measurements (Bhattacherjee, 2012).

Measures were taken to ensure that no student in the experimental group received preferential treatment regarding exposure to the intervention to establish external reliability. All materials used after the intervention were made available to the control group. Additionally, the presence of the subject head and a former student attending the classes helped confirm the study's reliability (Appendix A4).

Qualitative measures

In qualitative research, rigour is evaluated based on the use of systematic and transparent methods in analysis.

Credibility

The reasonableness of its interpretations can assess the credibility of a qualitative study. Internal validity is the term used to describe this in functionalistic research. Bhattacherjee (2012) advises employing various data-gathering strategies to triangulate data to improve the validity of qualitative research. Positive input from open-ended questions was confirmed to refine the intervention after utilising a pilot study to gauge how the students would respond to the intervention. According to Liamputtong and Serry (2013), triangulation is the most effective technique for raising the credibility of qualitative research. After analysis, qualitative and quantitative data were gathered separately throughout the same time frame before the results were converged. This ensures the credibility of the research by using various data collection tools to collect information on the same subject. The subject head and one of the former students attended the classes to confirm the study's credibility (Appendix A4).

Transferability

Findings from qualitative research can typically be used in different contexts if they can be transferred. Equal importance is given to the external validity of functionalistic research (Bhattacherjee, 2012). The data collection, research findings and mappings to repeat the study were detailed in depth, even though a case study may limit the generalisation of the analysis (Chapters 3 and 4). The data's structures, presumptions and methods allow the readers to decide whether and to what degree it can be applied to other situations.

Dependability

Bhattacherjee (2012) claims that dependability is the same as the idea of reliability used in positivist research. Because the researcher was not the topic instructor, it was guaranteed that every student had access to the information provided by their various lecturers. The fact that everyone had an equal probability of being assigned to the experimental group was confirmed by random sampling. It made sure that the outcome contributed significantly. To ensure dependability, the control group – which did not participate in the intervention – had access to all the material afterwards. However, the students were exposed to many lecturers during class time.

Confirmability

Researchers must explain how they arrived at their results and interpretations to ensure the validity of their findings (Bhattacharjee, 2012). The students' responses to the open-ended questionnaires were overwhelmingly positive. They even said they would appreciate additional interventions of a similar nature.

With factual evidence, the researcher could comprehend and analyse the occurrence that was the subject of the study. Even though the experimental and control groups were taught using different approaches, the researcher nevertheless felt objective while carrying out this investigation. The instructor and a former pupil attended the sessions and attested to their objectivity (Appendix A4).

4.3 ETHICAL CONSIDERATIONS

Ethical considerations should guide a researcher's designs and practices. Researchers and scientists must always abide by certain ethical principles when collecting data from people. It is crucial to put specific procedures in place to safeguard participants against any possible harm, no matter how confident the researcher is about the case (Andrews & Pradham, 2001).

The proposals for this study were handed to the Ethical Committee, which approved them before continuing the research (Jamrozik, 2004). The Review Board of all relative institutions approved the proposal (Appendix A). Any differences in their various standards were clarified. This research study was done with students from TUT because of the researcher's involvement in this institution. The Registrar and the Dean of TUT approved the research on one group of students, knowing that there may be a feeling that the experimental group could be unfairly favoured by using technology and brain-based learning in science education. Therefore, all the work done in the intervention was also given to the control group after the intervention. The marks of the intervention were not part of the students' year mark. The Ethical Committee at the University of Pretoria (UP) provided ethical clearance as this study was done as part of a study at this institution (Appendix A).

Random sampling ensured that all participants had the same chance of being part of the experimental group. This method enhances the study's validity and reliability. Participation was not forced on any participant. Although a number was allocated, it only linked the pre- and post-tests for statistical reasons. The numbers identified students who were not advantaged in any way. They could withdraw at any stage of this study if they felt uncomfortable about completing the study.

Informed consent refers to the agreement that all potential participants must complete before participating in the research study. Participants from the sample group agreed to participate in this case study. All the information was explained to them, including the study's benefits, risks, funding and institutional approval. The participating students completed a proper consent form (Appendix A3). They knew that by deciding to participate and completing the questionnaire on their current mindset and intrinsic motivation, the intervention could cause a change in them.

Anonymity means that the identity of the participants is not linked to their data. In this study, this was impossible as statistical data was needed for the analysis (data pseudonymisation). This caused personal information to be separated from the study data.

Feedback was given after the findings to ensure a good relationship between the researcher and the students, and was critical for the validity of the study. The data collected from the questionnaires was anonymous, but each participant provided feedback according to the allocated number.

Confidentiality refers to protecting critical information and keeping entrusted information secret. The content of this research study was communicated clearly to the students to understand the reason for the study. The right to privacy was respected, and all signed consent forms were saved in a password-protected file drawer. No delicate questions or tasks occurred that implied any negative feelings, humility or psychological harm. The incentives needed for the research were stipulated clearly.

Plagiarism was not part of the study, and the researcher considered this study her own. The data was interpreted and analysed to be trustworthy without any misconduct.

The researcher was not the subject lecturer, which ensured that all students had the right to the knowledge offered by their different lecturers. However, the researcher conducted this research study. The researcher believed that she was objective despite the differences in teaching methods between the experimental and control groups. To ensure that she was fair in her approach to the experimental group, she invited the subject head and one of the former students to attend some sessions of both groups. They ensured that there was no conflict of interest**.** The reports from both these individuals are included in Appendix A4.

4.4 SUMMARY

A concurrent triangular design with a pragmatism paradigm and a single case study method was utilised in this study to explore the research topics (Creswell, 2003). The focus of this case study was the development of the TBBaSK Framework to improve students' mindsets, intrinsic motivation and science performance, despite the inherent limitations of case studies, such as their inability to be generalised.

The following section describes the case study of this study.

CHAPTER 5: CASE STUDY

5.1 CONTEXT

The background of the case study is described in chapter 2.3. The researcher was a lecturer in Engineering Science at the Tshwane University of Technology in South Africa for more than 13 years. Almost all the students studying at TUT come from previously disadvantaged backgrounds. As stated in the background section of Chapter 1, this has several consequences for academic performance.

Over the past two decades, several academic support development programmes have been introduced to address this problem. This includes bridging courses, and foundation and extended programmes based on specific institutional needs. According to Machika (2007), bridging programmes are designed to bridge the education gap between secondary and tertiary levels (Machika, 2007). Scott et al. (2007) consider a foundation programme to be an extended programme in which a three-year qualification is spread out over four years to reduce the workload. Extended programmes are not “remedial” in the conventional sense of redoing previous-level work (schoolwork). All work must be at an appropriately demanding, higher education level (Yeld, 2010).

Viljoen (2015), the Head of Department for the extended engineering programmes at TUT, researched the progress of these courses. She wrote an article explaining how the bridging courses developed over time at TUT. The TUT has offered engineering foundation programmes since 2008. Engineering extended programmes were established in 2010, where the diploma programme’s first semester is spread over an entire year.

It is usual for students placed in these programmes to lack the background knowledge and skills required for direct entry into diploma programmes, particularly in sciences and mathematics.

To qualify for the extended programmes, Grade 12 students with an APS of 20 to 27 must have achieved the following: Level 4 in Mathematics, Level 3 in Physical Science and Level 4 in English. It is on a National Qualifications Framework (NQF) Level 5, and 140 credits are allocated. The pass rate at university is 50%.

In South African schools, the levels for the APS are as follows:

Code 7 (A symbol): 80–100%

Code 6 (B symbol): 70–79%

Code 5 (C symbol): 60–69%

Code 4 (D symbol): 50–59%

Code 3 (E symbol): 40–49%

Code 2 (F symbol): 30–39%

Code 1 (FF Symbol): 0–29% (Chapter 4.2.3)

The conclusion of the extended programme helps previously disadvantaged students to catch up and follow the mainstream programme from the second year. Viljoen (2015) compared the students' performance in a conventional three-year national diploma programme with the three-and-a-half-year extended programme at TUT over five years (2010 to 2014) (Table 5.1). The TUT's Information Technology System (ITS) was used to gather data for the analysis. Dropout rates and degree awards are compared between the two groups.

Table 5.1: Qualifications awarded to Civil Engineering students (2010–2014) (Viljoen, 2015)

	3 years		**3.5 years**		**4 years**		**4.5 years**		**5 years**	
Enrolled	**Extended**	**Diploma**	**Extended**	**Diploma**	**Extended**	**Diploma**	**Extended**	**Diploma**	**Extended**	**Diploma**
2010		0%	3%	8%	21%	18%	12%	14%	6%	
2011		4%	13%	9%	10%		5%			

Most of the extended students were supposed to complete their diplomas in three-and-a-half years, which was the case, and most of the diploma students were supposed to complete their diplomas in three years, which was not the case. According to the report, the extended programme has achieved its goals regarding "access with success". Students are performing at the same level as the National Diploma students. The completion results are, unfortunately, still unsatisfactory.

In 2018, the university decided to change the extended programme to a higher certificate and started with a degree qualification in Engineering. Higher certificates are skills-focused qualifications. Students are equipped with skills that enable them to acquire a basic understanding and practical knowledge of their field of study. It can be obtained over one year (Henderson et al., 2019).

The requirements for students to enter the programmes were the same, with completion in one year. The difference was that students might decide if they wanted to continue with the diploma or degree in Engineering after the year, or if they chose to leave the institution with a higher certificate. The disadvantage was that those students who wanted to complete the Engineering diploma or degree needed to start again from the first year for the diploma or degree. No data for the completion of the qualification is available yet because of the unplanned extension during the period of the COVID-19 pandemic.

Although the institution had already put measures in place to bridge the gap these previously disadvantaged students faced, there was still a gap, as seen in the success rate figures. Another approach to overcome these shortcomings is to look into alternative teaching methods – which is the goal of this research. This study aims to develop a brain-based learning teaching framework for science education. Implementing the TBBaSK Framework seeks to enhance students' mindsets, intrinsic motivation and science performance.

5.2 THE INTERVENTION

The TBBaSK Framework was implemented to teach first-year Engineering Science students enrolled for the Higher Certificate. Because the intervention occurred in the second semester, their initial test results for the first year should have been between 30 and 60%. After receiving those results from the subject head, the population was compiled. Out of the initial 90 students who signed the consent form, 41 were fully committed to all the research requirements, including attending all six research sessions. Twenty-three were randomly assigned to the experimental group and 18 to the control group (see Chapter 4.1.3.1) for more detail).

Of the participants, 54% was male, and 46% was female. More detail on the demographics of the students is given in Table 5.2. The table also shows the percentage of fathers, mothers and guardians with qualifications higher than matric. It shows that most parents and guardians graduated from college. For more detail, see Chapter 6.2.1.

Table 5.2: Percentage of male-to-female participants in the control and experimental groups

	Male students		Female students		Fathers		Mothers		Guardians		Total
					Qualification higher than Grade 12						
	N	**%**	**N**	**%**	**N**	**%**	**N**	**%**	**N**	**%**	**N**
Experimental group	10	43	13	57	4	17	7	39	6	26	23
Control group	12	67	6	33	5	28	8	45	7	39	18
Total	22	54	19	46	9	22	15	37	13	32	41

The intervention occurred after the target group of students had finished their first semester of the Higher Certificate in Engineering at TUT. The Grade 12 curriculum covered all aspects except for the intervention portion. Therefore, it was decided to address a problematic topic, Fluids, which was carried out immediately after different lecturers from the Higher Certificate had completed the relevant topic using their conventional teaching methods. This timing ensured that the control and experimental groups started the intervention from the same point with the same exposure, but from different lecturers.

The researcher, who was not one of the lecturers, conducted the intervention with the control and experimental groups to ensure consistency and similarity in the intervention process.

Before the intervention, the control and experimental groups wrote the same pre-test on Fluids to guarantee equal starting points for validity-related reasons. The control and experimental groups were taught the fluid-related material from scratch. The same content was taught to both groups, although the control group was exposed to conventional teaching and the experimental group to the brain-based learning techniques. Every experimental group session included all the components of the TBBaSK Framework (Table 5.3).

The intervention was spread across six consecutive Saturdays because that is when the university's facilities were available. However, the choice of Saturdays presented difficulties because of transportation constraints and extended weekends. Therefore, not all students could attend every session. Table 5.3 presents how the intervention and data collection took place.

Table 5.3: Flow of the intervention

<table>
<tr><th>Group</th><th>Pre-intervention tests</th><th>Intervention</th><th>Post-intervention tests</th><th>Structured feedback</th><th>Open-ended questions</th></tr>
<tr><td>Experimental</td><td rowspan="2">Pre-structured questionnaire on mindset
Pre-structured questionnaire on intrinsic motivation
Pre-test on science knowledge</td><td>Implementation of the TBBaSK Framework</td><td rowspan="2">Post-structured questionnaire on mindset
Post-structured questionnaire on intrinsic motivation
Post-test on science knowledge</td><td>Structured questions to compare pre- and post-intervention</td><td rowspan="2">Students' overall experience after the intervention</td></tr>
<tr><td>Control</td><td>Conventional teaching methods</td><td></td></tr>
</table>

A control and experimental group were set up to test the effect of implementing the TBBaSK Framework on science performance, mindset and motivation.

The pre- and post-intervention questionnaires were taken in lessons one and six – see Appendix F for a detailed overview of how the intervention was conducted.

Several data instruments were used to gather data before and after the intervention. This strategy investigates cause (TBBaSK) and effect (mindset, intrinsic motivation and science performance) using a hypothesis that could be retained or rejected. Data was collected for both groups in real-time using questionnaires and tests. Pre- and post-tests were written and structured questionnaires were conducted to analyse students' mindset, motivation and science performance. Open-ended questions revealed the students' feelings, demographic information and learning experiences (Chapter 4.1.3.2) for the detailed data collection procedure.

Qualitative feedback from the sample group was compared before and after the intervention. Table 5.4 (as a duplicate of Table 3.6) shows how all the components of the TBBaSK Framework were integrated into the lessons. An example of the implementation is added in Table 5.4.

The brain-based learning principles correlate with the numbers from Table 3.4.

Appendix F provides the detailed lesson plans that were used.

Table 5.4: Example of implementing the TBBaSK Framework

Example of implementing the TBBaSK Framework					
Curriculum (Fluids)	**Brain-based learning element**	**Brain-based learning principles** (Table 3.4)	**Technology** (Table 2.4)	**TBBaSK activity** (Table 2.12)	**Senses**
Density Pascal Archimedes Bernoulli	Orchestrated immersion	7. Patterns give meaning 8. Multisensory approach	Web 2.0: YouTube Mobile device: Laptop and data projector	Brain knowledge video on: The influence of threats on the brain Foundational drivers Brain and learning Stress response	Auditory Visual
	Orchestrated immersion	8. Multisensory approach	Mobile device: Laptop and data projector, whiteboard Animation: PNET simulations Social media: WhatsApp	Demonstrate practical experiment	Auditory Visual Kinaesthetic
	Active processing	10. Neuroplasticity 11. Feedback and repetition 12. Memory 13. Attention 14. Prior knowledge	PowerPoint slide show presentation Mobile device: Laptop and data projector	Do experiment (in groups while others are doing the exercise)	Auditory Visual Kinaesthetic
	Active processing	10. Neuroplasticity 11. Feedback and repetition 12. Memory 13. Attention 14. Prior knowledge	Mobile device: Laptop and data projector, whiteboard Learning management system: Schoology	Explain new knowledge and do an example	Auditory Visual

Example of implementing the TBBaSK Framework					
Curriculum (Fluids)	**Brain-based learning element**	**Brain-based learning principles** (Table 3.4)	**Technology** (Table 2.4)	**TBBaSK activity** (Table 2.12)	**Senses**
			Slide show presentation: PowerPoint		
	Relaxed alertness	4. Engages entire physiology 5. Physical activity and nutrition influence learning 6. Involve breaks in teaching sessions	Web 2.0: YouTube Mobile device: Laptop and data projector	Brain exercise: Mind moves Leg workout Power on Bilateral walk Temporal toner	Auditory Visual Kinaesthetic
	Active processing	8. Multisensory approach 10. Neuroplasticity 11. Feedback and repetition 12. Memory 13. Attention 14. Prior knowledge	PowerPoint slide show presentation Mobile device: Laptop and data projector	Do experiment (in groups while others are doing exercise to capture new knowledge)	Auditory Visual Kinaesthetic
	Relaxed alertness	2. Learning is improved by challenge and inhibited by depression, stress, threats and anxiety. 4. Engages entire physiology 5. Physical activity and nutrition influence learning	Mobile device: Laptop and data projector Web 2.0: YouTube	Brain exercise: Mindfulness (deep breathing)	Auditory Visual Kinaesthetic

Example of implementing the TBBaSK Framework					
Curriculum (Fluids)	**Brain-based learning element**	**Brain-based learning principles** (Table 3.4)	**Technology** (Table 2.4)	**TBBaSK activity** (Table 2.12)	**Senses**
		6. Involve breaks in teaching sessions			
	Relaxed alertness	4. Engages entire physiology 5. Physical activity and nutrition influence learning 6. Involve breaks in teaching sessions	Web 2.0: YouTube Mobile device: Laptop and data projector	Brain exercise: Mind moves Antennae adjuster Temporal toner	Auditory Visual Kinaesthetic
	Active processing	9. Learning involves conscious and unconscious processes, sleep 10. Neuroplasticity 11. Feedback and repetition 12. Memory 13. Attention 14. Prior knowledge	Mobile device: Laptop and data projector, whiteboard Learning management systems: Blackboard, Schoology Slide show presentation: PowerPoint	Do multiple-choice questions online in class to capture new knowledge, discuss and give feedback	Auditory Visual Kinaesthetic
	Active processing	9. Learning involves conscious and unconscious processes, sleep 10. Neuroplasticity 11. Feedback and repetition	Mobile device: Laptop and data projector, whiteboard Learning management systems: Blackboard, Schoology	Do challenging problems in class, discuss and give feedback	Auditory Visual Kinaesthetic

Example of implementing the TBBaSK Framework					
Curriculum (Fluids)	**Brain-based learning element**	**Brain-based learning principles** (Table 3.4)	**Technology** (Table 2.4)	**TBBaSK activity** (Table 2.12)	**Senses**
		12. Memory 13. Attention 14. Prior knowledge	Slide show presentation: PowerPoint		
	Relaxed alertness	2. Learning is improved by challenge and inhibited by depression, stress, threats and anxiety. 4. Engages entire physiology 5. Physical activity and nutrition influence learning 6. Involve breaks in teaching sessions	Mobile device: Laptop and data projector Student response system: Kahoot!	Brain exercise: Play Kahoot! of Fluids to capture new knowledge	Auditory Visual Kinaesthetic
	Orchestrated immersion	7. Patterns give meaning 8. Multisensory approach	Web 2.0: YouTube Mobile device: Laptop and data projector	Brain knowledge: Explain senses in the brain Videos on mindset and neuroplasticity	Auditory Visual
	Orchestrated immersion	7. Patterns give meaning 8. Multisensory approach	Mobile device: Laptop and data projector, whiteboard	Capture new knowledge: Put recording lessons on the web for the experimental group	Auditory Visual

Example of implementing the TBBaSK Framework					
Curriculum (Fluids)	**Brain-based learning element**	**Brain-based learning principles** (Table 3.4)	**Technology** (Table 2.4)	**TBBaSK activity** (Table 2.12)	**Senses**
			Learning management systems: Blackboard, Schoology	Put answers on the web for the control group	
	Relaxed alertness	1. Learning is developmental and experimental (nature and nurture) 2. Learning is improved by challenge and inhibited by depression, stress, threats and anxiety. 3. Social safety 4. Engages entire physiology 5. Physical activity and nutrition influence learning 6. Involve breaks in teaching sessions	Mobile device: Laptop and data projector Student response system: Kahoot!	Brain exercise: Kahoot! of the brain to capture new knowledge	Auditory Visual Kinaesthetic
	Orchestrated immersion	7. Patterns give meaning 8. Multisensory approach	Web 2.0: YouTube Mobile device: Laptop and data projector	Video to explain new knowledge	Auditory Visual

Example of implementing the TBBaSK Framework					
Curriculum (Fluids)	**Brain-based learning element**	**Brain-based learning principles** (Table 3.4)	**Technology** (Table 2.4)	**TBBaSK activity** (Table 2.12)	**Senses**
	Orchestrated immersion	7. Patterns give meaning 8. Multisensory approach	Mobile device: Laptop and data projector PowerPoint as a slideshow presentation	Revise senses to capture brain knowledge	Auditory Visual Kinaesthetic
	Active processing	9. Learning involves conscious and unconscious processes, sleep 10. Neuroplasticity 11. Feedback and repetition 12. Memory 13. Attention 14. Prior knowledge	Learning management systems: Blackboard, Schoology Social media: WhatsApp	Extra information	Visual

Table 5.5: Example of the application of the intervention

WEEK 2 (Density)				
Brain-based learning element	**Brain-based learning principles** (Table 3.4)	**Technology** (Table 2.4)	**TBBaSK activity** (Table 2.12)	**Senses**
Orchestrated immersion	7. Patterns give meaning 8. Multisensory approach	Web 2.0: YouTube Mobile device: Laptop and data projector	**Show a video on the influence that threats have on the brain:** When a threat is experienced, the amygdala sends more oxygen to one's arms and legs to freeze, flight or fight. That implies that less oxygen will be transferred to the pre-frontal cortex, which means that one cannot think clearly. When one feels anxious or stressed, breathe deeply so that the amygdala does not get upset. The amygdala sends the message to the endocrine glands to warn that danger is coming. Adrenaline is secreted – breathing is shallow and quick; the heart beats faster. Stress is the reaction – anxiety, which causes physiological problems like feeling jittery, a rapid heartbeat and headaches. The hypothalamus connects the endocrine and nervous systems to keep all in balance – homeostasis. The hippocampus is where short-term memory is formed. The pre-frontal cortex produces dopamine – a feel-good hormone (reward). Problem solving takes place unconsciously. By changing one's mindset, one can tell the amygdala what to see as a threat.	Auditory Visual
Orchestrated immersion	8. Multisensory approach	Mobile device: Laptop and data projector, whiteboard Animation: PNET simulations	**Demonstrate practical experiment:** Experiment with groups while the others are solving their problems on density. So, how can I measure the mass of water in my swimming pool? Can I put it on a scale?	Auditory Visual Kinaesthetic

WEEK 2 (Density)				
Brain-based learning element	**Brain-based learning principles** (Table 3.4)	**Technology** (Table 2.4)	**TBBaSK activity** (Table 2.12)	**Senses**
		Social media: WhatsApp		
Active processing	10. Neuroplasticity 11. Feedback and repetition 12. Memory 13. Attention 14. Prior knowledge	Mobile device: Laptop and data projector, whiteboard Learning management system: Schoology Slide show presentation: PowerPoint	Do an example on the whiteboard to capture new knowledge. Save it to the web: "The body of a man whose weight is 690 N contains about 5.2 x 10^{-3} m^3 of blood. (a) Find the blood weight (b) Express it as a percentage of the body weight.	Auditory Visual Kinaesthetic
Active processing	9. Learning involves conscious and unconscious processes, sleep 10. Neuroplasticity 11. Feedback and repetition 12. Memory 13. Attention 14. Prior knowledge	Mobile device: Laptop and data projector, whiteboard Learning management system: Blackboard Slide show presentation: PowerPoint	Do challenging problems in class (no 3, 8, 91, 100), discuss and give feedback	Auditory Visual Kinaesthetic
Relaxed alertness	4. Engages entire physiology	Web 2.0: YouTube	Brain exercise: Mind move (confidence booster) Assure more stable and even brain waves. It puts one in the most resourceful mental and emotional state. Putting one's	Auditory Visual Kinaesthetic

WEEK 2 (Density)				
Brain-based learning element	**Brain-based learning principles** (Table 3.4)	**Technology** (Table 2.4)	**TBBaSK activity** (Table 2.12)	**Senses**
	5. Physical activity and nutrition influence learning 6. Involve breaks in teaching sessions	Mobile device: Laptop and data projector	tongue against the palate is soothing and boosts the immune system and rhythm.	
Relaxed alertness	2. Learning is improved by challenge and inhibited by depression, stress, threats and anxiety. 4. Engages entire physiology 5. Physical activity and nutrition influence learning 6. Involve breaks in teaching sessions	Mobile device: Laptop and data projector Web 2.0: YouTube	Brain exercise**:** Mindfulness (deep breathing)	Auditory Visual Kinaesthetic
Relaxed alertness	4. Engages entire physiology	Web 2.0: YouTube	Brain exercise: Mind move (leg workout)	Auditory Visual

WEEK 2 (Density)				
Brain-based learning element	**Brain-based learning principles** (Table 3.4)	**Technology** (Table 2.4)	**TBBaSK activity** (Table 2.12)	**Senses**
	5. Physical activity and nutrition influence learning 6. Involve breaks in teaching sessions	Mobile device: Laptop and data projector	Improves concentration, listening skills, comprehension, task completion and confidence.	Kinaesthetic
Active processing	9. Learning involves conscious and unconscious processes, sleep 10. Neuroplasticity 11. Feedback and repetition 12. Memory 13. Attention 14. Prior knowledge	Mobile device: Laptop and data projector, whiteboard Learning management systems: Blackboard, Schoology Slide show presentation: PowerPoint	Do multiple-choice questions online in class to capture new knowledge, discuss and give feedback	Auditory Visual Kinaesthetic
Active processing	9. Learning involves conscious and unconscious	Learning management systems: Blackboard, Schoology	Extra information	Visual

WEEK 2 (Density)				
Brain-based learning element	**Brain-based learning principles** (Table 3.4)	**Technology** (Table 2.4)	**TBBaSK activity** (Table 2.12)	**Senses**
	processes, sleep 10. Neuroplasticity 11. Feedback and repetition 12. Memory 13. Attention 14. Prior knowledge	Social media: WhatsApp		

The subject head and a former student attended the control and experimental group sessions to ensure fairness and avoid researcher bias. Their reports are included as evidence of the fairness of the intervention (Appendix A4).

5.3 SUMMARY

The chapter dedicated to the case study provides an in-depth exploration of the study's contextual background. Furthermore, it thoroughly examines the precise execution of the intervention, covering aspects such as the time frame, demographic data, the intervention's progression and the application of the TBBaSK Framework within the study.

The findings are presented in the following chapter.

CHAPTER 6: RESEARCH FINDINGS

6.1 INTRODUCTION

A mixed-method study from a pragmatism philosophical stance was used to solve the research problem. The data collection and instruments used were discussed in detail in Chapter 4.

6.2 FINDINGS FROM THE QUANTITATIVE AND QUALITATIVE ANALYSIS

The following sections define the relevant descriptive and inferential quantitative statistical and qualitative data analysis terms used to analyse the data as per research questions 1 to 5.

In addition to the pre- and post-tests, structured questionnaires were employed to assess participants' motivation and mindset. To gather insight into students' experiences during the intervention, unstructured, open-ended questions were utilised. The specific question asked in these open-ended inquiries was: Please provide any comments regarding your learning experience during the intervention.

Before moving to the findings, this chapter presents the relevant demographic data to understand the sample's characteristics and representativeness.

6.2.1 Demographic statistics

In this study, 54% of the participants was male and 46% was female. This data is shown in Table 6.1:

Table 6.1: Percentage of male-to-female participants in the control and experimental groups

	Male participants		**Female participants**		**Total**	
	N	**%**	**N**	**%**	**N**	**%**
Experimental group	10	43	13	57	23	56
Control group	12	67	6	33	18	44
Total	22	54	19	46	41	100

A summary of descriptive statistics for the qualifications of fathers, mothers or guardians is given in Table 6.2 and Figure 6.1.

Table 6.2: Summary of parents' qualifications

	Fathers				Mothers				Guardian				Total				Total	
	Experimental		**Control**		**Experimental**		**Control**		**Experimental**		**Control**		**Experimental**		**Control**			
	N	**%**	**N**	**%**	**N**	**%**	**N**	**%**	**N**	**%**	**N**	**%**	**N**	**%**	**N**	**%**	**N**	**%**
Not answered	1	5	1	8		0	1	6	3	18	1	8	4	7	3	7	7	7
Lower than high school	5	24	1	8	6	29	1	6	2	13		0	13	22	2	5	15	15
High school qualification	3	14	3	23	4	19	2	13	2	13	4	31	9	16	9	21	18	18
Attended college	5	24	3	23	4	19	4	25	3	19	1	8	12	21	8	19	20	20
Graduated college	6	28	3	23	7	33	6	37	5	31	4	30	18	31	13	31	31	31
Master's or doctoral degree	1	5	2	15			2	13	1	6	3	23	2	3	7	17	9	9
Total	**21**		**13**		**21**		**16**		**16**		**13**		**58**		**42**		**100**	

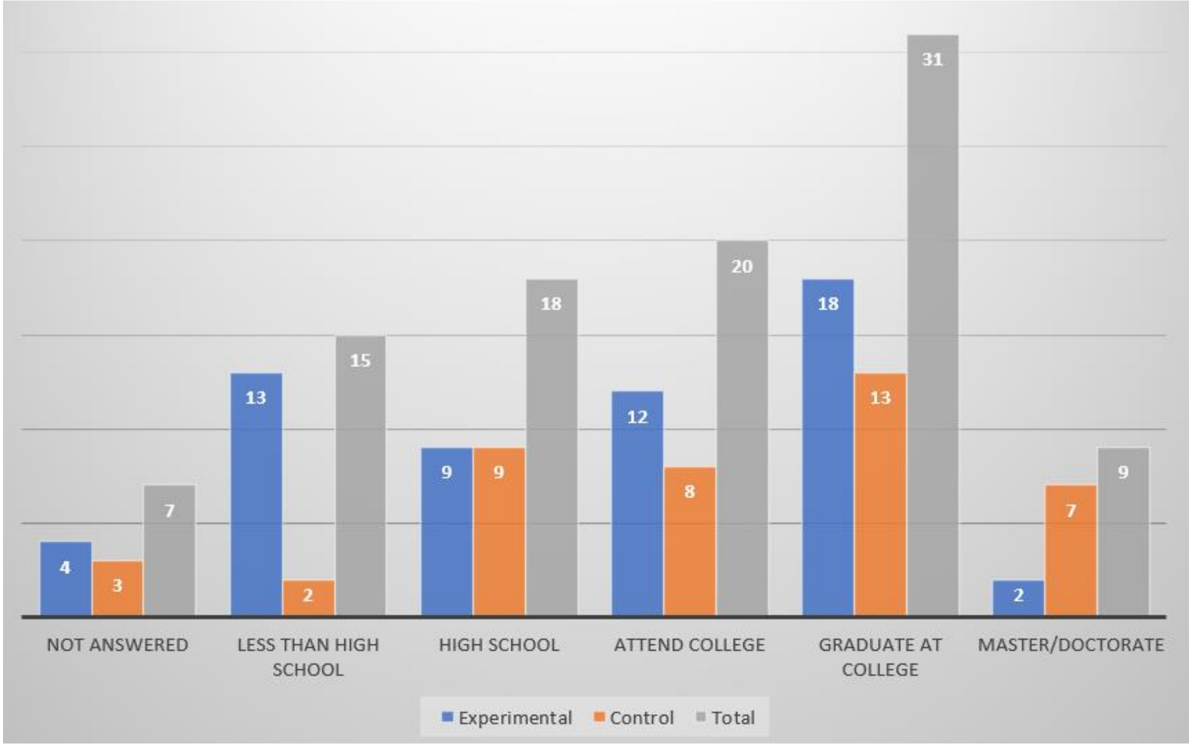

Figure 6.1: Graph of demographic results for parents' qualifications

Table 6.2 and Figure 6.1 show that most parents and guardians graduated from college (tertiary qualification).

6.2.2 Statistical tests used in this study

Table 6.3 summarises the tests used in this research study (see Chapter 4.1.3.2) for a full description).

Table 6.3: Summary of the statistical tests used in this study

Name of the test used in this study	Parametric or non-parametric	What does it measure?
Shapiro-Wilk	Determine if parametric	Test normality
Spearman	Non-parametric	Correlation – degree of association
Mann-Whitney	Non-parametric	Distribution across groups
Friedman	Non-parametric	The statistical difference within groups

6.2.2.1 Descriptive statistics

The analysis of the descriptive data interpretation is presented below.

Descriptive statistics for motivation

The pre- and post-intervention results of the questionnaire to test levels of motivation were compared based on data from the structured questionnaire (MSLQ) (Appendix C2). See Table 6.4 and Figure 6.2 for the descriptive statistics for motivation.

Table 6.4: Descriptive statistics for motivation

Descriptive statistics for motivation						
		Mean	**Std dev**	**Min**	**Median**	**Max**
Experimental group	Pre-test	5.750	1.250	1.750	6.000	7.000
	Post-test	6.185	0.654	4.500	6.250	7.000
	Difference	**0.435**	**-0.596**	**2.750**	**0.250**	**0.000**
Control group	Pre-test	6.083	0.575	5.000	6.000	7.000
	Post-test	5.514	1.523	1.500	5.875	7.000
	Difference	**-0.569**	**0.948**	**-3.500**	**-0.125**	**0.000**

The experimental group's mean and median (middle value) scores for motivation for the pre- to post-intervention increased. A decrease was observed in pre- to post-test motivation scores for the control group – the motivation of the experimental group that participated in the intervention was enhanced. The control group was, on average, more motivated before the intervention than the experimental group.

The standard deviation of the post-intervention experimental group for motivation was almost half that of the pre-intervention for motivation and was closer to the mean. The standard deviation for the control group increased before and after the intervention for motivation.

It can be noted that the minimum is greater than zero, since no negative values were allowed. The motivation from the MSQL was interpreted as a score out of seven; hence, a maximum of seven makes sense.

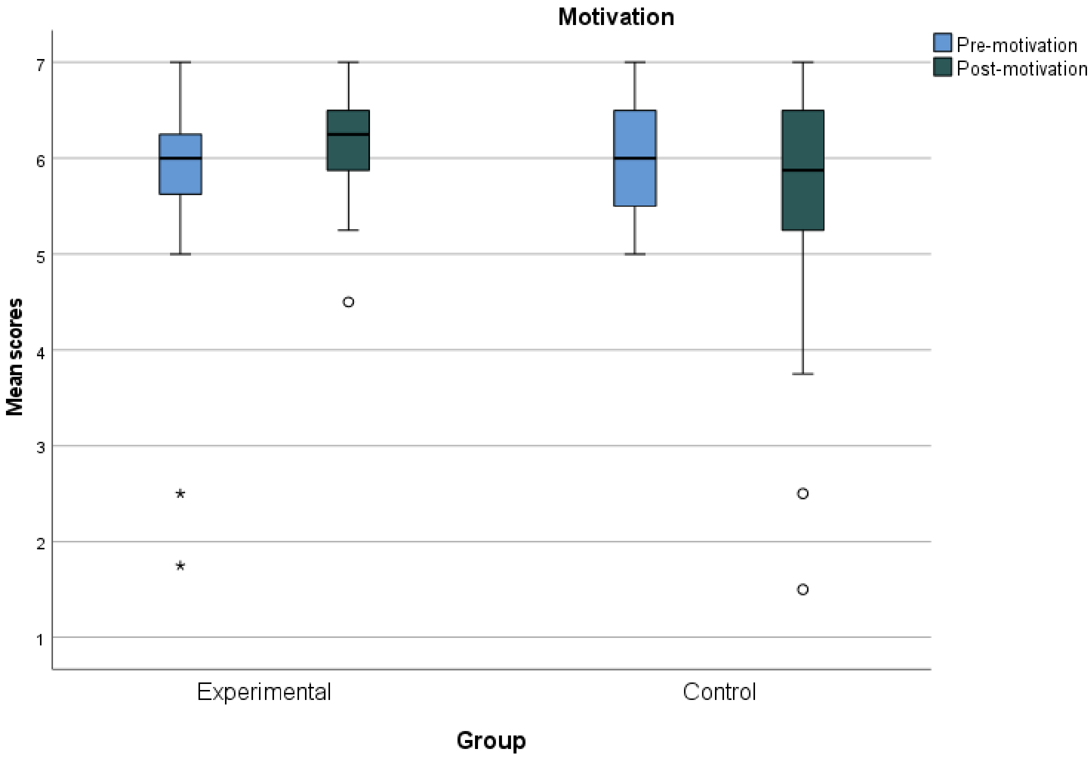

Figure 6.2: Graph of descriptive statistics pre- and post-intervention for motivation

Two outliers were identified for motivation pre-intervention and one outlier was identified post-intervention in the experimental group. The distribution of pre- and post-intervention results for motivation from Figure 6.2 can be similar in the experimental group when the outliers are excluded. It can be noted that the median in Figure 6.2 was higher post-intervention than pre-intervention for motivation in the experimental group (Table 6.4).

In the control group, there were two outliers post-intervention for motivation. Even after excluding the outliers, the post-intervention data was still more distributed than the pre-intervention data for motivation in Figure 6.2, as seen in Table 6.4. The median between the pre- and post-intervention data is seen to be close, with the median post-intervention being slightly lower.

Descriptive statistics for mindset

Data from a structured mindset questionnaire (Appendix C2) was used to compare the pre- and post-intervention results of change in mindset (Table 6.5 and Figure 6.3) for the descriptive statistics of mindset.

Table 6.5: Descriptive statistics pre- and post-intervention for mindset

Descriptive statistics for mindset						
		Mean	**Std dev**	**Min**	**Median**	**Max**
Experimental group	Pre-test	3.223	0.515	2.125	3.250	4.375
	Post-test	3.739	0.485	2.875	3.750	5.000
	Difference	**0.516**	**-0.030**	**0.750**	**0.500**	**0.625**
Control group	Pre-test	3.174	0.739	1.375	3.375	4.000
	Post-test	3.313	0.784	2.125	3.188	5.250
	Difference	**0.140**	**0.044**	**0.750**	**-0.188**	**1.250**

The mean scores pre- and post-intervention for mindset for the experimental and control groups increased. Although there was an increase in both cases, the experimental group increased to a greater extent.

The standard deviation values for the experimental group were relatively small, meaning that the results were close to the mean. It was a bit more dispersed for the control group.

It can be noted that the minimum is greater than zero, since no negative values were allowed. The difference in the median values of the experimental group's pre- and post-intervention results for mindset is similar to the difference in the mean values. The median value pre- and post-intervention for mindset for the control group decreased. An increase in the corresponding mean values is observed when comparing the difference in the median to the difference in the mean value. It can be noted that the average scores of the participants were higher, but that a lower number of participants scored higher than the mean. The change in the mindset of the participants as determined in the structured questionnaire was interpreted as a score out of six; hence, the maximum values of less than six make sense.

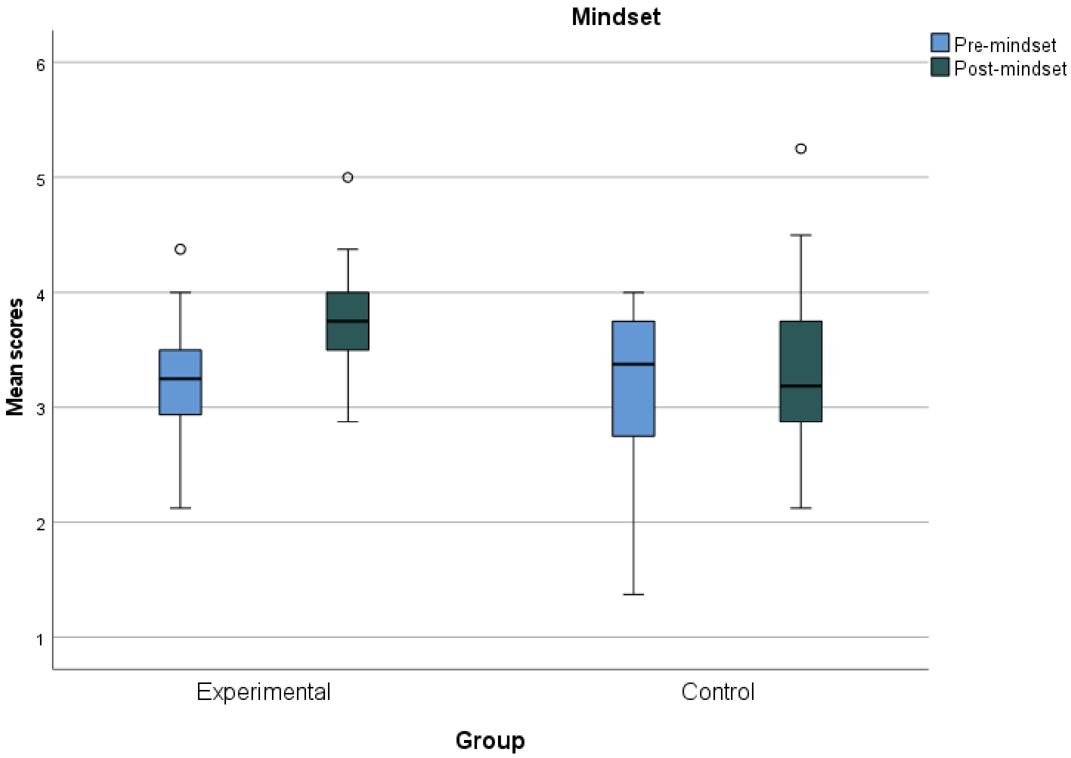

Figure 6.3: Graph of descriptive statistics pre- and post-intervention for mindset

The scores of one participant in the experimental group were excluded from the box plot in Figure 6.3 since it was an outlier. The median of the pre-intervention for mindset was lower than that of the post-intervention for mindset, while the distribution in Figure 6.3 was similar for the pre- and post-intervention for mindset in the experimental group.

In the control group for the post-intervention for mindset, one outlier was excluded. The pre- and post-interventions for mindset were similarly distributed in Figure 6.3. The median of the post-intervention was lower than for the pre-intervention for mindset.

Descriptive statistics for the science test

All 23 participants' science data was used in the experimental group. However, the data of only 17 of the 18 control group participants was used because of one significant outlier in the control group.

Descriptive data (as a percentage) from the pre- and post-tests for science performance are given in Table 6.6 and Figure 6.4.

Table 6.6: Descriptive statistics for science test

Descriptive statistics for the science test						
		Mean (%)	**Std dev**	**Min (%)**	**Median (%)**	**Max (%)**
Experimental group	Pre-test	15.870	8.925	3.000	15.000	40.000
	Post-test	37.040	11.880	15.000	33.000	58.000
	Difference	**21.170**	**2.955**	**12.000**	**18.000**	**18.000**
Control group	Pre-test	19.880	11.789	5.000	16.500	50.000
	Post-test	37.350	16.613	10.000	40.500	65.000
	Difference	**17.470**	**4.824**	**5.000**	**24.000**	**15.000**

The mean and median scores before and after the science test increased in the experimental and control groups. Although there was an increase in both cases, there was a greater difference for the experimental group.

There were not large changes in the standard deviation between the pre- and post-test for the experimental and control groups.

The positive minimum scores make sense since the participants could not gain negative scores. The maximum scores obtained were significantly lower than the test's maximum, measured as a percentage.

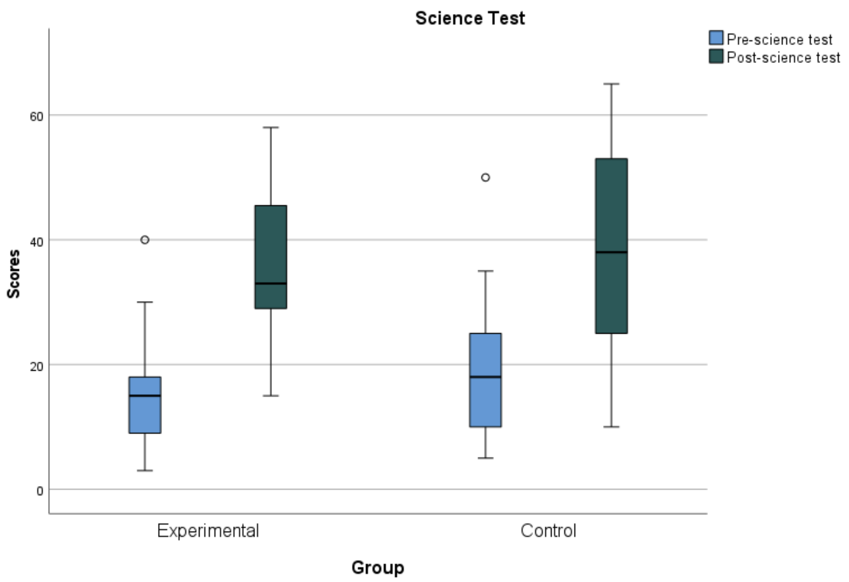

Figure 6.4: Graph of the descriptive statistics before and after the science test

There was one outlier in the pre-science test experimental group, which was excluded. The scores were more distributed in the post-science test than in the pre-science test. The median of the post-science test is higher than that of the pre-science test and even higher than the maximum of the pre-science test when the outlier is excluded.

One participant's score was an outlier in the pre-science test control group. The distribution of the post-science test is higher than that of the pre-science test, as seen in Figure 6.4. As for the experimental group, the median of the post-science test control group is higher than that of the pre-science test control group and even higher than the maximum of the pre-science test when the outlier is excluded.

6.2.2.2 Test for normality

The Shapiro-Wilk test (sample size less than 50) was conducted to test the normality of this study's mindset and motivation data sets and the science test marks using the SPSS statistical software platform (Lowry, 2014). If none of the data is normally distributed and the group is small, parametric tests cannot be used. The findings are listed in Table 6.7.

H_0: Scores are normally distributed

Table 6.7: Summary of the non-parametric Shapiro-Wilk test

Shapiro-Wilk test for normality (p-values)				
		Motivation	**Mindset**	**Science test**
Experimental group	Pre-test	<0.010	0.843	0.080
	Post-test	0.075	0.411	0.144
Control group	Pre-test	0.411	0.013	0.099
	Post-test	0.003	0.556	0.718

In this test, the p-values for the pre-test motivation experimental, post-test motivation control and pre-test mindset control groups are < 0.05, meaning that H_0 was rejected and the data was not normally distributed. All the other groups had p-values > 0.05, meaning that H_0 was retained. H_0 is rejected for some groups; therefore, H_0 is also rejected for the Shapiro-Wilk test, and the data is not normally distributed. Considering the small sample, clarification for using the non-parametric test was established.

The following statistical tests are used to analyse the feedback of more than one sub-research question and are therefore discussed only once.

6.2.2.3 Correlation test

A one-tail Spearman's rho non-parametric correlation test – used as an alternative to the Pearson's test in parametric data – was executed to measure the strength of association between the data before and after the intervention of the experimental and control groups to answer the mentioned sub-research questions partially. Schober et al. (2018) define the correlation coefficient as a measure of how a change in one variable predicts a difference in another. A positive correlation occurs when the value of the variable increases or decreases simultaneously. Correlation coefficients greater than zero indicate a positive correlation. In contrast, a negative correlation occurs if the value is less than zero.

6.2.2.4 Testing hypotheses across groups

The Mann-Whitney (two-sided) test measured the distribution across the experimental and control groups. If the H_0 hypothesis is rejected, it implies that the data is equally distributed across the groups and that the analysis results are statistically significant. Therefore, confirming if the data across the groups was equally distributed is essential. The two-sided Mann-Whitney test is similar to the parametric independent T-test.

6.2.2.5 Testing hypotheses within groups

The Friedman test was used to compare and determine if the means in ranking from the same subjects pre and post-test within the groups were statistically different (Glen, 2021)**.**

6.2.3 Findings from the quantitative and qualitative data analysis

These relevant statistical tests per research question are described in the following section.

RQ 1: What is the effect of using technology in science understanding?

The analysis of the feedback from participants from the experimental group on the use of technology, collected via questionnaires (Appendix E4), is given as frequency tables (Table 6.8) and themes (Table 6.9).

Table 6.8: Frequency table for questions on the impact of technology on science understanding for the experimental group.

Do you feel that the use of technology helped you to have a better understanding of science?						
		Frequency	Percentage	Valid %	Cumulative %	Combined %
Valid	I do not know	2	8.70	8.70	8.70	8.70
	Fairly	8	34.78	34.78	43.48	91.30
	Absolutely	13	56.52	56.52	100.00	
	Total	**23**	**100.00**	**100.00**	**23.00**	
Did the multiple-choice online questions help you?						
		Frequency	Percentage	Valid %	Cumulative %	Combined %
Valid	Not really	2	8.70	8.70	8.70	13.04
	I do not know	1	4.35	4.35	13.04	
	Fairly	10	43.48	43.48	56.52	86.96
	Absolutely	10	43.48	43.48	100.00	
	Total	**23**	**100.00**	**100.00**		
Did you make use of Schoology?						
		Frequency	Percentage	Valid %	Cumulative %	Combined %
Valid	Not at all	3	13.04	13.04	13.04	47.83
	Not really	7	30.43	30.43	43.48	
	I do not know	1	4.35	4.35	47.83	
	Fairly	5	21.74	21.74	69.57	52.17
	Absolutely	7	30.43	30.43	100.00	
	Total	**23**	**100.00**	**100.00**		

Did you enjoy playing Kahoot!?						
		Frequency	Percentage	Valid %	Cumulative %	Combined %
Valid	Not at all	1	4.35	4.35	4.35	4.35
	Fairly	1	4.35	4.35	8.70	95.65
	Absolutely	21	91.30	91.30	100.00	
	Total	**23**	**100.00**	**100.00**		

As seen in Table 6.8, 91.2% of the experimental group's participants found technology valuable in teaching, and 87% found using multiple-choice questions helpful. A total of 51% used Schoology as a tool, and an overwhelming 95.6% enjoyed Kahoot! to capture the work done. This can be interpreted as having an overall positive effect on science understanding.

Table 6.9: Feedback from the experimental group on technology

Participant number	Feedback from the experimental group
29	"…The lecturer started from the start and I developed interest from day one and understand why it is important for Engineering; the games, schoology and brain knowledge help us…."
52	"…Nice - The exercises helped me a lot. Games was also nice because it was a refreshment of the work done. Thankful"
77	"…Playing games while learning was fun and enjoyable-helped me to remember. Wish I knew it before I did matric…."
93	"I now know how to use my PC. Thankful for the opportunity. It was helpful and fun"
98	"…. Thankful - enjoy the games"
120	"I enjoyed MCQ's -…. MCQ's help me to use my brain and how to think faster…."

From the open-ended question, participants from the experimental group indicated that the games enabled them to capture the work and that technology makes the work more understandable (Table 6.9).

No feedback from the control group can be reported because the technology was part of the intervention, which they did not take part in.

RQ 2: What is the effect of brain-based learning on science understanding?

The analysis of the feedback from participants from the experimental group on brain knowledge, collected via questionnaires (Appendix E4), is given as frequency tables (Table 6.10) and themes (Table 6.11).

Table 6.10: Frequency table for questions on the influence of brain-based learning on science understanding from the experimental group

Do you feel using the brain-based learning helped you better understand science?						
		Frequency	Percentage	Valid %	Cumulative %	Combined %
Valid	Not at all	1	4.35	4.35	4.35	13.04
	I do not now	2	8.70	8.70	13.04	
	Fairly	10	43.48	43.48	56.52	86.96
	Absolutely	10	43.48	43.48	100.00	
	Total	**23**	**100.00**	**100.00**		
Did you understand the information on the brain?						
		Frequency	Percentage	Valid %	Cumulative %	Combined %
Valid	Not really	3	13.04	13.04	13.04	21.74
	I do not now	2	8.70	8.70	21.74	
	Fairly	13	56.52	56.52	78.26	78.26
	Absolutely	5	21.74	21.74	100.00	
	Total	**23**	**100.00**	**100.00**		
Did you enjoy doing the mind move exercises?						
		Frequency	Percentage	Valid %	Cumulative %	Combined %
Valid	Not really	2	8.70	8.70	8.70	17.39
	I do not now	2	8.70	8.70	17.39	
	Fairly	5	21.74	21.74	39.13	82.61
	Absolutely	14	60.87	60.87	100.00	
	Total	**23**	**100.00**	**100.00**		

Did you find the "deep breath" exercise helpful?

		Frequency	Percentage	Valid %	Cumulative %	Combined %
Valid	Not at all	1	4.35	4.35	4.35	
	Not really	1	4.35	4.35	8.70	17.39
	I do not now	2	8.70	8.70	17.39	
	Fairly	4	17.39	17.39	34.78	82.61
	Absolutely	15	65.22	65.22	100.00	
	Total	**23**	**100.00**	**100.00**		

Do you feel that using multiple modalities (the use of all your senses: seeing, hearing and movement) helps you better understand science?

		Frequency	Percentage	Valid %	Cumulative %	Combined %
Valid	Not really	1	4.35	4.55	4.55	27.27
	I do not now	5	21.74	22.73	27.27	
	Fairly	9	39.13	40.91	68.18	72.73
	Absolutely	7	30.43	31.82	100.00	
	Total	**22**	**95.65**	**100.00**		
Missing	System	1	4.35	0.00		
Total		**23**	**100.00**	**100.00**		

Did you find the practical experiments helpful?

		Frequency	Percentage	Valid %	Cumulative %	Combined %
Valid	Not really	2	8.70	8.70	8.70	8.70
	Fairly	5	21.74	21.74	30.43	91.30
	Absolutely	16	69.57	69.57	100.00	
	Total	**23**	**100.00**	**100.00**		

Did the videos help your understanding?

		Frequency	Percentage	Valid %	Cumulative %	Combined %
Valid	Not really	3	13.04	13.04	13.04	26.09
	I do not know	3	13.04	13.04	26.09	
	Fairly	7	30.43	30.43	56.52	73.91
	Absolutely	10	43.48	43.48	100.00	
	Total	**23**	**100.00**	**100.00**		

As seen in Table 6.10, 87% of the participants in the experimental group found brain-based learning worthy of teaching, and 78.2% now understand the information given to the brain. A total of 82.6% found making mind moves and the deep-breath exercises to refresh their minds to enhance their concentration. A total of 72.7% of the participants in the experimental group appreciated multiple modalities in teaching, and 91.3% found the practical experiment helpful. A total of 73.9% appreciated the use of videos during the intervention. This can be interpreted as having an overall positive effect on science understanding.

From the open-ended question, experimental group participants reported finding brain-based learning fascinating and beneficial. The brain exercises, mind moves and relaxation with deep breathing enabled them to focus on the work (Table 6.11). Several participants confirmed that guidance in answering questions in different ways and using a visual presentation helped them. The practical experiment enhanced their understanding. Some found that using all their senses enabled them to relax their brain and overcome stress (Table 6.11).

Table 6.11: Feedback from the experimental group on brain-based learning

Participant number	Feedback from the experimental group
3	"Technology and the experiments help me because I am more practical than theoretical. The mind moves were relaxing and amazing and experiments showed a clear picture of the theory."
9	"I did not really realize the importance of brain knowledge but wants to know more now"
13	"Brain knowledge helped met to improve my studies. I know it is growing- now I have a positive mindset. I learned through the intervention that I now have a growth mindset. Thankful and wish there was more"
17	"Through all the senses I learn to relax my brain - stay more focused and think clearly. Mind moves help me relax and use all senses, I can focus better to answer any question."
29	"… brain knowledge help us I also know now how to calm down and to take a deep breath when stressing…."
32	"I now understand how the brain functions and that it can grow. Was very helpful - wish there was more. The information helps me not only in studies but also for my future"
38	"Brain exercises gave me a clearer understanding and make me hunger to use in my studies.…"
48	"I would like to go deeper into the knowledge of the brain. Amazing. I learnt more that I was taught in class. Knowing how your brain works, helps me to perform academically better…."

Participant number	Feedback from the experimental group
71	"I wish I could know the working of the brain and the mind moves for concentration earlier. It was very helpful. I wish we could do this in all our studies."
77	"…I was never been introduced to the knowledge of the brain-found it very interesting. Thankful I know to use all senses and my brain to learn and to overcome stress. Can be helpful for so much more students…."
81	"Found the knowledge of the brain interesting - knowing which parts of the brain we use to think. Thankful for the opportunity."
110	"I learned to solve problems and will not fail again. I learned something that I did not ever experience in my whole life. I learned how the brain works, to focus and to relax. I know now how to solve the problems on fluids"
120	"… Deep breath helps me to cool down and relax my mind. …. MCQ's help me to use my brain and how to think faster. The experiment helps me to understand better"
149	"I did not know how the brain works and find this very interesting…."
153	"… The brain knowledge helped me to understand why I sometimes forget the work when I write a test…."
156	"I now know how my brain works and that sleeping is important for the brain…."

No feedback from the control group can be reported because the knowledge of the brain was part of the intervention that they did not take part in.

The results show that the participants found brain-based learning interesting and claimed it improved their science understanding.

The analysis of the feedback from participants from the experimental group on multiple modalities, collected via questionnaires (Appendix E4), is given as frequency tables (Table 6.10) and themes (Table 6.11).

A total of 72.7% of the participants in the experimental group appreciated multiple modalities in teaching, and 91.3% found the practical experiment helpful. A total of 73.9% appreciated the use of videos during the intervention. This can be interpreted as having an overall positive effect on their science understanding.

From the open-ended question, several participants from the experimental group confirmed that guidance in answering questions in different ways and using a visual presentation helped them. The practical experiment enhanced their understanding. Some found that using all their senses enabled them to relax their brain and overcome stress (Table 6.10).

No feedback from the control group can be reported because the explicit use of multiple modalities was part of the intervention that they did not take part in.

For research questions 3 and 4, the descriptive data from the pre- and post-intervention are used as given in section 6.2.2, Table 6.4, Table 6.5 and Table 6.6, respectively.

RQ 3: What is the effect of intrinsic motivation on science performance?

The Spearman's rho test was executed in inferential statistics to determine the correlation between intrinsic motivation and science performance (Table 6.12).

H_0: The impact on motivation and the impact on the science test is not correlated

Table 6.12: Spearman's rho – correlation between intrinsic motivation and science performance

Spearman's rho – correlation between intrinsic motivation and science performance			
	Correlation	**p (one-tail)**	**Null hypothesis**
Experimental group	0.182	0.203	Retained
Control group	-0.039	0.441	Retained

All 23 participants' science data was used in the experimental group. However, the data of only 17 of the 18 control group participants was used because of one significant outlier in the control group.

The correlation for the experimental group seems positive, but the p-values are > 0.05, so a strong correlation could not be established.

No positive correlation for the control group could be established.

RQ 4: What is the effect of mindset on science performance?

The Spearman's rho test was used in inferential statistics to statistically determine the correlation between mindset and science performance (Table 6.13).

H_0: The impact on mindset and the impact on the science test is not correlated.

Table 6.13: Spearman's rho – correlation between mindset and science performance

Spearman's rho – correlation between mindset and science performance			
	Correlation	**p (one-tail)**	**Null hypothesis**
Experimental group	0.467	0.012	Rejected
Control group	0.460	0.031	Rejected

The science data of all 23 participants in the experimental group was used. However, the data of only 17 of the 18 participants in the control group was used because of one significant outlier in the control group.

The correlation between the experimental and the control groups was positive, and the p-values were < 0.05, so a strong correlation was established.

The quantitative part of sub-research question 5 could be analysed using statistics, while the qualitative part revealed the participants' experiences after the TBBaSK intervention. Because only the experimental group took part in the intervention, they could also answer specific questions using a Likert scale (Appendix E4). However, the control group could not answer those questions because they did not participate in the intervention.

An explanation of how the TBBaSK intervention impacts intrinsic motivation, mindset and science performance follows below.

RQ 5: What is the effect of implementing the TBBaSK Framework on intrinsic motivation, mindset and science performance?

(a) The effect of the TBBaSK Framework on intrinsic motivation

The Mann-Whitney U test determined the data distribution across the experimental and control groups.

The hypotheses used in this report are given below:

H_0: $\mu_{experimental} = \mu_{control}$ across the experimental and control groups for motivation (equally distributed)

Alternative H_0: $\mu_{experimental} \neq \mu_{control}$

where μ is the mean rank values

The results are listed in Table 6.14.

Table 6.14: Results to determine the data distribution for motivation

Mann Whitney (two-sided test) for motivation		
		Pre-test
Mean rank values	**Experimental group**	20.370
	Control group	21.810
Significance		0.700
Null hypothesis		Retained
H_0: The distribution is the same across the experimental and control groups		

From the results, H_0 is retained, which means that the distribution across the experimental and control groups for motivation was equally distributed.

Table 6.15 summarises the values for the independent samples. The data is also presented in Figure 6.5.

Table 6.15: Independent samples for Mann-Whitney U test distribution across pre-test for motivation

Independent samples Mann-Whitney U test summary	
Total N	41
Mann-Whitney U	221.500
Wilcoxon W	392.500
Test statistic	221.500
Standard error	37.664
Standardised test statistic	0.385
Asymptotic significance (two-sided test)	0.700

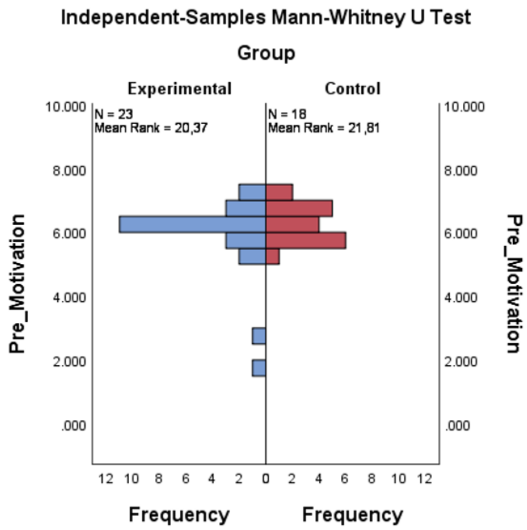

Figure 6.5: Pre-test for motivation across the group

The equal distribution is also seen in the graph. Knowing that the data for motivation pre- and post-intervention across the experimental and control groups was equally distributed, the next inferential test could be executed.

The Friedman test was used to determine whether motivation scores (pre-test vs. post-test) for the groups (experimental vs. control) were similar.

H_0: $\mu_{pre} = \mu_{post}$ within the experimental and control groups for motivation

Alternative H_0: $\mu_{pre} < \mu_{post}$ within the experimental and control groups

where μ is the mean rank values

If H_0 is rejected, it means there was an improvement in values from before to after the intervention. The results for the Friedman test can be seen in Table 6.16 and the represented graphs in Figure 6.6 and Figure 6.7.

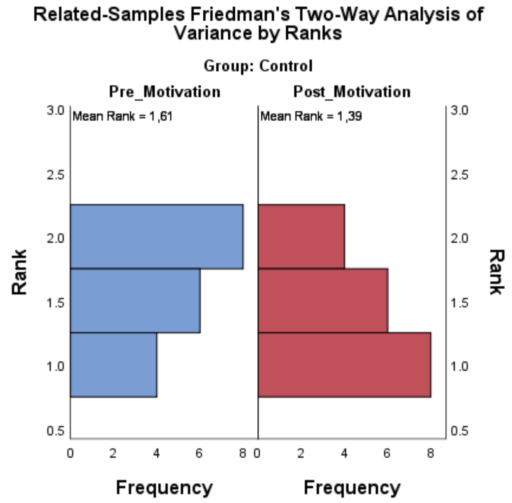

Figure 6.6: Motivation within the experimental group

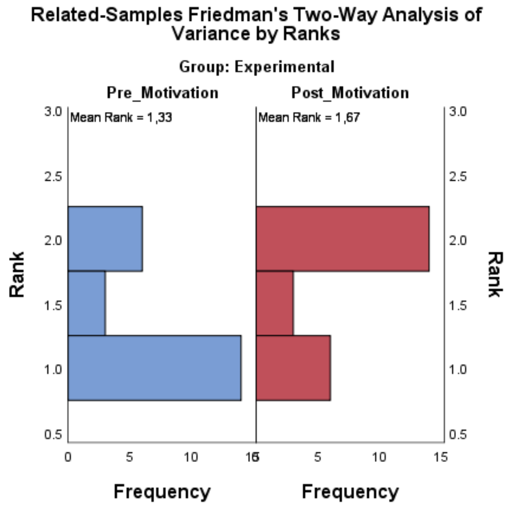

Figure 6.7: Motivation within the control group

Table 6.16: A non-parametric test for motivation within the experimental and control groups

Friedman test for motivation					
		Pre-test	**Post-test**	**p**	**Null hypothesis**
Mean rank values	**Experimental group**	1.330	1.670	0.074	Retained
	Control group	1.610	1.390	0.248	Retained

Since H_0 was retained in the Friedman test for motivation in the experimental and control groups, it implied no improvement in motivation from pre- to post-intervention. There are indications that the experimental group that participated in the intervention showed better motivation than the control group p(experimental) = 0.074 vs. p(control) = 0.248.

From the qualitative data, seven participants from the control group experienced an improvement due to motivation, the reward when answering the multiple questions and the value of sacrificing Saturdays. They found that problems could be answered more confidently (Table 6.17).

Table 6.17: Feedback from the control group on motivation

Participant number	Feedback from the control group
19	"Boost Science knowledge; Fun and helpful."
42	"Boost Science knowledge; Lecturer friendly; Not scared to ask questions; Classes are productive and good explained; Caring, understanding and helpful."
43	"Boost Science knowledge; Better understanding and confidence of fluids; Rewarding with a sweet – inspiring; Enjoy every class."
67	"Worth coming to class even on Saturdays; Better understanding; Would like more similar classes in other chapters."
130	"Better insight in a challenging chapter-see light now; I Would like a similar class on heat; Thankful for the help."
134	"Able to approach questions positively with confidence; Thankful for the opportunity"
166	"Understand and have confidence; Learn to read a question 3 times to understand before answering."

From the open-ended question, four experimental group participants reported that they felt more motivated and experienced personal growth after the intervention. They are confident about achieving better marks. Some of the feedback is stated below:

Table 6.18: Feedback from the experimental group on motivation

Participant number	Feedback from the experimental group
32	"… The information helps me not only in studies but also for my future"
38	"… I understand myself better and know that I can achieve more. The intervention helped me with the current module but also with other. Most important it helped me to understand myself better."
156	"…It has changed how I think of myself and got to understand my brain better."
159	"… Helpful. I now have a better understanding of myself. I never experienced this before…."

The feedback from Table 6.17 and Table 6.18 showed that the participants felt more motivated after the intervention. The participants from the experimental group gave feedback on their experiences with motivation after the intervention. The analysis of participant feedback was collected via questionnaires (Appendix E4) and is provided as frequencies (Table 6.19).

Table 6.19: Feedback on the impact of the TBBaSK Framework on intrinsic motivation from the experimental group

Do you feel more self-motivated about the work than before the intervention?						
		Frequency	Percentage	Valid %	Cumulative %	Combined %
Valid	Not really	1	4.35	4.35	4.35	8.70
	I do not know	1	4.35	4.35	8.70	
	Fairly	5	21.74	21.74	30.43	91.30
	Absolutely	16	69.57	69.57	100.00	
	Total	**23**	**100.00**	**100.00**		

Results from this table indicated that 91.3% of participants from the experimental group felt more self-motivated after the intervention. No feedback from the control group can be reported because they did not participate in the intervention or fill in this questionnaire.

(b) The effect of the TBBaSK Framework on mindset

The Mann-Whitney U test determined the data distribution across the groups.

The hypotheses used in this study are given below:

H_0: $\mu_{experimental} = \mu_{control}$ across the experimental and control groups for mindset (equally distributed)

Alternative H_0: $\mu_{experimental} \neq \mu_{control}$

where μ is the mean rank values

The results are listed in Table 6.20.

Table 6.20: Results to determine the data distribution for mindset

Mann Whitney (two-sided test) for mindset		
		Pre-test
Mean rank values	**Experimental group**	20.150
	Control group	22.080
Significance		0.607
Null hypothesis		Retained
H_0: The distribution is the same across the experimental and control groups		

The H_0 is retained, meaning that the experimental and control groups' distribution before the test on mindset was equally distributed.

Table 6.21 summarises the independent samples of the Mann-Whitney U test values across mindsets. The data is also presented in Figure 6.8.

Table 6.21: Independent samples of Mann-Whitney U test distribution across pre-test for mindset

Independent samples Mann-Whitney U test summary	
Total N	41
Mann-Whitney U	226.500
Wilcoxon W	397.500
Test statistic	226.500
Standard error	37.923
Standardised test statistic	0.514
Asymptotic significance (two-sided test)	0.607

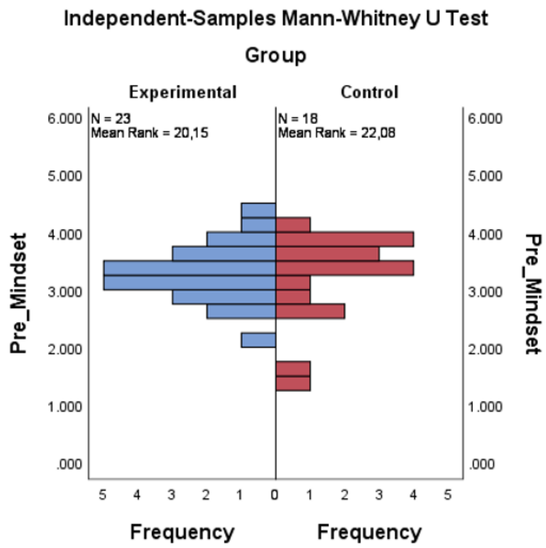

Figure 6.8: Pre-test for mindset across groups

The Friedman test for non-parametric data was used to determine if the scores (pre-test vs. post-test) within the groups (experimental vs. control) were similar for mindset after the intervention.

H_0: $\mu_{pre} = \mu_{post}$ within the experimental and control groups for mindset

Alternative H_0: $\mu_{pre} < \mu_{post}$ within the experimental and control groups

where μ is the mean rank values

If H_0 is rejected, it means there was an improvement in values from before to after the intervention. The results for the Friedman test can be seen in Table 6.22 and the represented graphs in Figure 6.9 and Figure 6.10.

Table 6.22: A non-parametric test for mindset within experimental and control groups

Friedman test for mindset					
		Pre-test	**Post-test**	**p**	**Null hypothesis**
Mean rank values	**Experimental group**	1.150	1.850	0.001	Rejected
	Control group	1.560	1.440	0.617	Retained

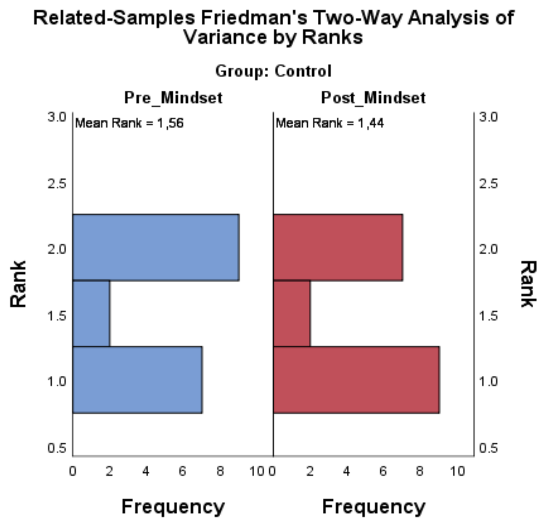

Figure 6.9: Mindset within the control group

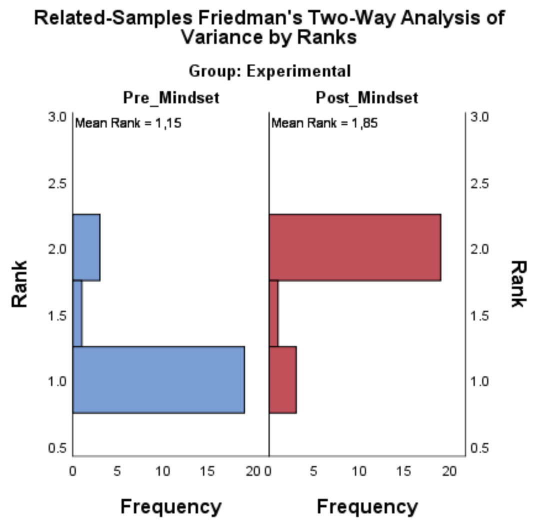

Figure 6.10: Mindset within the experimental group

The H_0 was retained in the Friedman test for mindset in the control group, and by implication, no improvement occurred in the control group in mindset pre- and post-intervention. However, H_0 was rejected in the Friedman test for mindset in the experimental group. It is, therefore, clear that the experimental group that participated in the intervention showed a substantial change in their mindsets. However, the control group, which did not participate in the intervention, did not show improvement in mindset pre- and post-intervention.

Responding to the open-ended question, three participants from the control group found that the classes changed their mindset and they experienced a positive influence and change of opinion (Table 6.23).

Table 6.23: Feedback from the control group on mindset

Participant number	Feedback from the control group
84	"Positive influence; catch up where I felt lost; Will improve performance; Very helpful and understanding"
131	"Grateful to be part; The best preparation for tomorrow is to do your best today; Your mindset can be changed."
148	"Opinion about the level of difficulty of fluids changed; Thankful for the opportunity"

From the open-ended question, eight experimental group participants reported learning that their brains can grow. The paths of their brain can change to develop a growth mindset through repetition and by doing things differently (Table 6.24).

Table 6.24: Feedback from the experimental group on mindset

Participant number	Feedback from the experimental group
2	"To see the picture help me - as well as the practical experiment. Help in my studying, to concentrate with brain exercises and to change the brain paths."
13	"… I know it is growing- now I have a positive mindset. I learned through the intervention that I now have a growth mindset.…"
29	"I did not know that one can change your intellect and improve it by the way you think…."
32	"I now understand how the brain functions and that it can grow…."
120	"I enjoyed MCQ's - help me how to think-knowing that my mind grows...."
128	"I am proud of myself because I now know that anything is possible if you give more effort. Thankful"
153	"Enjoy all because all help me to realize that my mind is not fixed…."
159	"I learned that anyone can make their mind to have a better understanding of things and that I can change my mind set by repetition and doing things differently…."

From this feedback, the participant's experiences were all very positive.

The analysis of the feedback from participants from the experimental group on mindset, collected via questionnaires (Appendix E4), is given as frequency tables (Table 6.25). The experimental group participants' feedback was also analysed via frequency tables.

Table 6.25: Feedback on the impact of the TBBASK Framework on mindset from the experimental group

Do you realise that your brain is elastic and your mind can grow?						
		Frequency	Percentage	Valid %	Cumulative %	Combined %
Valid	Not really	1	4.35	4.35	4.35	8.70
	I do not know	1	4.35	4.35	8.70	
	Fairly	8	34.78	34.78	43.48	91.30
	Absolutely	13	56.52	56.52	100.00	
	Total	**23**	**100.00**	**100.00**		

The feedback from the experimental group showed that 91.3% of participants now realise that their minds can grow because of neuroplasticity. No feedback from the control group can be reported because they did not participate in the intervention or fill in this questionnaire.

(c) The effect of the TBBaSK Framework on science performance

The Mann-Whitney U test determined the data distribution across the groups.

The hypotheses used in this report are given below:

H_0: $\mu_{experimental} = \mu_{control}$ across the experimental and control groups for the science test (equally distributed)

Alternative H_0: $\mu_{experimental} \neq \mu_{control}$ where μ is the mean rank value

The results are listed in Table 6.26.

Table 6.26: Results to determine the data distribution for the science test

Mann Whitney (two-sided test) for science test		
		Pre-test
Mean rank values	**Experimental group**	19.200
	Control group	23.310
Significance		0.273
Null hypothesis		Retained
H_0: The distribution is the same across the experimental and control groups		

From the results, H_0 is retained, which means that distribution across the experimental and control groups for the science test was equally distributed.

Table 6.27 summarises the values for the independent samples in the Mann-Whitney U test across science test. The data is also presented in Figure 6.11.

Table 6.27: Independent samples Mann-Whitney U test distribution across the pre-science set

Independent samples Mann-Whitney U test summary	
Total N	41
Mann-Whitney U	248.500
Wilcoxon W	419.500
Test statistic	248.500
Standard error	37.873
Standardised test statistic	1.096
Asymptotic significance (two-sided test)	0.273

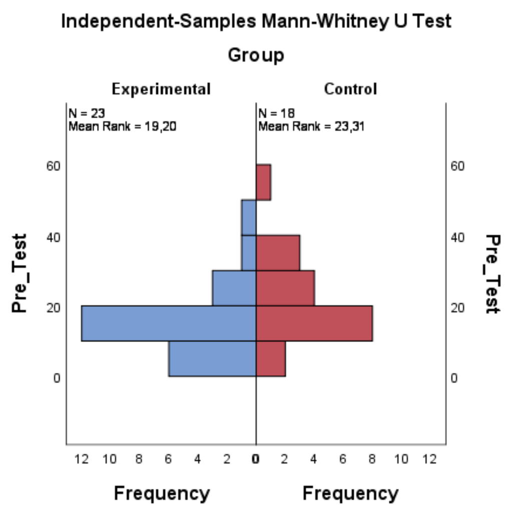

Figure 6.11: Pre-science test across the groups

Because the data was equally distributed, the following inferential statistics could be implemented using non-parametric tests.

The Friedman test for non-parametric data was also used to determine if the scores (pre-test vs. post-test) within the groups (experimental vs. control) were similar for the science test (Appendix E2 and E3).

H_0: $\mu_{pre} = \mu_{post}$ within the experimental and control groups for the science test.

Alternative H_0: $\mu_{pre} < \mu_{post}$ within the experimental and control groups

where μ is the mean rank values

If H_0 is rejected, it means there was an improvement in values from before to after the intervention. The results for the Friedman test can be seen in Table 6.28 and the represented graphs in Figure 6.12 and Figure 6.13.

Table 6.28: A non-parametric test for science tests within the experimental and control groups

Friedman test for the science test						
		Pre-test	**Post-test**	**p**	**Null hypothesis**
Mean rank values	**Experimental group**	1.070	1.930	0.000	Rejected
	Control group	1.150	1.850	0.003	Rejected

N = 17 for the control group instead of 18 due to one participant's extremely high mark that was seen as an outlier and excluded for this part.

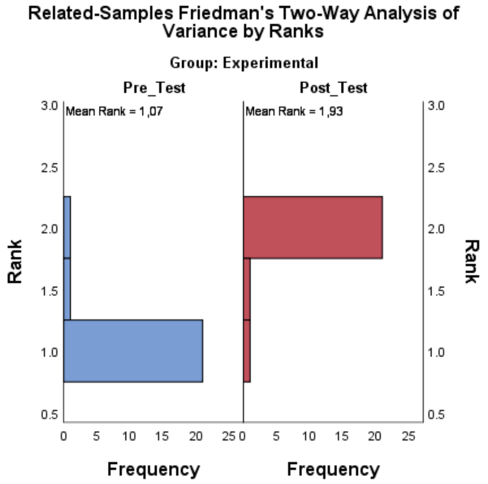

Figure 6.12: Science tests within the experimental group

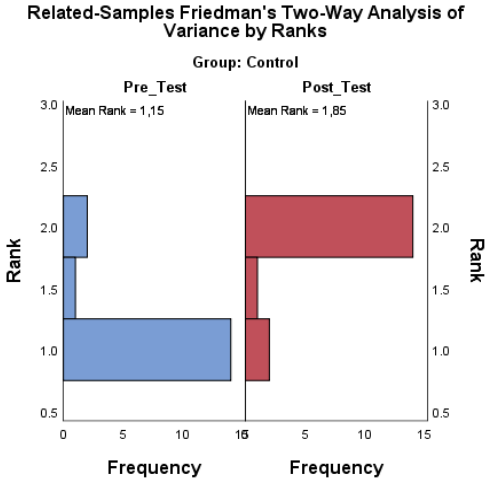

Figure 6.13: Science tests within the control group

H_0 was rejected in the Friedman test for the science test for both groups and indicated improvement in science understanding for the experimental and control groups after intervention. Although the difference was slight, the science performance of the experimental group ($p = 0.000$) improved better than the control group ($p = 0.003$).

The results of the open-ended question showed that all participants from the control group experienced an improvement in their understanding of science. They can now solve their mistakes and approach questions differently, which is informative and beneficial. The quotes from their responses not mentioned earlier are given in Table 6.29.

Table 6.29: Feedback from the control group on the intervention

Participant number	Feedback from the control group
46	"Help to perform better; Help to discover own mistakes; Next test/exam will be easier on fluids"
58	"Learn how to break down a question into simpler parts; draw pictures to help the understanding; Classes were very helpful; Learn different methods, styles and ways of answering questions"
57	"A clear and better understanding of fluids; Experience a clear understanding of fluids; Learn to approach and answer questions; Would like more similar classes in other chapters."
101	"Better insight in a challenging chapter; Learning different techniques to answer questions; Informative and beneficial; Explaining and individual help from the lecturer was good"
132	"Appreciate guidance and help in class with questions and MCQs; Helped to differentiate between different parts of fluids"
150	"Understand everything clearly; Lecturer was prepared, kind and loving- therefore attending all classes"
148	"Opinion about the level of difficulty of fluids changed; Thankful for the opportunity"
176	"Appreciate the way of explaining and all the examples being done; Thankful"

From the open-ended question, all experimental participants reported that they found the intervention worthwhile. They experienced an improvement in science understanding, but are also adamant about applying this knowledge and problem-solving techniques in their other subjects. The quotes from their responses that were not mentioned earlier are given in Table 6.30.

Table 6.30: Feedback from the experimental group on the intervention

Participant number	Feedback from the experimental group
13	"… Thankful and wish there was more"
29	"… All were helpful and also fun"
51	"Everything was interesting and I learned a lot."
71	"… It was very helpful. I wish we could do this in all our studies…."
81	"… Thankful for the opportunity."
93	"... Thankful for the opportunity. It was helpful and fun."
149	"... Helpful and fun - wish there can be more classes than this."
153	"Enjoy all because all help me to realize that my mind is not fixed. Thankful - having a better understanding of science. I also apply this knowledge to mathematics and Statistics."
156	"…Thankful. It was very helpful. It has changed how I think of myself and got to understand my brain better."
159	"... Helpful. I now have a better understanding of myself and can change my intelligence. I never exprienced this before - I will remember it for lifetime."

The feedback from participants, as seen in Table 6.30 and Table 6.31, is overwhelmingly positive – meaning that the participants found the TBBaSK intervention helpful and positive.

The analysis of the experimental group participants' feedback on the science test, collected via questionnaires (Appendix E4), is given as a frequency table (Table 6.31).

Table 6.31: Feedback on the impact of the intervention on science understanding from the experimental group

Do you feel that this intervention helped you to have a better understanding of science?						
		Frequency	Percentage	Valid %	Cumulative %	Combined %
Valid	Not really	1	4.35	4.35	4.35	8.70
	I do not know	1	4.35	4.35	8.70	
	Fairly	8	34.78	34.78	43.48	91.30
	Absolutely	13	56.52	56.52	100.00	
	Total	**23**	**100.00**	**100.00**		

Would you like to have more classes like these in the future?						
		Frequency	Percentage	Valid %	Cumulative %	Combined %
Valid	Not really	1	4.35	4.35	4.35	8.70
	Fairly	1	4.35	4.35	8.70	
	Absolutely	21	91.30	91.30	100.00	91.30
	Total	**23**	**100.00**	**100.00**		

The feedback from the experimental group showed that 91.3% of the participants from the experimental group felt optimistic that the intervention helped them understand science, and they expressed the need for more similar classes in the future.

No feedback from the control group can be reported because they did not participate in the intervention or fill in this questionnaire.

6.3 SUMMARY

Summary of findings for research question 5

(a) Results from the Friedman test for motivation showed that the experimental group that participated in the intervention showed better motivation than the control group. The feedback from the qualitative analysis showed that the participants felt more motivated after the intervention. Results from the experimental group on their experiences with motivation after the intervention indicated that 91.3% of participants from the experimental group felt more self-motivated after the intervention.

(b) Results from the Friedman test for mindset showed no improvement for the control group, but the experimental group that participated in the intervention showed a substantial change in their mindset. The feedback from the qualitative analysis showed that the participants felt positive. Results from the feedback from the experimental group showed that 91.3% of participants now realise that their minds can grow because of neuroplasticity.

(c) Results from the Friedman test for the science test indicated a better improvement in science performance for the experimental group. The feedback from the qualitative analysis was overwhelmingly positive, meaning that the participants found the

TBBaSK intervention to be helpful and positive. Results from the feedback from the experimental group showed that 91.3% of participants from the experimental group felt optimistic that the intervention had helped them in their understanding of science.

The purpose of this chapter is to present the results of a mixed-method case study that determined the influence of the implementation of the TBBaSK Framework on mindset, motivation and academic performance in science for undergraduate Engineering participants (see summary in Table 6.32).

Table 6.32: Summary of findings

	Research question	Finding
1	What is the effect of using technology in science understanding?	Participants from the experimental group found that technology enhanced their science understanding and made the work more understandable.
2	What is the effect of brain-based learning on science understanding?	The experimental group participants found brain-based learning fascinating and beneficial, and the experimental group participants indicated that multiple modalities positively affected their science understanding in several ways. They claimed it improved their science understanding.
3	What is the effect of intrinsic motivation on science performance?	Values for the correlation coefficient between motivation and science performance indicated a positive relationship between motivation and science performance, but the correlation was not significant.
4	What is the effect of mindset on science performance?	Results for the correlation between mindset and science understanding indicated a positive relation (qualitative data), but an insignificant correlation between mindset and science performance.
5	What is the effect of the implementation of the TBBASK Framework on mindset, motivation and science performance?	Statistical results from the Friedman test for motivation and the science test indicated an improvement for the experimental group that participated in the intervention compared to the control group. Although the results from the Friedman test showed no gain for the control group, a substantial change in the mindset of the experimental group that participated in the intervention was found. The feedback from the qualitative analysis was overwhelmingly positive, meaning that the participants found the TBBASK intervention to be helpful and positive. Results from the feedback from the experimental group showed that 91.3% of participants from the experimental group felt optimistic that the intervention had helped them in their understanding of science.

The next chapter will conclude the thesis and discuss the research questions by reflecting on the results.

CHAPTER 7: CONCLUSION

7.1 INTRODUCTION

The rationale of this study was formed when the researcher wanted to address a way to use technology and brain-based learning to support the mindset, intrinsic motivation and, eventually, students' performance in science. This was done by developing the Technology-enhanced, Brain-based and Science Knowledge (TBBaSK) Framework for science education. It was meant for lecturers teaching science undergraduate students from diverse backgrounds. Having thoroughly examined various teaching methods, the researcher directed their attention towards combining brain-based learning (referencing Caine et al., 2005; Schachl, 2013; Tokuhama-Espinosa, 2017) with the Technological Pedagogical Content Knowledge (TPACK) Framework proposed by Mishra and Koehler (2006) to achieve this objective. This integration aimed to enhance the academic performance of university science students.

In this chapter, the research questions are revisited, along with an explanation of the study's conclusions and recommendations. The chapter also outlines the contributions made by the researcher to the field and concludes with suggestions for future research. The principal objective of this study was to investigate the impact of the TBBaSK Framework on mindset, intrinsic motivation and science performance among first-year undergraduate university students.

An interpretative case study approach was employed, involving 41 first-year Engineering Science students from the Tshwane University of Technology in South Africa to fulfil the goals of this study. Data collection utilised a mixed-methods approach, combining quantitative structured and unstructured questionnaires with qualitative unstructured, open-ended questionnaires. This research's philosophical assumptions were grounded in pragmatism, incorporated into the suggested framework. The following primary research question and four sub-research questions were formulated to guide the study:

Main research question:

What constitutes a technology-enhanced brain-based framework for science education (the TBBaSK Framework)?

The sub-research questions that help to solve the main research question are:

RQ 1: What is the effect of using technology in science understanding?

RQ 2: What is the effect of brain-based learning on science understanding?

RQ 3: What is the effect of intrinsic motivation on science performance?

RQ 4: What is the effect of mindset on science performance?

RQ 5: What is the effect of implementing the TBBaSK Framework on mindset, intrinsic motivation and science performance?

Table 7.1 offers guidance on locating the research instruments and literature sources.

Table 7.1: Research instrument per research question

Research approach: mixed methods	**Quantitative**				**Qualitative**
Research instruments / **Research questions**	**Literature**	**Pre- and post-tests**	**Structured standardised Likert-scale questionnaires**	**Structured Likert-scale questionnaires on feedback**	**Open-ended questionnaires**
RQ 1: What is the effect of using technology in science understanding?	✓			✓	✓
RQ 2: What is the effect of brain-based learning on science understanding?	✓			✓	✓
RQ 3: What is the effect of intrinsic motivation on science performance?	✓	✓	✓		
RQ 4: What is the effect of mindset on science performance?	✓	✓	✓		
RQ 5: What is the effect of the implementation of the TBBaSK Framework on mindset, intrinsic motivation and science performance?		✓	✓	✓	✓

7.2 REVISITING THE RESEARCH QUESTIONS

The following research question addresses the purpose of this study:

RQ 1: What is the effect of using technology in science understanding?

Chapter 2.9 presents the incorporation of technology into science education. This section discusses various technologies utilised in science education, as outlined in a study conducted by Lai and Bower (2019).

From the case study, an analysis of the structured questionnaires (Appendix E4) from students in the experimental group regarding the use of technology is presented in the form of frequency tables (Table 6.8). According to the data obtained from the structured questionnaires, it was found that 91.2% of the participants in the experimental group considered technology to be valuable in teaching, and 87% found the use of multiple-choice questions to be beneficial.

These findings are aligned with existing literature, which highlights the growing interest in Web 2.0 technologies such as social media, YouTube and learning management systems in the context of science education (Ansari & Khan, 2020; Haşiloğlu et al., 2020; Mpungose, 2020). Furthermore, it was observed that 51% of the participants used Schoology as a tool, and an overwhelming 95.6% enjoyed using Kahoot! to enhance their learning experience. These findings are consistent with literature suggesting that students have a positive disposition towards mobile games like Kahoot! in science education (Khazanchi & Khazanchi, 2019; Mpungose, 2020; Rahmahani, 2020).

Based on the responses to open-ended questions, students in the experimental group expressed that using games helped them grasp the course content more effectively and that technology enhanced their understanding (Table 6.9). It is important to note that no feedback from the control group is available for reporting since the technology was integrated as part of the intervention, and the control group did not take part in this aspect of the study.

RQ 2: What is the effect of brain-based learning on science understanding?

Brain-based learning is discussed in chapter 2.11 of the literature review, including multisensory approaches. Several studies have investigated the effectiveness of brain-based learning techniques and approaches in enhancing students' academic achievement in science courses. The findings from these studies indicate that brain-based learning techniques and approaches tend to be more effective in improving students' academic performance than traditional teaching methods. These studies include the works of Achor and Gbadamosi (2020), Adadan (2013), Lagoudakis et al. (2022), Ozden and Gultekin (2008) and Saleh and Subramaniam (2019).

In 2022, Bada and Jita (2022) systematically reviewed integrating brain-based learning into science classes. Their review encompassed the analysis and discussion of findings from 25 peer-reviewed studies. Their objective was to shed light on the methods and approaches employed to facilitate the incorporation of brain-based learning in science classrooms.

Throughout their review, they systematically evaluated the effectiveness of brain-based learning in enhancing learning outcomes within the context of science classrooms. They also explored various strategies for integrating brain-based learning in primary and secondary educational institutions.

The case study results in this research study are consistent with findings reported in the existing literature. An analysis of the feedback obtained from students in the experimental group regarding brain-based learning, collected through structured questionnaires (as detailed in Appendix E4), is presented in the form of a frequency table (Table 6.10).

The data reveals that a significant proportion of participants in the experimental group reported positive outcomes related to their science understanding through brain-based learning:

- Some 87% of the participants expressed that brain-based learning positively contributed to their understanding of science.
- Some 78.2% of the students appreciated the information about the brain that was part of the brain-based learning approach.
- Incorporating techniques like "mind moves" and mindfulness was helpful to 82.6% of the students.

- Some 72.7% of the experimental group participants valued using multiple teaching modalities, a part of the brain-based learning approach.
- A substantial 91.3% of the students found practical experiments beneficial for their understanding of science.
- The use of videos during the intervention was appreciated by 73.9% of the participants.

These findings suggest an overall positive impact of the brain-based learning approach on students' understanding of science, as indicated by the high percentages of students who found various aspects of brain-based learning to be beneficial for their learning.

Based on responses to open-ended questions (Table 6.11), students in the experimental group expressed several positive experiences and benefits related to brain-based learning: Students found the knowledge of the brain fascinating and beneficial. Brain exercises, mind moves and deep breathing relaxation techniques helped students focus on their work. Students reported that learning about the brain was interesting and contributed to an improved understanding of science. Guidance in answering questions in different ways and using visual presentations were cited as helpful strategies. Practical experiments were noted as enhancing students' understanding. Some students mentioned that engaging all their senses helped them relax their brains and alleviate stress.

It is important to note that no feedback from the control group is available for reporting since brain-based learning and the associated interventions were specific to the experimental group and not part of the control group's experience.

RQ 3: What is the effect of intrinsic motivation on science performance?

Intrinsic motivation is reviewed and discussed in chapters 2.6 and 2.7.

In the literature, it has been challenging to discern the distinct influences of intrinsic motivation, mindset and goals, and to establish explicit correlations between intrinsic motivation and academic performance in science. Liu (2021) examined the effects of a fixed mindset and performance-based goals on intrinsic motivation and mathematical performance. This author's research emphasised the influence of cultural factors on students' motivation, goal-setting and mindsets, highlighting the importance of considering cultural context in understanding these dynamics. The research of Jaipal (2010) identified differences in motivation and achievement among students with different orientations.

Students with a maladaptive orientation (extrinsically motivated) experienced improved motivation, but did not necessarily achieve higher science scores. Students with an adaptive orientation (intrinsically motivated) did not show a shift in motivation, but demonstrated a notable increase in science achievement. Olić et al. (2016) noted that students' significance of intrinsic motivation, mindset and goals varies. This suggests that these factors have a personalised impact, and their effects may differ from one student to another.

The findings in this study correlated with those from the literature. Although some students may be extrinsically motivated initially, this study measured only the students' intrinsic motivation levels before and after the intervention (Table 6.4). The scores for motivation before the intervention were relatively high for the experimental and control groups, which did not give much room for improvement during the intervention. The experimental group's mean and median (middle value) scores for motivation before and after the intervention increased. From the table, the control group was, on average, more motivated before the intervention than the experimental group. This may explain the decrease in the motivation scores before and after the intervention for the control group.

Table 6.5 shows that pre- and post-science test scores increased in the experimental and control groups, with a more considerable difference for the experimental group.

The one-sided Spearman's rho test was executed on the differences between the pre- and post-intervention for motivation and pre- and post-science tests for the experimental and control groups.

The correlation for the experimental group seems positive, but the p-values are > 0.05, so a strong correlation could not be established.

No positive correlation could be established for the control group.

The findings in this study are aligned with those reported in the existing literature, but some specific observations were made regarding intrinsic motivation levels and test scores.

RQ 4: What is the effect of mindset on science performance?

Research on mindset, science understanding, and performance is covered in chapters 2.4 and 2.5 of the literature study.

Studies on the relationship between mindset and academic performance have yielded contradictory results. Research shows a correlation between mindset and academic achievement. Students with a growth mindset typically outperform their peers. These studies include those conducted on secondary school or university students (Alesi et al., 2016; Costa & Faria, 2018; Müllensiefen et al., 2015; Wiersema et al., 2015; Yan et al., 2014; Yeager et al., 2016).

On the other hand, there is evidence from other studies suggesting that academic achievement is not significantly influenced by a growth mindset (Bahník & Vranka, 2017; Li & Bates, 2019; Moreau et al., 2019). Dweck and Leggett (1988) argue that mindset is foundational in achieving goals because it shapes beliefs that guide individuals' goal-setting behaviour.

The case study's findings are consistent with existing literature, and specific insights were gained regarding the relationship between growth mindset levels and test score improvements. While some students may have initially held a fixed mindset, this study focused exclusively on measuring students' growth mindset levels before and after the intervention (as indicated in Table 6.5).

Table 6.6 demonstrates that pre- and post-intervention science test scores increased for the experimental and control groups, with a more substantial difference observed in the experimental group that participated in the intervention.

A one-sided Spearman's rho test was conducted on the differences between pre- and post-intervention mindset levels and pre- and post-intervention science test scores for both groups to explore the changes in growth mindset and science test scores. An apparent positive correlation and the p-values < 0.05, indicating a strong and statistically significant positive correlation, was established.

Despite the contradictory findings from the literature, the findings of this study are aligned with studies that find a positive correlation between growth mindset and academic performance.

RQ 5: What is the effect of the TBBaSK Framework on intrinsic motivation, mindset and science performance?

(a) What is the effect of the TBBaSK Framework on intrinsic motivation?

A 2019 study by Sani et al. (2019) examined the effect of brain-based learning on students' desire to comprehend the electric circuit and found that brain-based learning increased pupils' motivation. Mejías et al. (2021) conducted a workshop-based intervention based on the idea that insights from neuroscience can be applied in science education to transform students' self-concept, boost their motivation and equip them with valuable tools to lever educational challenges throughout their lives. Using the MSLQ, the findings indicate that a programme focusing on neuroeducation and learning strategies directly and positively impacted student motivation.

These studies collectively demonstrate the potential of brain-based learning techniques to enhance students' motivation and engagement in science education, aligning with the broader goal of improving learning outcomes and self-concept in science.

The case study's results are consistent with the existing body of literature. According to the findings of the Friedman motivation test, presented in Table 6.16, it is evident that the experimental group, which participated in the intervention, exhibited higher levels of motivation compared to the control group, with p-values of 0.074 for the experimental group and 0.248 for the control group. Among the participants in the experimental group, the post-intervention feedback regarding motivation was overwhelmingly positive, as shown in Table 6.19. Remarkably, 91.3% of the participants in the experimental group reported feeling significantly more self-motivated after the intervention. These findings emphasise the beneficial impact of the intervention on enhancing students' motivation, aligning well with the broader literature that explores effective strategies for promoting motivation within educational settings.

The qualitative analysis of feedback, presented in Table 6.17, further supports the notion that students experienced increased motivation following the intervention. It is noteworthy that seven control group participants reported improvement in motivation. They attributed these improvements to factors such as rewards for correctly answering multiple questions and recognising the value of dedicating their Saturdays to the intervention. These participants also expressed greater confidence in their ability to tackle problems, as highlighted in Table 6.17.

Findings from the literature and this study show that brain-based learning positively impacts intrinsic motivation.

(b) What is the effect of the TBBASK Framework on mindset?

In 2013, Fitzakerley and colleagues (Fitzakerley et al., 2013) launched a programme incorporating training in neuroscience to enhance science performance and shift students' fixed mindsets towards a growth mindset, according to Blackwell et al. (2007). The programme's primary goals were to deepen students' understanding of crucial brain functions involving discussions and activities centred around the brain and neuroscience. Students were surveyed to assess their attitudes towards science and their comprehension of neuroscience to gauge the programme's effectiveness. The results showed that the brain awareness presentations successfully encouraged growth mindsets and fostered positive attitudes toward science among the students.

The findings of this study are aligned with the existing body of literature. As indicated by the results of the Friedman mindset test, presented in Table 6.22, it is clear that the experimental group, which engaged in the intervention, demonstrated higher levels of growth mindset than the control group. The p-values further support this, with a value of 0.001 for the experimental group and 0.617 for the control group. The post-intervention feedback regarding mindset, as presented in Table 6.25, was overwhelmingly positive within the experimental group. Notably, a remarkable 91.3% of the participants in the experimental group reported experiencing a growth in mindset after the intervention. These findings underscore the positive impact of the intervention on enhancing students' growth mindset, consistent with the broader literature on effective strategies within educational settings aimed at fostering a growth mindset.

The qualitative analysis of feedback, as depicted in Table 6.23, reinforces the idea that students indeed experienced a growth mindset through the intervention. It is worth mentioning that three participants reported improvements in their mindset, even in the control group. In response to an open-ended question, eight participants from the experimental group mentioned learning that their brains can grow. They recognised that their thought patterns and abilities can evolve through repetition and adopting different approaches, as highlighted in Table 6.24. Findings from the literature and this study show that brain-based learning positively impacts on a growth mindset.

(c) What is the effect of the TBBaSK Framework on science performance?

In the literature discussed in chapter 2.12, it is noteworthy that multiple studies suggest that brain-based learning and multisensory approaches positively impact science performance within educational environments. Nevertheless, it is important to consider each study's specific context, methodologies and variables when interpreting these findings. Some of the most recent studies that support these conclusions include research conducted by Achor and Gbadamosi (2020), Alanazi (2020), Al-Balushi and Al-Balushi (2018), Lagoudakis et al. (2022), Olatunde-Aiyedun and Ogunode (2020), Saleh and Subramaniam (2019) and Sani et al. (2019).

The findings of this study are in harmony with the existing body of literature. As indicated by the results of the Friedman science test, presented in Table 6.28, the experimental group, which actively participated in the intervention, demonstrated superior performance compared to the control group. The statistical analysis revealed p-values of 0.000 for the experimental group and 0.003 for the control group, underscoring the significance of the differences observed.

Post-intervention feedback regarding the science test in the experimental group was overwhelmingly positive, as illustrated in Table 6.31. An impressive 91.3% of the participants in the experimental group reported a heightened understanding of science following the intervention. These findings underscore the positive impact of the intervention on enhancing students' performance in the field of science, aligning well with the broader literature on effective strategies to foster motivation within educational settings.

The qualitative analysis of feedback, presented in Table 6.17, provides further support for the idea that students experienced improvements in their comprehension of science. They noted their ability to rectify mistakes and approach questions differently, recognising the informativeness and benefits of these changes (Table 6.29). In response to an open-ended question, all participants in the experimental group reported that they found the intervention valuable. They experienced an enhanced understanding of science and were committed to applying this newfound knowledge and problem-solving techniques in their other subjects, as highlighted in Table 6.30.

These findings highlight the favourable influence of the intervention on improving science performance, aligning with the broader body of literature that explores effective strategies in educational settings aimed at enhancing science performance.

Main research question:
What constitutes a technology-enhanced brain-based framework for science education (the TBBaSK Framework)?

It is crucial to emphasise that the TBBaSK Framework should be executed as a consistent whole rather than as a collection of its components when responding to the main research topic. It embodies a holistic approach in which all elements work together to produce the desired results.

In chapter 7.3.3, as part of the contribution, several recommendations from the literature were discussed, leading to the identification of key elements that form the basis of the TBBaSK Framework. This framework, derived from the TPACK Framework proposed by Mishra and Koehler (2006), comprises three primary components: technology, brain-based learning and science knowledge. Figure 7.1 visually represents the TBBaSK Framework.

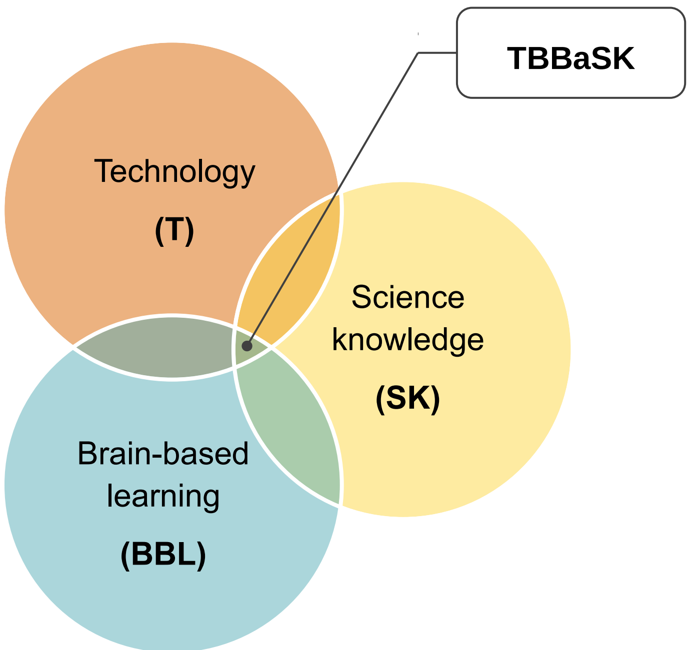

Figure 7.1: The TBBaSK Framework

In the context of science education at the tertiary level, the TBBaSK Framework puts forward a comprehensive approach that advocates for integrating technology, brain-based learning and science knowledge. The framework emphasises the knowledge lecturers need in each domain and its intersections, as illustrated in Figure 7.1.

Specific technology-related information and knowledge regarding its use, acceptance, adaptation, exploration and advancement can be found in chapter 2.9 and Table 2.4. The overview in this section draws from the insights provided by Lai and Bower (2019).

The Faculty responsible for this field of study determines the science-related knowledge.

The brain-based learning principles that serve as a pedagogical foundation for the framework are documented in Table 7.2. The table references the respective researchers whose work formed the basis for these principles. The numerical values appearing in the last three columns of the table correspond to specific principle or tenet numbers as outlined in the reference tables mentioned earlier.

Table 7.2: Brain-based learning principles for this study

Element (Caine et al., 2005)	**Principle**
Relaxed alertness	1. Learning is developmental and experimental (nature and nurture)
	2. Learning is improved by challenge and inhibited by depression, stress, threats and anxiety.
	3. Social safety
	4. Engages entire physiology
	5. Physical activity and nutrition influence learning
	6. Involve breaks in teaching sessions
Orchestrated immersion	7. Patterns give meaning
	8. Multisensory approach
Active processing	9. Learning involves conscious and unconscious processes, sleep
	10. Neuroplasticity
	11. Feedback and repetition
	12. Memory
	13. Attention
	14. Prior knowledge

Implementing the TBBaSK Framework can be facilitated by utilising the domain competencies outlined in Table 3.3. These competencies provide a foundation for effectively incorporating the elements of brain-based learning.

The domain competencies and knowledge within the TBBaSK Framework, which draw from the research of Thohir et al. (2022), are detailed in Table 7.3, as discussed in chapter 4.1.3.5. These competencies serve as a guide for understanding and applying the framework in practice, ensuring that it is effectively integrated into science education at the tertiary level.

Table 7.3: Domain competencies and knowledge needed for TBBaSK – adapted from Thohir et al. (2022)

The TBBaSK Framework	
Competencies	**Knowledge**
Brain-based learning	Knowledge of student characteristics in the cognitive, social, socio-emotional, economic and culture domains Knowledge of curriculum development Theory of learning knowledge Knowledge of teaching management in the classroom Knowledge of procedure assessment Knowledge and application of brain-based learning principles Application of brain-based learning in the classroom Brain-based learning principles
Science knowledge	Content knowledge of science in specific Physics and Chemistry courses integrating science knowledge
Technological knowledge	Knowledge of general technology Knowledge of specific technology in using, accepting, adapting and exploring, and advancing this knowledge
Brain-based science knowledge	Knowledge of student difficulty and misconception of science content Knowledge of selecting the appropriate learning strategy with science knowledge Structuring science learning materials with the curriculum Knowledge to apply brain-based learning in the science classroom
Technological science knowledge	Knowledge of using, accepting, adapting, exploring and advancing technology in learning science material Knowledge to integrate technology into science
Technological brain-based knowledge	Knowledge of using, accepting, adapting, exploring and advancing technology in student management Knowledge of using, accepting, adapting, exploring and advancing technology to select the appropriate learning strategy

	Knowledge of using, accepting, adapting, exploring and advancing technology to evaluate learning Knowledge to integrate technology with brain-based learning
Technological brain-based science knowledge	Knowledge of using, accepting, adapting, exploring and advancing technology to facilitate science learning and remediate misconceptions using brain-based learning Integrating specific technology and brain-based learning strategies to facilitate science learning.

Recommendations for mapping these components and an illustrative example of their practical application can be found in Table 3.5 and Table 3.6, respectively. These tables provide guidance and real-world examples to assist in understanding how to effectively apply the framework in the context of science education at tertiary level.

7.3 REFLECTION

7.3.1 Personal reflections

After 13 years of lecturing in Engineering Science at a university of technology in South Africa, the researcher realised specific changes were needed to improve the subject's understanding for students who did not achieve the prerequisite marks to pursue engineering. Most students came from highly challenging socioeconomic backgrounds (Chapter 2.3).

Many students in South Africa attend institutions with inadequate facilities, which negatively affects how well pupils do in class. Many learners attend schools in formerly underprivileged metropolitan areas that are overcrowded, lack decent libraries and study spaces, and have outdated classrooms. The situation is even worse for children living in rural regions because they must cope with a lack of electricity and pit toilets that threatens their health and safety. Due to the inadequate infrastructure, this type of structure puts students' health at risk and hinders their ability to concentrate and perform well in class.

Participating in the Neurozone neuroscience course deeply piqued the researcher's interest in unravelling the mysteries of the brain. This newfound fascination with neuroscience holds the potential to lead to further academic or career pursuits in this field, where she can contribute to advancing an understanding of the brain's functions and its profound influence on human cognition, behaviour, and wellbeing.

The significance of our holistic nature lies in the emphasis on leveraging the integration of various disciplines within this study. This approach underscores the importance of combining insights from multiple fields to gain a comprehensive understanding of our complex makeup.

The neuroscience course included a variety of neuroscience topics, such as how the brain responds to threats, stress and depressive states. To name a few, neuroplasticity, multiple senses and the importance of sleep were emphasised. The significance of intrinsic motivation and mindset were examined in a Life Exchange course. The desire to combine all these life-changing elements to make a difference led to the development of this thesis. By adding technology to these components, the TBBaSK Framework was suggested.

With appreciation, the researcher recognised the importance of approaching the issue from a unique perspective, as such circumstances are not always reversible or swiftly resolved. The researcher felt fortunate to delve into this matter and play a part in contributing to a brighter future for the students.

7.3.2 Scientific reflections

The use of quantitative and qualitative research methods in this study demonstrated their complementary nature, enhancing the research's ability to address the research questions effectively. It is advisable to replicate this study at other universities to strengthen its reliability. Opinions from diverse perspectives enhance reliability and help confirm the absence of conflicts of interest.

Random sampling techniques ensure the study's reliability and dependability. Additionally, statistical measures were applied to identify and analyse patterns, trends, anomalies and outliers, thereby bolstering the reliability and validity of the collected data.

The study also delves into how the research findings align with existing theories or contribute to developing new ones. This reflection is carried out in the context of each research question, ensuring a thorough examination of the study's theoretical implications.

Scientific reflection is recognised as an ongoing and iterative process. Consequently, the study concludes with recommendations for further research, aiming to refine the proposed framework. The researcher eagerly anticipates feedback from peers, reviewers and subsequent scholars, which will be invaluable in improving research methodologies, addressing limitations and advancing upon prior work.

7.3.3 Contribution

The contributions of this study are based on recommendations from the literature.

7.3.3.1 Recommendations of the TPACK Framework based on the research

The TPACK Framework of Mishra and Koehler (2006) has influenced educational technology research and practice. However, some challenges and uncertainties are associated with its application. Mishra and Koehler (2006) acknowledged that the interactions between the different components of the TPACK Framework – technology, pedagogy and content knowledge – can be complex and sometimes ambiguous. This ambiguity can make it challenging to categorise cases that do not neatly fit within the defined constructs. As a result, educators may find it challenging to apply the framework effectively in real-world teaching situations.

There is a need for ongoing research to refine the TPACK Framework to address these challenges. This refinement may involve a more precise understanding of how the components interact with and influence each other. Researchers can work on developing more explicit guidelines and criteria to identify and categorise cases within the framework. Researchers and educators can focus on identifying the subtle differences between the elements of the TPACK Framework and how these differences impact teaching and learning. The framework may need to be expanded to include new elements that have emerged as significant factors in integrating technology into education. Educational technology is constantly evolving, and the framework should evolve accordingly.

Cox (2008) and Angeli and Valanides (2009) have emphasised the need for greater understanding of the TPACK Framework. This clarity is essential for educators to apply it effectively in their teaching practices. Furthermore, the framework should remain grounded in sound pedagogical principles to ensure that technology integration enhances the learning experience rather than detracts from it.

As Voogt et al. (2013) highlighted, ongoing research and development efforts are necessary to keep the TPACK Framework relevant and effective. Researchers, educators and curriculum developers should collaborate to refine and adapt the framework to the changing education and technology landscape.

7.3.3.2 Recommendations of brain-based learning based on the research

Based on the recommendations from the systematic review conducted by Bada and Jita (2022) on using brain-based learning in science teaching, educators should be encouraged to adopt brain-based learning techniques and methods because of their proven effectiveness. It recommends integrating brain-based learning into science subjects such as Chemistry and Physics. This can help diversify the use of brain-based learning and explore its potential in different contexts within the field of science education. The review recommends efforts to improve the integration of brain-based learning across all levels of education, including primary and secondary schools, and higher education institutions.

This thesis aims to address the abovementioned recommendations by adding to research on the TPACK Framework by introducing the TBBaSK Framework. The TBBaSK Framework builds on the TPACK Framework's foundation, but focuses explicitly on the implementation by integrating brain-based learning elements, principles and tenets. The TBBaSK Framework contributes to TPACK research by responding to the call for considering educational contexts and practical classroom applications. It strongly emphasises the development of metacognition in teaching and learning approaches, aligning with the evolving needs of educators and learners.

The primary goal is to assist science lecturers in enhancing the science performance, mindset and intrinsic motivation of undergraduate students, specifically students from previously disadvantaged students and low socioeconomic groups. This was done by mapping suggestions that can be applied to any part of the curriculum or even other subjects.

One of the critical aspects of the TBBaSK Framework is to encourage the exploration of various constructs of brain-based learning. Educators are encouraged to be open to different brain-based learning approaches and techniques, recognising that tailoring brain-based learning strategies to specific learning objectives and student populations can significantly enhance their effectiveness.

Furthermore, the TBBaSK Framework responds to recommendations from studies on brain-based learning by providing more significant support for science lecturers to apply brain-based learning in classrooms. It incorporates brain-based learning principles and applications, including mindfulness techniques, utilising mind moves as brain exercises, fostering a growth mindset, implementing multisensory teaching methods and promoting the development of metacognition. These brain-based learning techniques are seamlessly integrated with technology in science education, aligning with the principles of TPACK.

7.3.3.3 Contribution of information technology on the science education

This study contributes to understanding how information technology in education can be effectively utilised by integrating it with innovative teaching approaches. Sections 2.7 and 2.8 of this study emphasise the importance of information technology as a specialised field, underscoring its critical role in developing the TBBaSK Framework.

7.4 ASSUMPTIONS AND LIMITATIONS OF THE STUDY

For the TBBaSK Framework to be implemented effectively, it is assumed that lecturers are already familiar with technology. This assumption is made to complement their specialised knowledge with additional technological information. This study presumes that students are sufficiently familiar with technology. Some instructional methods will involve using a data projector, and students may occasionally engage in online learning through platforms like Schoology or their Blackboard interface. For tasks such as completing online quizzes and participating in the game, participants in the experimental group must use a computer or their cell phones.

While the study's results may yield positive outcomes, it is crucial to acknowledge several essential limitations:

- It is necessary to replicate the study at other universities to ensure the findings have broader applicability. The outcomes may vary based on the specific university context and student population.
- The limited sample size due to the characteristics of the participating group might have impacted the generalisability of the findings to a broader student population.
- The investigation was projected to require only six Saturdays. This relatively short time frame might have limited the depth and comprehensiveness of the study's findings.

7.5 RECOMMENDATIONS FOR FUTURE RESEARCH

The findings and limitations of this study provide several ideas for future research directions.

Future studies can consider including a broader range of topics and involve a more extensive number of universities to enhance the breadth and diversity of research findings.

Increasing the sample group size in future research endeavours can provide a more robust and representative dataset, allowing for more comprehensive analysis and generalisability.

Extending the study's time frame to a more suitable duration can provide researchers with a more comprehensive understanding of the phenomena under investigation and allow for the observation of long-term effects.

Incorporating brain-based activities like mind moves and mindfulness techniques, particularly within the science classroom, highlights the need for additional studies to explore these approaches' potential benefits and challenges.

Gaining insights from fellow instructors who have worked with the framework will be valuable in shaping their perspective on this intervention.

7.6 CLOSING

The study addresses the issue of poor science performance among undergraduate students at a university of technology in South Africa, highlighting that this problem is not unique to developing contexts, but is a global concern. The researcher developed a framework for science education known as the Technology-enhanced, Brain-based and Science Knowledge (TBBaSK) Framework for science education to respond to the poor performance issue. It is designed to improve science education.

The TBBaSK Framework contributes to technological pedagogical content knowledge research by addressing the need to consider educational contexts and practical classroom applications, emphasising the fostering of metacognition in teaching and learning approaches.

The TBBaSK Framework incorporates brain-based learning principles, including mindfulness techniques, mind moves as brain exercises, multisensory teaching methods and the promotion of intrinsic motivation and a growth mindset.

The framework is designed to assist lecturers to make class content engaging for students, ensuring that they remain interested and actively participate in their learning. It acknowledges that implementing the framework may require initial preparation by the lecturer, but suggests that this process will become more manageable with time. It also underscores the lecturer’s commitment to contribute to student learning positively.

APPENDIXES

APPENDIX A1 – TUT ETHICAL CLEARANCE

Tshwane University of Technology

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Research Ethics Committee

The TUT Research Ethics Committee is a registered Institutional Review Board (IRB 00005968) with the US Office for Human Research Protections (IORG# 0004997) (Expires 30 Jan 2020). Also, it has Federal Wide Assurance for the Protection of Human Subjects for International Institutions (FWA 00011501) (Expires 22 Jan 2019). In South Africa it is registered with the National Health Research Ethics Council (REC-160509-21).

August 15, 2019

REC Ref #: REC/2018/10/004
Name: Terblanche HA
Student #: 80261061, UP

Ms HA Terblanche
C/o Prof M Matthee
Faculty of Engineering, Built Environment and Information Technology
University of Pretoria

Dear Ms Terblanche,

Decision: Final Approval

Name: Terblanche HA
Project title: *The influence of using technology- and Neuroscience-based multiplemodality teaching on intrinsic motivation, mind-set and science- performance*
Qualification: PhD in Information Systems, University of Pretoria
Study Leaders: Prof M Matthee & Prof C de Villiers

Thank you for submitting the project documents for review by the Research Ethics Committee (REC), Tshwane University of Technology (TUT). In reviewing the documents, the comments and notes below are tabled for your consideration, attention and/or notification:

- **University of Pretoria (UP), Ethics Letter**
  - The REC takes note of the final clearance letter provided by the Fcaulty Committee for Research Ethics and Integrity at the University of Pretoria (Ref#: EBIT/113/2019).

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The Chairperson of the Research Ethics Committee, Tshwane University of Technology, reviewed the project documents on August 15, 2019. **Final Approval** is granted to the study.

The proposed research project may now continue with the proviso that:

1) The researcher/s will conduct the study according to the procedures and methods indicated in the **approved proposal**, particularly in terms of any undertakings and/or assurances made regarding the confidentiality of the collected data.
2) The proposal will be submitted to the Committee for prospective ethical clearance if there are any substantial **deviations** and/or changes from the approved proposal.
3) The researcher/s will act within the parameters of any applicable **national legislation, professional codes of conduct**, institutional guidelines and scientific standards relevant to the specific field of study. Strict adherence to the following South African legislation, where applicable, is especially important: Protection of Personal Information Act (Act 4 of 2013), Children's Act (Act 38 of 2005) and the National Health Act (Act 61 of 2003).
4) The researcher will inform the REC as soon as possible of any **adverse events** involving research participants that may have occurred during the course of the study. It includes the actions and/or processes that were implemented to mitigate and/or prevent any further injuries and/or adverse outcomes.
5) The researcher will inform the REC of any **new or unexpected ethical issues** that may have emerged during the course of the study, as well as how these ethical issues were addressed. The researcher must consult with the REC for advice and/or guidance in any such event.
6) The current ethics approval expiry date for this project is **July 31, 2021**. No research activities may continue after the ethics approval expiry date. An application for the extension of ethics approval must be submitted for projects that need to continue beyond the expiry date.

Note:

The reference number [top right corner of this communiqué] should be clearly indicated on all forms of communication [e.g. Webmail, E-mail messages, letters] with the intended research participants.

Yours sincerely,

HD Mason (Dr)
Chairperson: Research Ethics Committee
[TUTRef#2018=10=004=TerblancheHA]

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APPENDIX A2 – UP ETHICAL CLEARANCE

UNIVERSITEIT VAN PRETORIA
UNIVERSITY OF PRETORIA
YUNIBESITHI YA PRETORIA

Faculty of Engineering, Built Environment and Information Technology

Fakulteit Ingenieurswese, Bou-omgewing en Inligtingtegnologie / Lefapha la Boetšenere, Tikologo ya Kago le Theknolotši ya Tshedimošo

Reference number: EBIT/113/2019

Mrs HA Terblanche
Department: Computer Science
University of Pretoria
Pretoria
0083

Dear Mrs HA Terblanche

FACULTY COMMITTEE FOR RESEARCH ETHICS AND INTEGRITY

Your recent application to the EBIT Research Ethics Committee refers.

Approval is granted for the application with reference number that appears above.

1. This means that the research project entitled "THE INFLUENCE OF USING TECHNOLOGY- AND NEUROSCIENCE-BASED MULTIPLE-MODALITY TEACHING ON INTRINSIC MOTIVATION, MIND-SET AND SCIENCE- PERFORMANCE" has been approved as submitted. It is important to note what approval implies. This is expanded on in the points that follow.
2. This approval does not imply that the researcher, student or lecturer is relieved of any accountability in terms of the Code of Ethics for Scholarly Activities of the University of Pretoria, or the Policy and Procedures for Responsible Research of the University of Pretoria. These documents are available on the website of the EBIT Research Ethics Committee.
3. If action is taken beyond the approved application, approval is withdrawn automatically.
4. According to the regulations, any relevant problem arising from the study or research methodology as well as any amendments or changes, must be brought to the attention of the EBIT Research Ethics Office.
5. The Committee must be notified on completion of the project.

The Committee wishes you every success with the research project.

Prof JJ Hanekom
Chair: Faculty Committee for Research Ethics and Integrity
FACULTY OF ENGINEERING, BUILT ENVIRONMENT AND INFORMATION TECHNOLOGY

APPENDIX A3 – CONSENT

Allocated number: ______________

UNIVERSITEIT VAN PRETORIA
UNIVERSITY OF PRETORIA
YUNIBESITHI YA PRETORIA
Denkleiers • Leading Minds • Dikgopolo tša Dihlalefi

Invitation to participate in research

PROJECT TITLE:

THE INFLUENCE OF USING TECHNOLOGY AND BRAIN-BASED LEARNING IN THE INTEGRATION OF BRAIN-BASED LEARNING AND SCIENCE KNOWLEDGE ON INTRINSIC MOTIVATION, MINDSET AND SCIENCE PERFORMANCE

Primary investigator: Mrs HA Terblanche

PhD (Information Technology)

Study leaders: Prof M Matthee and Prof C de Villiers

I invite you to participate in a research study that forms part of my formal PhD-studies in Information Technology. This information leaflet will inform you about the research details and help you decide whether you are willing to participate.

WHAT IS THE STUDY ALL ABOUT?

Science performance at universities is currently a problem. I am researching to address this problem to explore the influence of mindset and the state of intrinsic motivation on science achievement. Research proved that making students aware of the brain's functionality and educating them on the brain's neuroplasticity could improve their intrinsic motivation.

Mindset happens in someone's head; it controls one's attitude and behaviour. A fixed mindset is where students believe that their intellectual abilities are unchallengeable. In contrast, students with a growth mindset realise they can develop academic skills. Therefore, I intend to use technology during the intervention period using multiple modality and integrate Brain-Based Learning to motivate you to believe in yourself and that a change in your mindset can happen. The experimental group will be exposed to multiple modalities like YouTube videos, PowerPoint presentations, online lectures, online tutorials, interactive media like Schoology, games like Kahoot! and practical experiments relevant to the topic based on technology. You will also receive information on the brain's neuroplasticity during the intervention period and how your mindset can grow. The intervention will take place on six Saturdays. The control group will also receive revisions on the specified topic but actively without using technology- and multiple-modality teaching. For ethical purposes, I will also give all the technology to the control group after the intervention period.

The data will be collected during the intervention period. Higher Certificate Engineering students at TUT who have less than 60% for the previous tests of the year will be used as the population. The experimental and control groups will then be randomly selected from the population.

WHAT WILL YOU BE REQUIRED TO DO IN THE STUDY?

If you decide to take part in the study, you will be required to do the following:

Sign this informed consent form.

Fill in the questionnaires to determine your mindset, state of intrinsic motivation, demographic information and marks before the intervention.

One of the complex topics not done in the school syllabus will be used to revise - Fluids. You will write a pre-test on the topic. The experimental group will be exposed to the technology and multiple modality teaching during the intervention. In contrast, the control group will get the same exposure without technology and multiple modality teaching. Because all of you had exposure to the work of your different lecturers during class time, the intervention method will not harm you. A similar test will then be given after the intervention period. The technology used for the experimental group will be available to the control group after the intervention.

Fill in the questionnaires again after the intervention.

Take note that no cost will be involved in this study's participants.

ARE THERE ANY CONDITIONS THAT MAY EXCLUDE YOU FROM THE STUDY?

If you fall into the population group, there is no condition applicable to the study for exclusion.

CAN ANY OF THE STUDY PROCEDURES RESULT IN PERSONAL RISK, DISCOMFORT OR INCONVENIENCE?

There is no risk involved in participating in this research.

WHAT ARE THE POTENTIAL BENEFITS THAT MAY COME FROM THE STUDY?

Participating in this study will expose you to multiple modality teaching and technology used to integrate Brain-Based Learning with science knowledge. This might lead to a growth mindset and a better intrinsic belief in yourself. This is proposed to improve your understanding and performance of science.

WILL YOU RECEIVE ANY FINANCIAL COMPENSATION OR INCENTIVE FOR PARTICIPATING IN THE STUDY?

Unfortunately, you will not be paid to participate in the study.

WHAT ARE YOUR RIGHTS AS A PARTICIPANT IN THIS STUDY?

Your participation in this study is voluntary. You can withdraw at any time without penalty or future disadvantage. You do not even have to provide the reason/s for your decision. Your withdrawal will in no way influence your continued relationship. You are not waiving any legal claims, rights or remedies because you participated in this research study.

HOW WILL CONFIDENTIALITY AND ANONYMITY BE ENSURED IN THE STUDY?

All information obtained during this study is strictly confidential. Although a number is allocated, it is only used to link the data. The findings of the survey will be discussed with all participants. Although the assigned number will be used to connect the data, your identity will not be revealed. At the same time, the study is being conducted or when the study is reported in scientific journals. All the data sheets that have been collected will be stored in a secure place. Any information obtained in connection with this study that can be identified with you will remain confidential and be disclosed only with your permission or as required by law. The information received during the project will only be used for research purposes and will not be released for any academic assessment, study progress, disciplinary purposes and/or study permit-related matters.

IS THE RESEARCHER QUALIFIED TO CARRY OUT THE STUDY?

The researcher is adequately trained and qualified in the study fields this research project covers, specifically education.

HAS THE STUDY RECEIVED ETHICAL APPROVAL?

Yes. The Faculty Committee for Postgraduate Studies and the Research Ethics Committee of the University of Pretoria have approved the formal study proposal. All study parts will be conducted according to internationally accepted ethical principles.

WHO CAN YOU CONTACT FOR ADDITIONAL INFORMATION REGARDING THE STUDY?

The primary investigator, Mrs H Terblanche, can be contacted during office hours at her cellular phone at 082 888 5769. The study leader, Prof M Matthee, can be contacted at Tel (012) 420 3365 during office hours. Prof C de Villiers office number is 012 420 3798. Should you have any questions regarding the ethical aspects of the study, you can contact the UP REC.

DECLARATION: CONFLICT OF INTEREST

The researcher will not be the lecturer of the subject, ensuring that all students have the right to the knowledge offered by their different lecturers. The researcher will conduct the intervention where students will be selected to attend revision classes. The researcher takes cognizance of the fact that she is subjective and might, apart from the difference in teaching methods between the control and experimental group, be biased in her approach to the experimental group. Therefore, she will invite an objective lecturer to attend the two groups' revision sessions to help minimise conflict of interest.

A FINAL WORD

Your cooperation and participation in the study will be greatly appreciated. Please sign the informed consent below if you agree to participate in the study. In such a case, you will receive a copy of the signed informed consent from the researcher.

INFORMED CONSENT

I hereby voluntarily grant my permission to participate in the project, as explained to me by Hettie Terblanche.

I understand my right to choose whether to participate in the project and that the information furnished will be handled confidentially. I am aware that the investigation results may be used for publication.

Upon signing this form, the participant will be provided with a copy.

Signed: ____________________________ Date: ________________

Researcher: ____________________________ Date: ________________

APPENDIX A4 – LETTER FROM ATTENDEES TO THE INTERVENTION

Tshwane University of Technology

30 August 2019

Faculty of Science
Department of Physics

To whom it may concern

CONTROL AND EXPERIMENTAL INTERVENTION OF MRS HETTIE TERBLANCHE

I attended interventions of Mrs Hettie Terblanche of the control and experimental groups for her PhD study on 17 and 24 August 2019.

The participants were at risk students enrolled for the Higher Certificate in various engineering disciplines for the module, Engineering Physics I. The at-risk students were identified according to their marks in their first major test.

The control group intervention was the normal intervention to present the applicable topics of fluid dynamics, with the follow up problem solving exercises. The experimental group intervention included the brain profile and mind moves exercises with technology enhanced teaching methods.

Mrs Terblanche treated both groups with the same passion. Both groups were active and enthusiastic about the problems solving exercises. The control group was not disadvantaged. They received the same knowledge and understanding content.

Mrs Terblanche was not biased, with no conflict of interest.

Please contact me in case of more information needed.

Regards

Dr Annaretha Coetzee
Subject Head: Engineering Physics I
Senior lecturer: Department Physics
E-mail: coetzeea@tut.ac.za

We empower people

Feedback of class for Ms. H. Terblanche:

I was asked by Ms. Terblanche to sit in two of her sessions on 24 August 2019. I was asked to make a comparison of both classes to see if one style of teaching was better than the other one.

In both classes Ms. Terblanche did a quick revision of Fluids and then proceeded to teach them dynamic fluids. The first class was a normal class, as taught by every lecturer on campus, where the lecturer stands in front of the class and explains the work on a white board. She proceeded to tell them what dynamic fluids are and showed them the formulas and why it is needed. The students in the class listened to what she was saying and proceeded to make notes as well as ask questions if they had any. A few exercises were given to them and she walked around helping those who needed it. After the class she gave them a quiz to do. She displayed the question on the board as well as the multiple-choice answers. The first student who got the question correct received an award.

In the second class the students watched an introduction video where the work was explained graphically on a screen. The presentation contained images showing exactly how dynamic fluids worked. The class also took a 1-minute break after the video where they all took deep breathes in and out just to calm them down before they continued with class. After the work was explained everyone proceeded to stand up and do some physical exercises. Everyone enjoyed it, because it made them more relaxed to do the work. At the end of the second class another quiz was done, but this time each student logged into the computer on a program where they had to choose between 4 answers. After each question a small leader board appear to show the students who was in the lead with the most correct answers.

Conclusion:

During both classes the work was thoroughly explained and both classes did the same work. The difference was that in the second class the students were more interactive, and they enjoyed the way the class was given. They had more energy during the class and seemed more relaxed when doing the work. I can thus conclude that both classes did the same work, but used different teaching methods.

Kind regards

Morne Olivier

m.olivier0512@gmail.com

082 074 9742

APPENDIX B1 – PERMISSION FOR FIGURE

Permission letter for Figure 2.18 in the study

On Mon, Nov 5, 2018 at 9:24 AM Hettie Terblanche <hettiet@gmail.com> wrote:

Dear Michael Frank

I am currently busy with my PhD study and interested in Brain-Based Learning. The topic of my research is:

THE INFLUENCE OF USING TECHNOLOGY- AND BRAIN-BASED LEARNING-BASED MULTIPLE MODALITY TEACHING INTRINSIC MOTIVATION, MINDSET AND SCIENCE PERFORMANCE

Your article "Cross-task individual differences in error processing: Neural, electrophysiological, and genetic components" is very interesting.

I would appreciate it if you permit me to use Figure 2.18 of the article in my study.

Figure 2.18. Response-locked ERPs during correct and erroneous choices in the recognition memory task. Grand average waveforms are shown separately for positive (A) and negative (B) learners, as determined behaviourally by the probabilistic learning task. Larger error-related negativities (ERNs) were observed in negative learners; this effect did not interact with error condition. Scalp topographies are shown 32 msec post response (the peak of the ERN) across correct, uncorrected error, and switch-to-correct (STC) conditions for positive (C) and negative (D) learners.

I am looking forward to your reply, please.

Regards

Hettie Terblanche

On Tue, Nov 6, 2018, at 11:37 AM, Michael J Frank <Michael_Frank@brown.edu> wrote:

I permit HA Terblanche to use the figure from my article" Cross-task individual differences in error processing: Neural, electrophysiological, and genetic components."
Best
Michael

APPENDIX B2 – PERMISSION FOR FIGURES

neurozone®

OPTIMIZING THE BRAIN/BODY SYSTEM

To Whom it May Concern,

I, Mariza van Wyk, Head of Science & Research at Neurozone, grant PhD candidate, Hettie Terblanche, permission to use Neurozone images as part of her research and thesis.

Yours sincerely

Mariza van Wyk

DIRECTORS: DR ETIENNE VAN DER WALT, PAUL THEODOSIO, TONY KIRTON, JONATHAN RENS, BRIAN KANTOR, MEL MILLER

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APPENDIX C1 – STRUCTURED QUESTIONNAIRE FOR INTELLIGENCE SCALE

Allocated number:___________

Theories of Intelligence Scale (Dweck, Self-theories,1999)

This questionnaire has been designed to investigate ideas about intelligence. There is no right or wrong answers. We are interested in your ideas.

Using the scale below, please indicate the extent to which you agree or disagree with each of the following statements by drawing a cross through the number that corresponds the best to your opinion.

1- Strongly agree

6 – Strongly disagree

1. You have a certain amount of intelligence, and you cannot really do much to change it.	1	2	3	4	5	6
2. Your intelligence is something about yourself and you cannot do anything to change it.	1	2	3	4	5	6
3. No matter who you are, you can significantly change your intelligence.	1	2	3	4	5	6
4. To be honest, you cannot really change how intelligent you are.	1	2	3	4	5	6
5. You can always substantially change how intelligent you are.	1	2	3	4	5	6
6. You can learn new things, but cannot really change your basic intelligence.	1	2	3	4	5	6
7. No matter how much intelligence you have, you can always change quite a bit.	1	2	3	4	5	6
8. You can change even your basic intelligence level considerably.	1	2	3	4	5	6

APPENDIX C2 – STRUCTURED QUESTIONNAIRE FOR INTRINSIC MOTIVATION

Allocated number:______________

Motivated Strategies for Learning Questionnaire

(Pintrich, Smith, Garcia, & McKeachie, 1993)

Part A. Motivation

The following questions ask about your motivation for and attitudes about this class. Remember there are no right or wrong answers; just answer as accurately as possible. Use the scale below to answer the questions.

Using the scale below, please indicate the extent to which you agree or disagree with each of the following statements by drawing a cross through the number that corresponds the best to your opinion.

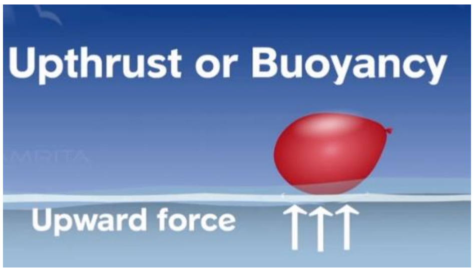
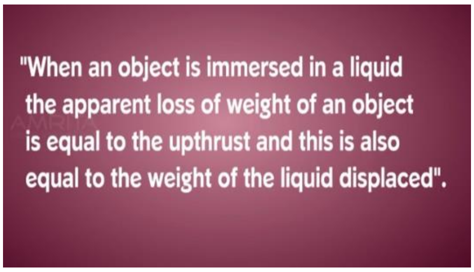
1- Strongly disagree

7 – Strongly agree

1. In a class like this, I prefer course material that really challenges me so I can learn new things.	1	2	3	4	5	6	7
16. In a class like this, I prefer course material that arouses my curiosity, even if it is difficult to learn.	1	2	3	4	5	6	7
22. The most satisfying thing for me in this course is trying to understand the content as thoroughly as possible.	1	2	3	4	5	6	7
24. When I have the opportunity in this class, I choose course assignments that I can learn from even if they do not guarantee a good grade.	1	2	3	4	5	6	7

APPENDIX D – PILOT STUDY

	Technology	Senses	Time
Topic The influence of using technology and multiple modalities in the integration of Brain-Based Learning and science knowledge	Data projector		
Four drivers for optimal performance from Neurozone: 1. Nutrition 2. Sleep/Wake cycle Sleep 7 – 9 hours per night 3. Exercise Use mind moves in this intervention 4. Silencing the mind Focus attention and Open Monitoring	Data projector		
Mindset video	Data projector	Auditory Visual	5 min
Fixed mindset- a mindset where one believes that their intellectual abilities are unchallengeable **Growth mindset**- a mindset where one realises that it is possible to improve one's intellectual abilities by repetition			
Neuroplasticity – video	Data projector	Auditory Visual	2 min
Neuroplasticity is rewiring your brain by forming new connections and weakening old ones.			
Fluids are materials that can flow like liquids and gases, Density = mass/Volume $p = m/V$			
Practical demo Take a balloon and try to keep it underwater. Is it possible? Why? Will lifting your friend inside the swimming pool be easier than outside? Why?	Practical demo	Auditory Visual Kinaesthetic	9 min

BUOYANCY Archimedes said that F_B = W (displaced fluid) = pVg			
	Data projector	Visual	
	Data projector	Visual	
Buoyancy and Archimedes's principle F_B = W (weight of the displaced fluid) = pVg If $W_{Object} > F_B$, The object will sink If $W_{Object} < F_B$, The object will float So, the most challenging part is the displaced volume of the fluid If an object is submerged, $V_{fluid} = V_{object}$		Auditory Visual	5 min
Practical experiment Pour water into the beaker Read volume Measure the mass of the object. Calculate the weight of the object. W_{object} = mg Put the object in the water to be submerged Measure the change in the volume of the water. Calculate the buoyancy force. F_B = pVg (water) Compare the buoyancy force with the weight of the object. Let the object be partially submerged. Displaced volume is less	Practical – in groups	Auditory Visual Kinaesthetic	20 min
Focus attention Deep breathe	Data projector Practical	Auditory Visual Kinaesthetic	4 min

Example "A solid, square pinewood raft measures 4.0 m on a side and is 0.30 m thick. **(a)** Determine whether the raft floats in water, and **(b)** if so, how much of the raft is beneath the surface."	Whiteboard	Auditory Visual	10 min
Mind move Antennae Adjuster Increases ability, memory and abstract reasoning skills Sharpen attention to listen actively and attentively before responding	Data projector Practical	Auditory Visual Kinaesthetic	2 min
Do now in class no 40, 45, 47	Data projector	Auditory Visual Kinaesthetic	30 min
Do MCQ online in class Show due to time	Respondus via MyTutor	Visual Kinaesthetic	

Buoyancy (problems from textbook to do in class)

"40. The density of ice is 917 kg/m^3, and the density of seawater is 1025 kg/m^3. A swimming polar bear climbs onto a piece of floating ice that has a volume of 5.2 m^3. What is the weight of the heaviest bear that the ice can support without sinking completely beneath the water?

42. A hydrometer is a device used to measure the density of a liquid. It is a cylindrical tube weighted at one end, so it floats with the heavier end downward. The tube is inside a large "medicine dropper," and the liquid is drawn using the squeeze bulb. For use with your car, marks are put on the tube so that the level at which it floats indicates whether the liquid is battery acid (denser) or antifreeze (less dense). The hydrometer weights $W = 5.88 \times 10^{-2}$ N and a cross-sectional area of $A = 7.85 \times 10^{-5}$ m^2. How far from the bottom of the tube should the mark be put that denotes **(a)** battery acid (p = 1280 kg/m^3) and **(b)** antifreeze (p = 1073 kg/m^3)?

45. An 81kg person puts on a life jacket, jumps into the water, and floats. The jacket has a 3.1 x 10-2 m3 volume and is completely submerged under the water. The volume of the person's body underwater is 6.2×10^{-2} m^3. What is the density of the life jacket?

46. A lost shipping container rests on the ocean floor and is completely submerged. The container is 6 m long, 2 m wide, and 3 m high. Salvage experts attach a spherical balloon to the top of the container and inflate it with air pumped down from the surface. The shipping container rises toward the surface when the balloon's radius is 1.2 m. What is the mass of the container? Ignore the mass of the balloon and the air within it. Do *not* neglect the buoyant force exerted on the shipping container by the water. The density of seawater is 1025 kg/m^3.

47. What is the smallest number of whole logs (p = 725 kg/m^3, radius = 0.0800 m, length = 3.00 m) that can be used to build a raft carrying four people, each with a mass of 80.0 kg?

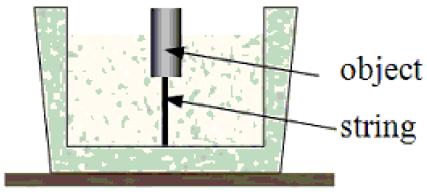
Buoyancy MCOs (As set up in Blackboard)

Title: Question 1

1. A balloon inflated with helium gas (density = 0.2 kg/m^3) has a volume of 6×10^{-3} m^3. If the air density is 1.3 kg/m^3, what is the buoyant force exerted on the balloon? A) 0.01 N * B) 0.08 N C) 0.8 N D) 1.3 N E) 7.8 N

Title: Question 2

2. A 2-kg block displaces 10 kg of water when fully immersed. As shown in the figure, the object is then tied down, displacing 5 kg of water. What is the tension in the string?



A) 10 N B) 20 N *C) 30 N D) 70 N E) 100 N

Title: Question 3

3. The density of ice is 0.92 g/cm^3; and the density of seawater is 1.03 g/cm^3. A large iceberg floats in Arctic waters. What fraction of the volume of the iceberg is exposed? A) 0.080 % *B) 11 % C) 89 % D) 92 % E) 99 %

Title: Question 4

4. An object weighs 15 N in air and 13 N when submerged in mineral spirits, with a 788 kg/m3 density. Determine the density of the object.

A) 330 kg/m^3 B) 500 kg/m^3 C) 1.2×10^3 kg/m^3 *D) 5.9×10^3 kg/m^3 E) 7.5×10^3 kg/m^3

Title: Question 5

5. After a moving van drives onto a river ferry, the ferry sinks 0.0367 m. The length and width of the ferry are 15.24 m and 6.10 m, respectively. Determine the weight of the moving van.

A) 6.09×10^3 N B) 1.00×10^4 N * C) 3.34×10^4 N D) 5.11×10^4 N E) 6.68×10^4 N

When a block of volume 1.00×10^{-3} m^3 is hung from a spring scale, as shown in Figure A, the scale reads 19.8 N. As Figure B suggests, when the same block is placed in an unknown liquid, it floats with 2/3 of its volume submerged.

The density of water is 1.00×10^3 kg/m^3.

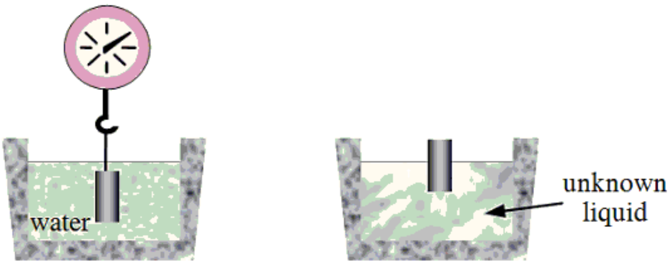


Figure A Figure B

Title: Question 6

6. Determine the mass of the block.

A) 1.02 kg *B) 2.02 kg C) 3.02 kg D) 4.04 kg E) 9.80 kg

Title: Question 7

7. Determine the density of the unknown liquid.

*A) 3.03×10^3 kg/m^3 B) 4.62×10^3 kg/m^3 C) 6.16×10^3 kg/m^3 D) 8.01×10^3 kg/m^3

E) 1.57×10^4 kg/m^3

A balloon is released from a tall building. The total mass of the balloon, including the enclosed gas, is 2.0 kg. Its volume is 5.0 m^3. The density of air is 1.3 kg/m^3.

Title: Question 8

8. What is the average density of the balloon?

A) 0.2 kg/m^3 *B) 0.4 kg/m^3 C) 0.8 kg/m^3 D) 1.0 kg/m^3 E) 1.2 kg/m^3"

Summary of Pilot Feedback

Indicate your experience by making a cross of your choice.

	Yes	No	Yes, but not this specific one chosen
Do you think using videos, in general, was worth it?	33		
Video on the mindset	32	1	
Video on neuroplasticity	31	2	
Video of Archimedes	31	1	1
Was the way to explain buoyancy clear?	32	1	
Do you think that the practice, in general, helps your understanding?			
Practical demo	32	1	
Practical experiment	32	1	
Did the knowledge of the brain interest you?			
Mindset	30	3	
Neuroplasticity	30	2	1
Did the way to silence your mind and the mind move exercise help you focus?			
Focus Attention	27	4	1
Mind move	29	3	1
Although there was no time to do the MCQs, do you think it will help your understanding?	30	2	1
Did this lesson help your understanding of Fluids?	32	1	

APPENDIX E1 – DEMOGRAPHIC INFORMATION

Allocated number:_______________

Please indicate your demographic information with a cross

What is the highest education obtained by your father?	< High school	High school	Some college education	College graduate	Advanced Masters/ Doctorate	Not applicable
What is the highest education obtained by your mother?	< High school	High school	Some college education	College graduate	Advanced Masters/ Doctorate	Not applicable
What is the highest education obtained by your guardian?	< High school	High school	Some college education	College graduate	Advanced Masters/ Doctorate	Not applicable

Indicate your gender	Male	Female

APPENDIX E2 – TEST MARK BEFORE INTERVENTION

Allocated number:______________

a)

Capture your mark pre- intervention:

Mark pre-intervention	

APPENDIX E3 – MARK OF TEST AFTER INTERVENTION

Allocated number:___________

b)

Capture your mark post-intervention:

Mark post-intervention	

Add any comment about your learning experience during the intervention.

____

____

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____

Did the use of technology and multi-modality teaching help you to have a better understanding of Science?

____

____

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____

APPENDIX E4 – EXPERIMENTAL INTERVENTION FEEDBACK

Allocated number: ____

I would appreciate it if you could give me your feedback on this intervention

Indicate your experience by making a cross through your choice, were

1 = Not at all, 2 = Not really, 3 = I don't know, 4 = Fairly, 5 = Absolutely

1	Do you feel that this intervention helped you to have a better understanding of science?	1	2	3	4	5
2	Do you feel that the use of **technology** helped you to have a better understanding of science?	1	2	3	4	5
	Did the videos help your understanding?	1	2	3	4	5
	Did the Multiple online Questions help you?	1	2	3	4	5
	Did you make use of Schoology?	1	2	3	4	5
	Did you enjoy playing Kahoot!	1	2	3	4	5
3	Do you feel that using **multiple modalities** (the use of all your senses: seeing, hearing and movement) helps you better understand Science?	1	2	3	4	5
	Did you find the practical experiments helpful?	1	2	3	4	5
4	Do you feel using the brain's knowledge helped you better understand Science?	1	2	3	4	5
	Did you understand the information on the brain?	1	2	3	4	5
	Did you enjoy doing the mind move exercises?	1	2	3	4	5
	Did you find the "deep breath" exercise helpful?	1	2	3	4	5
	Do you now realize that your brain is elastic and your mind can grow?	1	2	3	4	5
5	Do you feel more self-motivated about the work than before the intervention?	1	2	3	4	5
6	Would you like to have more classes like these in the future?	1	2	3	4	5

	Brain-Based Learning	**Technology**	**Use of all senses**
What part of this intervention did you find the most interesting?			
What part of this intervention did you find the least interesting?			

APPENDIX E5 – CONTROL INTERVENTION FEEDBACK

Control feedback **Allocated number**: ____

I will appreciate if you can give me your feedback on this intervention

Indicate your experience by making a cross through your choice,

	Yes	No
Did you find the classes worthy?		

Please, motivate your choice.

____
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Please add any comment about your learning experience during the intervention.

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APPENDIX F – INTERVENTION

Guidelines to Improve mindset, intrinsic motivation and science performance

Determine prior information by completing a pre-questionnaire on mindset.
Determine prior information by completing a pre-questionnaire on intrinsic motivation.
Determine prior knowledge by completing a pre-test in science.
Intervention using technology, Multiple Modalities and Brain-Based Learning
Determine post information by completing a postal questionnaire on mindset.
Determine post information by completing a postal questionnaire on intrinsic motivation.
Determine post-knowledge by completing a post-test in science.

Weekly interventions

WEEK BEFORE
Give class list with names of population average for both tests < 60% to be signed.
Give letters to physics lecturers.
Divide the population into two random groups.

Preparations for interventions

WEEK 1
Explain the intervention in more detail to students.
Give allocated numbers to students for statistical purposes.
Hand out consent forms to be signed.
Explain questionnaires
Do mindset and intrinsic motivation questionnaires
Do pre-test on fluids

WEEK 2 (Density)				
Brain-based learning element	**Brain-based learning principles** (Table 3.4)	**Technology** (Table 2.4)	**TBBaSK activity** (Table 2.12)	**Senses**
Orchestrated immersion	7. Patterns give meaning 8. Multisensory approach	Web 2.0: YouTube Mobile device: Laptop and data projector	**Show a video on the influence that threats have on the brain:** When a threat is experienced, the amygdala sends more oxygen to your arms and legs to freeze flight or fight. That implies that less oxygen will be transferred to the prefrontal cortex, which means one cannot think clearly. When you feel anxious or stressed, breathe deeply so the amygdala does not get upset. The amygdala sends the message to the endocrine glands to warn that danger is coming. Adrenaline is secreted – breathing is shallow and quick; the heart beats faster. Stress is the reaction – anxiety, which causes physiological problems like jittery, heartbeat, and headaches. The hypothalamus connects the endocrine and nervous systems to keep all in balance – homeostasis. The hippocampus is where short-term memory is formed The prefrontal cortex produces dopamine – a feel-good hormone (reward). Problem solving takes place unconsciously. By changing your mindset, you can tell the amygdala what to see as a threat.	Auditory Visual
Orchestrated immersion	8 Multisensory approach	Mobile device: Laptop and data projector, whiteboard	**Demonstrate practical experiment:** Experiment with groups while the others are solving their problems on density. So, how can I measure the mass of water in my swimming pool?	Auditory Visual Kinaesthetic

WEEK 2 (Density)				
Brain-based learning element	**Brain-based learning principles** (Table 3.4)	**Technology** (Table 2.4)	**TBBaSK activity** (Table 2.12)	**Senses**
		Animation: PNET simulations Social media: WhatsApp	Can I put it on a scale?	
Active processing	10. Neuroplasticity 11. Feedback and repetition 12. Memory 13. Attention 14. Prior knowledge	Mobile device: Laptop and data projector, whiteboard LMS: Schoology Slide show presentation: PowerPoint	**Do an example** on the whiteboard to capture new knowledge Save it to the web: "The body of a man whose weight is 690 N contains about 5.2×10^{-3} m^3 of blood. (a) Find the blood weight and (b) Express it as a percentage of the body weight."	Auditory Visual Kinaesthetic
Active processing	9. Learning involves conscious and unconscious processes, sleep 10. Neuroplasticity 11. Feedback and repetition	Mobile device: Laptop and data projector, whiteboard LMS: Blackboard Slide show presentation: PowerPoint	Do challenging **problems** in class no 3;8;91;100, discuss and give feedback	Auditory Visual Kinaesthetic

WEEK 2 (Density)				
Brain-based learning element	**Brain-based learning principles** (Table 3.4)	**Technology** (Table 2.4)	**TBBaSK activity** (Table 2.12)	**Senses**
	12. Memory 13. Attention 14. Prior knowledge			
Relaxed alertness	4. Engages entire physiology 5. Physical activity and nutrition influence learning 6. Involve breaks in teaching sessions	Web 2.0: YouTube Mobile device: Laptop and data projector	**Brain exercise:** Mind move (Confidence booster) Assure more stable and even brain waves. It puts you in the most resourceful mental and emotional state. Putting your tongue against the palate is soothing and boosts the immune system and rhythm.	Auditory Visual Kinaesthetic
Relaxed alertness	2. Learning is improved by challenge and inhibited by depression, stress, threats and anxiety. 4. Engages entire physiology	Mobile device: Laptop and data projector Web 2.0: YouTube	**Brain exercise:** Mindfulness (Deep breathing)	Auditory Visual Kinaesthetic

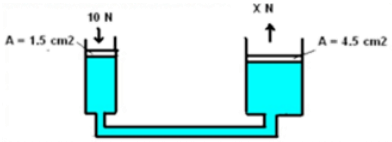
WEEK 2 (Density)				
Brain-based learning element	**Brain-based learning principles** (Table 3.4)	**Technology** (Table 2.4)	**TBBaSK activity** (Table 2.12)	**Senses**
	5. Physical activity and nutrition influence learning 6. Involve breaks in teaching sessions			
Relaxed alertness	4. Engages entire physiology 5. Physical activity and nutrition influence learning 6. Involve breaks in teaching sessions	Web 2.0: YouTube Mobile device: Laptop and data projector	**Brain exercise:** Mind move (Leg workout) Improves concentration, listening skills, comprehension, task completion and confidence.	Auditory Visual Kinaesthetic
Active processing	9. Learning involves conscious and unconscious processes, sleep	Mobile device: Laptop and data projector, whiteboard	Do **MCQ** online in class to capture new knowledge and Feedback	Auditory Visual Kinaesthetic

WEEK 2 (Density)				
Brain-based learning element	**Brain-based learning principles** (Table 3.4)	**Technology** (Table 2.4)	**TBBaSK activity** (Table 2.12)	**Senses**
	10. Neuroplasticity 11. Feedback and repetition 12. Memory 13. Attention 14. Prior knowledge	LMS: Blackboard, Schoology Slide show presentation: PowerPoint		
Active processing	9. Learning involves conscious and unconscious processes, sleep 10. Neuroplasticity 11. Feedback and repetition 12. Memory 13. Attention 14. Prior knowledge	LMS: Blackboard, Schoology Social media: WhatsApp	**Extra** information	Visual

WEEK 3 (Pascal’s principle)				
Brain-based learning element	**Brain-based learning principles** (Table 3.4)	**Technology** (Table 2.4)	**TBBaSK activity** (Table 2.12)	**Senses**
Orchestrated immersion	7. Patterns give meaning 8. Multisensory approach	Web 2.0: YouTube Mobile device: Laptop and data projector	**Revise the video** to explain the influence of a threat on the brain	Auditory Visual
Orchestrated immersion	7. Patterns give meaning 8. Multisensory approach	Web 2.0: YouTube Mobile device: Laptop and data projector	**Show video** on foundational drivers Four drivers for optimal performance from Neurozone 1. Nutrition. 2. Sleep/Wake cycle: Sleep 7 – 9 hours per night. 3. Exercise: Use mind moves in this intervention. 4. Silencing the mind Focus attention and Open Monitoring.	Auditory Visual
Relaxed alertness	4. Engages entire physiology 5. Physical activity and nutrition influence learning 6. Involve breaks in teaching sessions	Web 2.0: YouTube Mobile device: Laptop and data projector	**Brain exercise:** Mindfulness (Deep breathing)	Auditory Visual Kinaesthetic

WEEK 3 (Pascal's principle)				
Brain-based learning element	**Brain-based learning principles** (Table 3.4)	**Technology** (Table 2.4)	**TBBaSK activity** (Table 2.12)	**Senses**
Orchestrated immersion	7. Patterns give meaning 8. Multisensory approach	Web 2.0: YouTube Mobile device: Laptop and data projector	**Show a video** on the brain and learning • The brain learns to survive by constantly seeking out the new – it craves to learn so that it may not only survive but thrive • Learning is a physical process. It mainly occurs at the synapsis, the junctions between neurons where information is relayed. Synopsis increases in number and strength, making it easier to remember information as it is recalled from already-formed neurons and neuronal circuits • Learning starts in the hippocampus. It functions as the memory hub and forms new brain cells. We can improve our learning capabilities through exercise, sleep and silencing the mind. This encourages the release of growth factors that enhance synaptogenesis – the formation of connections between neurons and neuronal circuits. • Information needed to be stored longer is sent to the hippocampus and stored as knowledge in long-term memory sites. Quick recall of short-term information like a telephone number is stored in the prefrontal cortex.	Auditory Visual
Orchestrated immersion	7. Patterns give meaning 8. Multisensory approach	Web 2.0: YouTube Mobile device: Laptop and data projector	Video to explain the **senses** The average human brain weighs about 1,400 grams (3 lb). The brain looks a little like a sizeable pinkish-grey walnut. The brain can be divided down the middle lengthwise into two cerebral hemispheres. Each cerebral hemisphere is divided into four lobes: sulci and gyri. The sulci (or fissures) are the grooves, and the gyri	Auditory Visual

<table>
<tr><th colspan="5">WEEK 3 (Pascal’s principle)</th></tr>
<tr><th>Brain-based learning element</th><th>Brain-based learning principles
(Table 3.4)</th><th>Technology
(Table 2.4)</th><th>TBBaSK activity
(Table 2.12)</th><th>Senses</th></tr>
<tr><td></td><td></td><td></td><td>are the "bumps" seen on the brain’s surface. Each person has a unique pattern of gyri and sulci.
<table>
<tr><td></td><td>Frontal lobe</td><td>Parietal lobe</td><td>Temporal</td><td>Occipital lobe</td></tr>
<tr><td>Located</td><td>Front of the central sulcus</td><td>Central sulcus</td><td>Lateral fissure</td><td>Back of the brain, behind the parietal and temporal lobes</td></tr>
<tr><td>Function</td><td>Reasoning, planning, speech, movement, emotions, problem-solving</td><td>Touch, pressure, temperature. pain</td><td>Hearing, memory (hippo-campus)</td><td>Vision</td></tr>
</table></td><td></td></tr>
<tr><td></td><td></td><td></td><td></td><td></td></tr>
</table>

WEEK 3 (Pascal's principle)				
Brain-based learning element	**Brain-based learning principles** (Table 3.4)	**Technology** (Table 2.4)	**TBBaSK activity** (Table 2.12)	**Senses**
Relaxed alertness	4. Engages entire physiology 5. Physical activity and nutrition influence learning 6. Involve breaks in teaching sessions	Web 2.0: YouTube Mobile device: Laptop and data projector	**Brain exercise**: Mind move (Mouse pad) Stimulates the visual, auditory and kinaesthetic wiring while integrating the left and the right visual fields. Improves reading, eye contact and eye-teaming skills	Auditory Visual Kinaesthetic
Active processing	10. Neuroplasticity 11. Feedback and repetition 12. Memory 13. Attention 14. Prior knowledge	Mobile device: Laptop and data projector, whiteboard LMS: Schoology Slide show presentation: PowerPoint	**Do an example** on the whiteboard to capture new knowledge Save it to the web: $P_2 – P_1 = \rho gh$ P_2 (higher pressure) < P_1 (lower pressure) Pascal example "A 10 N weight balances an X N weight placed on a bigger syringe. What is the value of x. The density (oil) = 800 kgm^{-3} Calculate the force on the plunger (same level). The plunger is 2 m higher than the piston." 	Auditory Visual

WEEK 3 (Pascal's principle)				
Brain-based learning element	**Brain-based learning principles** (Table 3.4)	**Technology** (Table 2.4)	**TBBaSK activity** (Table 2.12)	**Senses**
Orchestrated immersion	7. Patterns give meaning 8. Multisensory approach	Web 2.0: YouTube Mobile device: Laptop and data projector	**Video** on mindset Fixed- versus growth mindset Fixed mindset- a mindset where one believes that their intellectual abilities are unchangeable Growth mindset- a mindset where one realises that it is possible to improve one's intellectual abilities by repetition	Auditory Visual
Orchestrated immersion	7. Patterns give meaning 8. Multisensory approach	Web 2.0: YouTube Mobile device: Laptop and data projector	**Video** on Neuroplasticity Neuroplasticity describes the brain's capacity to modify its shape and function in response to new information, life experiences, and environmental factors. It is a fundamental brain characteristic that can create new neural connections, enhance existing ones, and even reassign some functions to various brain parts.	Auditory Visual
Relaxed alertness	4. Engages entire physiology 5. Physical activity and nutrition influence learning 6. Involve breaks in teaching sessions	Web 2.0: YouTube Mobile device: Laptop and data projector	**Brain exercise:** Mind moves (Power on) Stimulates the carotid arteries that supply freshly oxygenated blood to the eyes and brain, relieving eye and mental strain	Auditory Visual Kinaesthetic

WEEK 3 (Pascal's principle)				
Brain-based learning element	**Brain-based learning principles** (Table 3.4)	**Technology** (Table 2.4)	**TBBaSK activity** (Table 2.12)	**Senses**
Active processing	9. Learning involves conscious and unconscious processes, sleep 10. Neuroplasticity 11. Feedback and repetition 12. Memory 13. Attention 14. Prior knowledge	Mobile device: Whiteboard LMS: Schoology Slide show presentation: PowerPoint	**Do problems** in class to capture new knowledge no 15, 20, 35, 98 Put solutions on the web and Feedback	Auditory Visual Kinaesthetic
Relaxed alertness	2. Learning is improved by challenge and inhibited by depression, stress, threats and anxiety. 4. Engages entire physiology	Web 2.0: YouTube Mobile device: Laptop and data projector	**Brain exercise:** Mindfulness (Deep breath)	Auditory Visual Kinaesthetic

WEEK 3 (Pascal's principle)				
Brain-based learning element	**Brain-based learning principles** (Table 3.4)	**Technology** (Table 2.4)	**TBBaSK activity** (Table 2.12)	**Senses**
	5. Physical activity and nutrition influence learning 6. Involve breaks in teaching sessions			
Active processing	9. Learning involves conscious and unconscious processes, sleep 10. Neuroplasticity 11. Feedback and repetition 12. Memory 13. Attention 14. Prior knowledge	Mobile device: Laptop and data projector, whiteboard LMS: Blackboard Slide show presentation: PowerPoint	Do **MCQ** online in class to capture new knowledge, discuss and give feedback	Auditory Visual Kinaesthetic

WEEK 3 (Pascal's principle)				
Brain-based learning element	**Brain-based learning principles** (Table 3.4)	**Technology** (Table 2.4)	**TBBaSK activity** (Table 2.12)	**Senses**
Active processing	9. Learning involves conscious and unconscious processes, sleep 10. Neuroplasticity 11. Feedback and repetition 12. Memory 13. Attention 14. Prior knowledge	LMS: Blackboard, Schoology Social media: WhatsApp	**Extra** information	Visual

WEEK 4 (Buoyancy)				
Brain-based learning element	**Brain-based learning principles** (Table 3.4)	**Technology** (Table 2.4)	**TBBaSK activity** (Table 2.12)	**Senses**
Orchestrated immersion	7. Patterns give meaning 8. Multisensory approach	Web 2.0: YouTube Mobile device: Laptop and data projector	**Brain knowledge:** Mindset to revise	Auditory Visual
Orchestrated immersion	7. Patterns give meaning 8. Multisensory approach	Web 2.0: YouTube Mobile device: Laptop and data projector	**Brain knowledge:** Neuroplasticity to revise	Auditory Visual
Orchestrated immersion	7. Patterns give meaning 8. Multisensory approach	Web 2.0: YouTube Mobile device: Laptop and data projector	**Brain knowledge** Four drivers for optimal performance from Neurozone to revise 1. Nutrition. 2. Sleep/Wake cycle: Sleep 7 – 9 hours per night. 3. Exercise: Use mind moves in this intervention. 4. Silencing the mind: Focus attention and Open Monitoring.	Auditory Visual
Relaxed alertness	4. Engages entire physiology 5. Physical activity and	Mobile device: Laptop and data projector SRS: Kahoot	**Brain exercise:** Kahoot! of the brain to capture new knowledge	Auditory Visual Kinaesthetic

WEEK 4 (Buoyancy)				
Brain-based learning element	**Brain-based learning principles** (Table 3.4)	**Technology** (Table 2.4)	**TBBaSK activity** (Table 2.12)	**Senses**
	nutrition influence learning 6. Involve breaks in teaching sessions			
Active processing	10. Neuroplasticity 11. Feedback and repetition 12. Memory 13. Attention 14. Prior knowledge	Mobile device: Laptop and data projector, whiteboard	**Explain** new knowledge Fluids are materials that can flow like liquids and gasses, Density = mass/Volume $p = m/V$	Auditory Visual Kinaesthetic
Active processing	8. Multisensory approach	Mobile device: Laptop and data projector, whiteboard Animation: PNET simulations Social media: WhatsApp	**Demonstrate** practical experiment Take a balloon and try to keep it underwater. Is it possible? Why? Will lifting your friend inside the swimming pool be easier than outside? Why? BUOYANCY: Archimedes said that F_B = W (displaced fluid) = pVg	Auditory Visual Kinaesthetic

WEEK 4 (Buoyancy)				
Brain-based learning element	**Brain-based learning principles** (Table 3.4)	**Technology** (Table 2.4)	**TBBaSK activity** (Table 2.12)	**Senses**
Orchestrated immersion	7. Patterns give meaning 8. Multisensory approach	Web 2.0: YouTube Mobile device: Laptop and data projector	**Video** to explain Archimedes' principle	Auditory Visual
Active processing	8. Multisensory approach 10. Neuroplasticity 11. Feedback and repetition 12. Memory 13. Attention 14. Prior knowledge	PowerPoint slide show presentation Mobile device: Laptop and data projector	**Do experiment** (in groups while others are doing exercise} Pour water into the beaker Read volume Measure the mass of the object. Calculate the weight of the object. Put the object in the water to be submerged Measure the change in the volume of the water. $F_B = pVg$ (water) 1 ml = 10^{-6} m^3 $W_{object} = mg$ Compare the buoyancy force with the weight of the object. Let the object be partially submerged. Displaced volume is less	Auditory Visual Kinaesthetic
Relaxed alertness	4. Engages entire physiology 5. Physical activity and nutrition	Web 2.0: YouTube Mobile device: Laptop and data projector	**Brain exercise:** Mind moves (Bilateral walk) Crossing the visual, auditory and kinaesthetic midline to improve reading, listening, writing and communication skills	Auditory Visual Kinaesthetic

WEEK 4 (Buoyancy)				
Brain-based learning element	**Brain-based learning principles** (Table 3.4)	**Technology** (Table 2.4)	**TBBaSK activity** (Table 2.12)	**Senses**
	influence learning 6. Involve breaks in teaching sessions			
Active processing	10. Neuroplasticity 11. Feedback and repetition 12. Memory 13. Attention 14. Prior knowledge	Mobile device: Laptop and data projector, whiteboard LMS: Schoology Slide show presentation: PowerPoint	**Do example** "A solid, square pinewood raft measures 4.0 m on a side and is 0.30 m thick. (a) Determine whether the raft floats in water, and (b) if so, how much of the raft is beneath the surface."	Auditory Visual
Relaxed alertness	2. Learning is improved by challenge and inhibited by depression, stress, threats and anxiety. 4. Engages entire physiology	Mobile device: Laptop and data projector Web 2.0: YouTube	**Brain exercise:** Mindfulness (Deep breathing)	Auditory Visual Kinaesthetic

WEEK 4 (Buoyancy)				
Brain-based learning element	**Brain-based learning principles** (Table 3.4)	**Technology** (Table 2.4)	**TBBaSK activity** (Table 2.12)	**Senses**
	5. Physical activity and nutrition influence learning 6. Involve breaks in teaching sessions			
Active processing	9. Learning involves conscious and unconscious processes, sleep 10. Neuroplasticity 11. Feedback and repetition 12. Memory 13. Attention 14. Prior knowledge	Mobile device: Laptop and data projector, whiteboard LMS: Blackboard, Schoology Slide show presentation: PowerPoint Social media: WhatsApp	**Do in class to** capture knowledge no 40;42;45;46;47, discuss and give feedback Put recording lessons on the web for experimental Put answers on the web for the control group	Auditory Visual Kinaesthetic

WEEK 4 (Buoyancy)				
Brain-based learning element	**Brain-based learning principles** (Table 3.4)	**Technology** (Table 2.4)	**TBBaSK activity** (Table 2.12)	**Senses**
Relaxed alertness	4. Engages entire physiology 5. Physical activity and nutrition influence learning 6. Involve breaks in teaching sessions	Web 2.0: YouTube Mobile device: Laptop and data projector	**Brain exercise:** Mind move (Antennae Adjuster) Increases ability, memory and abstract reasoning skills. Sharpen attention to listen actively and attentively before responding.	Auditory Visual Kinaesthetic
Active processing	9. Learning involves conscious and unconscious processes, sleep 10. Neuroplasticity 11. Feedback and repetition 12. Memory 13. Attention	Mobile device: Laptop and data projector, whiteboard LMS: Blackboard, Schoology Slide show presentation: PowerPoint	**Do MCQ** online in class to capture new knowledge, discuss and give feedback	Visual Kinaesthetic

WEEK 4 (Buoyancy)				
Brain-based learning element	**Brain-based learning principles** (Table 3.4)	**Technology** (Table 2.4)	**TBBaSK activity** (Table 2.12)	**Senses**
	14. Prior knowledge			
Active processing	9. Learning involves conscious and unconscious processes, sleep 10. Neuroplasticity 11. Feedback and repetition 12. Memory 13. Attention 14. Prior knowledge	LMS: Blackboard, Schoology Social media: WhatsApp	**Extra** information	Visual

<table>
<tr><th colspan="5">WEEK 5 (Bernoulli’s principle)</th></tr>
<tr><th>Brain-based learning element</th><th>Brain-based learning principles
(Table 3.4)</th><th>Technology
(Table 2.4)</th><th>TBBaSK activity
(Table 2.12)</th><th>Senses</th></tr>
<tr>
<td>Orchestrated immersion</td>
<td>7. Patterns give meaning
8. Multisensory approach</td>
<td>Mobile device: Laptop and data projector
Web 2.0: YouTube</td>
<td>Video on stress response
Stress symptoms may affect your health, even though you might not realise it. You may think illness is to blame for that irritating headache, frequent insomnia, or decreased productivity at work. However, stress may be the cause. Indeed, stress symptoms can affect your body, emotions, and behaviour. Being able to recognise common stress symptoms can help you manage them.
Common effects of stress:
<table>
<tr><th>On body</th><th>On mood</th><th>On behaviour</th></tr>
<tr><td>Headache</td><td>Anxiety</td><td>Over or undereating</td></tr>
<tr><td>Muscle tension pain</td><td>Restlessness</td><td>Angry outbursts</td></tr>
<tr><td>Chest pain</td><td>Lack of motivation or focus</td><td>Drug or alcohol misuse</td></tr>
<tr><td>Fatigue</td><td>Feeling overwhelmed</td><td>Tobacco use</td></tr>
<tr><td>Sleep problems</td><td>Irritable or anger</td><td>Social withdraw</td></tr>
<tr><td>Stomach upset</td><td>Depression or sadness</td><td>Exercising less often</td></tr>
</table>
</td>
<td>Auditory
Visual</td>
</tr>
</table>

WEEK 5 (Bernoulli's principle)				
Brain-based learning element	**Brain-based learning principles** (Table 3.4)	**Technology** (Table 2.4)	**TBBaSK activity** (Table 2.12)	**Senses**
			How to manage stress Managing stress can have many health benefits if you have stress symptoms. Explore stress management strategies, such as: • Getting regular physical activity • Practising relaxation techniques, such as deep breathing or meditation • Keeping a sense of humour • Spending time with family and friends • Setting aside time for hobbies, such as reading a book or listening to music • Get plenty of sleep • Eat a healthy, balanced diet. • Avoid tobacco use, excess caffeine and alcohol, and illegal substances.	
Relaxed alertness	2. Learning is improved by challenge and inhibited by depression, stress, threats and anxiety. 4. Engages entire physiology	Mobile device: Laptop and data projector Web 2.0: YouTube	**Brain exercise:** Mindfulness Deep breath	Auditory Visual Kinaesthetic

WEEK 5 (Bernoulli's principle)				
Brain-based learning element	**Brain-based learning principles** (Table 3.4)	**Technology** (Table 2.4)	**TBBaSK activity** (Table 2.12)	**Senses**
	5. Physical activity and nutrition influence learning 6. Involve breaks in teaching sessions			
Orchestrated immersion	7. Patterns give meaning 8. Multisensory approach	Mobile device: Laptop and data projector Web 2.0: YouTube	**Brain knowledge:** Video on mindset Revise to capture	Auditory Visual
Orchestrated immersion	7. Patterns give meaning 8. Multisensory approach	Mobile device: Laptop and data projector Web 2.0: YouTube	**Brain knowledge** Revise neuroplasticity.	Auditory Visual
Active processing		Mobile device: Laptop and data projector, whiteboard	**Revision** of fluids (Capture) Fluids are materials that can flow like liquids and gasses, $p = m/V$	Auditory Visual Kinaesthetic

WEEK 5 (Bernoulli's principle)				
Brain-based learning element	**Brain-based learning principles** (Table 3.4)	**Technology** (Table 2.4)	**TBBaSK activity** (Table 2.12)	**Senses**
		LMS: Schoology Slide show presentation: PowerPoint	Pascal Principle : $P_2 - P_1 = \rho gh$	
Relaxed alertness		Mobile device: Laptop and data projector Web 2.0: YouTube	**Brain exercise:** Mind move (Temporal toner) Stimulates the sense of balance in your inner ear and your listening, organisational, Mathematical and critical thinking abilities.	Auditory Visual Kinaesthetic
Active processing	10. Neuroplasticity 11. Feedback and repetition 12. Memory 13. Attention 14. Prior knowledge	Mobile device: Laptop and data projector, whiteboard LMS: Schoology Slide show presentation: PowerPoint	**Explain** new knowledge Show Mass flow rate Show Volume flow rate $pAv = V/t = Av$ Equation of continuity $A_1v_1 = A_2v_2$ Bernoulli from Energy Conservation $P_1 + \frac{1}{2} \rho v_1^2 + \rho gh_1 = P_2 + \frac{1}{2} \rho v_2^2 + \rho gh_2$	Auditory Visual
Active processing	8. Multisensory approach 10. Neuroplasticity	Mobile device: Laptop and data projector, whiteboard LMS: Schoology	**Make a video** of the following problem in groups Garden Hose "A garden hose has an unobstructed opening with a cross-sectional area of 2.85×10^{-4} m^2, from which water fills a bucket in 30.0 s. The volume of the bucket is 8.00×10^{-3} m^3. Find the speed	Auditory Visual Kinaesthetic

WEEK 5 (Bernoulli's principle)				
Brain-based learning element	**Brain-based learning principles** (Table 3.4)	**Technology** (Table 2.4)	**TBBaSK activity** (Table 2.12)	**Senses**
	11. Feedback and repetition 12. Memory 13. Attention 14. Prior knowledge	Slide show presentation: PowerPoint	of the water that leaves the hose through (a) the unobstructed opening and (b) an obstructed opening with half as much area." Why do you put your thumb in front of the house pipe to water your garden? **Make a video and paste it on Schoology**	
Active processing	10. Neuroplasticity 11. Feedback and repetition 12. Memory 13. Attention 14. Prior knowledge	Mobile device: Laptop and data projector, whiteboard LMS: Schoology Slide show presentation: PowerPoint	**Explain problem** The Physics of an Enlarged Blood Vessel "An aneurysm is an abnormal enlargement of a blood vessel such as the aorta. Because of an aneurysm, the normal cross-sectional area A_1 of the aorta increases to $A_2 = 1.7\ A_1$. The speed of the blood (p=1060 kg/m^3) through a regular portion of the aorta is v_1 = 0.40 m/s. Assuming that the aorta is horizontal (the person is lying down), determine how the pressure P_2 in the enlarged region exceeds the pressure P_1 in the normal region."	Auditory Visual
Active processing	9. Learning involves conscious and unconscious processes, sleep 10. Neuroplasticity	Mobile device: Laptop and data projector, whiteboard LMS: Schoology	**Do challenging problems** to capture new knowledge in class no 59, 64, 69, 71 and Feedback	Auditory Visual Kinaesthetic

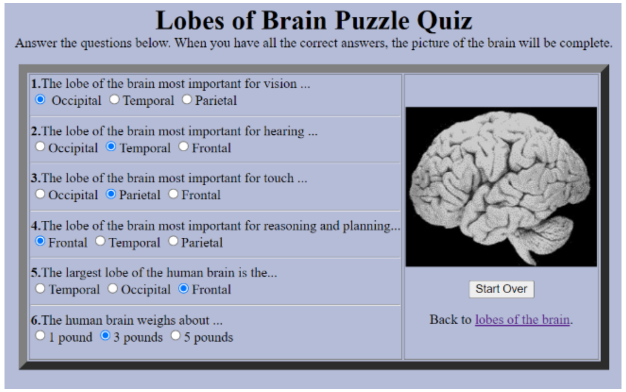
WEEK 5 (Bernoulli's principle)				
Brain-based learning element	**Brain-based learning principles** (Table 3.4)	**Technology** (Table 2.4)	**TBBaSK activity** (Table 2.12)	**Senses**
	11. Feedback and repetition 12. Memory 13. Attention 14. Prior knowledge	Slide show presentation: PowerPoint		
Relaxed alertness	2. Learning is improved by challenge and inhibited by depression, stress, threats and anxiety. 4. Engages entire physiology 5. Physical activity and nutrition influence learning	Mobile device: Laptop and data projector SRS: Kahoot	**Brain exercise** Play Kahoot! of Fluids to capture new knowledge	Auditory Visual Kinaesthetic

WEEK 5 (Bernoulli's principle)				
Brain-based learning element	**Brain-based learning principles** (Table 3.4)	**Technology** (Table 2.4)	**TBBaSK activity** (Table 2.12)	**Senses**
	6. Involve breaks in teaching sessions			
Orchestrated immersion	7. Patterns give meaning 8. Multisensory approach	Mobile device: Laptop and data projector, whiteboard LMS: Blackboard, Schoology	**Capture new knowledge** Put recording lessons on the web for experimental Put answers on the web for the control group	Auditory Visual
Active processing	9. Learning involves conscious and unconscious processes, sleep 10. Neuroplasticity 11. Feedback and repetition 12. Memory 13. Attention	Mobile device: Laptop and data projector, whiteboard LMS: Blackboard Slide show presentation: PowerPoint	**Do MCQ online** in class to capture new knowledge, discuss and give feedback	Auditory Visual Kinaesthetic

WEEK 5 (Bernoulli's principle)				
Brain-based learning element	**Brain-based learning principles** (Table 3.4)	**Technology** (Table 2.4)	**TBBaSK activity** (Table 2.12)	**Senses**
	14. Prior knowledge			
Active processing	9. Learning involves conscious and unconscious processes, sleep 10. Neuroplasticity 11. Feedback and repetition 12. Memory 13. Attention 14. Prior knowledge	LMS: Blackboard, Schoology Social media: WhatsApp	**Extra** information	Visual

WEEK 6 Post information				
Brain-based learning element	**Brain-based learning principles** (Table 3.4)	**Technology** (Table 2.4)	**TBBaSK activity** (Table 2.12)	**Senses**
Orchestrated immersion	7. Patterns give meaning 8. Multisensory approach	Mobile device: Laptop and data projector Web 2.0: YouTube	**Brain knowledge:** Show the brain video again as a revision	Auditory Visual Kinaesthetic
Relaxed alertness	2. Learning is improved by challenge and inhibited by depression, stress, threats and anxiety. 4. Engages entire physiology 5. Physical activity and nutrition influence learning 6. Involve breaks in teaching sessions	Mobile device: Laptop and data projector SRS: Kahoot!	**Brain exercise:** Play Kahoot! of the brain to capture brain knowledge	Auditory Visual Kinaesthetic

WEEK 6 Post information				
Brain-based learning element	**Brain-based learning principles** (Table 3.4)	**Technology** (Table 2.4)	**TBBaSK activity** (Table 2.12)	**Senses**
Orchestrated immersion	7. Patterns give meaning 8. Multisensory approach	Mobile device: Laptop and data projector PowerPoint as a slideshow presentation	**Revise** senses to capture brain knowledge	Auditory Visual Kinaesthetic
Relaxed alertness	2. Learning is improved by challenge and inhibited by depression, stress, threats and anxiety. 4. Engages entire physiology 5. Physical activity and nutrition influence learning 6. Involve breaks in teaching sessions	Mobile device: Laptop and data projector SRS: Kahoot!	**Brain exercise:** Play Kahoot! of senses.	Auditory Visual Kinaesthetic

WEEK 6 Post information				
Brain-based learning element	**Brain-based learning principles** (Table 3.4)	**Technology** (Table 2.4)	**TBBaSK activity** (Table 2.12)	**Senses**
Orchestrated immersion	Learning is developmental and experimental (nature and nurture) 2. Learning is improved by challenge and inhibited by depression, stress, threats and anxiety. 3. Social safety 4. Engages entire physiology 5. Physical activity and nutrition influence learning 6. Involve breaks in teaching sessions	Mobile device: Laptop and data projector Web 2.0: YouTube	**Brain exercise:** Do brain puzzles to capture brain knowledge 	Auditory Visual Kinaesthetic

WEEK 6 Post information				
Brain-based learning element	**Brain-based learning principles** (Table 3.4)	**Technology** (Table 2.4)	**TBBaSK activity** (Table 2.12)	**Senses**
	7. Patterns give meaning 8. Multisensory approach			
			Post Questionnaires	
			Post-test on fluids	

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