DEVELOPING A MODEL ON EXECUTIVE FUNCTION SKILLS AND UNDERSTANDING OF PHYSICS CONCEPTS TO DESIGN A TEACHING GUIDE OF FORCE CONCEPTS AND MEASURING ITS EFFECTIVENESS

BALA MURALI A/L TANIMALE

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by

BALA MURALI A/L TANIMALE

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LIST OF ABBREVIATIONS

EF	Executive Function
4QM	The Four-Quadrant Model of Facilitated Learning
PLS-SEM	Partial Least Squares Structural Equation Modelling
WM	Working memory
CSDA	Curriculum Standard Document and Assessment
AMOS	Analysis of Moment Structure
HCM	Hierarchical Component Model
USA	United States of America
BRIEF	Behaviour Rating Inventory of Executive Function
BDEFS-CA	Barkley Deficits in Executive Function Scale—Children and Adolescents
D-REF	Delis Rating of Executive Functions
CEFI	Comprehensive Executive Function Inventory
CDC	Curriculum Development Centre
ANOVA	Analysis of Variance
BRIEF2	Behaviour Rating Inventory of Executive Function Second Edition
ESQ	Executive Skill Questionnaire
FCT	Force Concept Test
SPM	Sijil Pelajaran Malaysia
IQ	Intelligence Quotient
PFC	Prefrontal cortex
STM	Short-term memory
LTM	Long-term memory
ER	Emotional Regulation
ADHD	Attention deficit/hyperactivity disorder
BR	Behaviour Regulation
SBCPS	Standard-Based Curriculum for Primary School
SCSS	Standard Curriculum for Secondary School
GPA	Grade Point Average

CB-SEM	Covariance-based Structural Equation Modelling
SEM	Structural Equation Modelling
MMR	Mixed Method Research
EFA	Exploratory Factor Analysis
GSQ	Goal Setting Questionnaire
AVE	Average Variance Extracted
CFA	Confirmatory Factor Analysis
MSA	Measure of sampling adequacy
KMO	Kaiser-Meyer-Olkin
CMIN/DF	Chi Square Df Ratio
RMSEA	Root mean square error of approximation
SRMR	Standardised root mean residual
CFI	Comparative fit index
AGFI	Adjusted Goodness-of-Fit Index
CR	Composite reliability
MSV	Maximum Shared Variance
HTMT	Heterotrait-Monotrait
MI	Modification indices
EPC	Estimated Parameter Change
CMB	Common method bias
CLF	Common Latent Factor
VIF	Variance Inflation Factor
R^2	Coefficient of determination
R^2_{adj}	Adjusted coefficient of determination
f^2	Effect size
Q^2	Predictive relevance

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PEMBANGUNAN MODEL KEMAHIRAN FUNGSI EKSEKUTIF DAN PEMAHAMAN KONSEP FIZIK UNTUK MEREKABENTUK PANDUAN PENGAJARAN KONSEP DAYA DAN MENGUKUR KEBERKESANANNYA.

ABSTRAK

Fungsi Eksekutif ialah satu set proses yang terlibat untuk mengurus diri sendiri dan sumber kendiri untuk mencapai sesuatu matlamat (Gioia, Isquith, Guy, & Kenworthy, 2015). Fungsi Eksekutif mempunyai tiga komponen utama: metakognitif, regulasi tingkah laku dan regulasi emosi (Gioia et al., 2015), dengan pelbagai kemahiran Fungsi Eksekutif yang merangkumi tiga komponen ini. Instrumen untuk mengukur tahap Fungsi Eksekutif pelajar Malaysia adalah kurang dan tiada model yang boleh dirujuk untuk diintegrasikan dalam pengajaran dan pembelajaran Daya dan Gerakan. Tahap Fungsi Eksekutif pelajar adalah berbeza, dan peranan Fungsi Eksekutif dalam pengajaran dan pembelajaran konsep fizik di Malaysia adalah minimum. Rekabentuk berbilang fasa dalam penyelidikan kaedah campuran digunakan dalam kajian ini. Dalam fasa pertama, kaedah analisis kandungan dan temu bual dengan guru dan pelajar dijalankan untuk meneroka kemahiran Fungsi Eksekutif yang terdapat dalam diri pelajar-pelajar fizik tingkatan empat. Analisis tematik menunjukkan terdapat 13 kemahiran Fungsi Eksekutif. Dalam fasa kedua, Soal Selidik Fungsi Eksekutif telah dibangunkan dan telah ditadbir menggunakan 529 orang pelajar. Satu model Fungsi Eksekutif dengan pemahaman konsep fizik telah dibangunkan dengan menggunakan Pemodelan Persamaan Berstruktur. Dalam fasa ketiga, satu panduan pengajaran yang menerapkan komponen model Fungsi Eksekutif, strategi seperti yang dicadangkan dalam *The Four-Quadrant Model of Facilitated Learning* dan strategi untuk mengatasi defisit kemahiran Fungsi Eksekutif telah dibangunkan. Dalam fasa yang keempat, Ujian Pemahaman Daya telah dibangunkan untuk mengukur keberkesanan panduan pengajaran. Panduan pengajaran ini kemudiannya telah ditadbir di dua buah sekolah, dan keberkesanan panduan pengajaran diukur dengan menggunakan analisis-t untuk rekabentuk ujian pra dan ujian pasca. Keputusan menunjukkan bahawa terdapat peningkatan yang ketara dalam skor *Force Concept Test* bagi sekolah A, daripada ujian pra (M = 34.53, SD = 10.19) kepada ujian pasca (M = 45.90, SD = 10.66), *t*(61) = 15.11, p<.001. Bagi sekolah B pula terdapat peningkatan yang ketara dalam skor *Force Concept Test*, daripada ujian pra (M = 34.80, SD = 12.70) kepada ujian pasca (M = 44.84, SD = 13.56), *t*(44) = 10.14, p<.00. Temu bual dengan guru dan pelajar kemudiannya telah dijalankan untuk mengenal pasti persepsi guru dan pelajar yang menggunakan panduan pengajaran. Analisis tematik menunjukkan bahawa terdapat banyak kelebihan dengan menggunakan panduan pengajaran yang telah dibangunkan. Penerapan model Fungsi Eksekutif dalam pengajaran fizik merupakan satu pendekatan alternatif yang guru boleh gunakan. Panduan pengajaran menggunakan model Fungsi Eksekutif ini menerapkan proses pembelajaran sains abad ke-21 dan telah menjadikan pembelajaran fizik seronok dan telah meningkatkan minat pelajar dalam subjek fizik.

DEVELOPING A MODEL ON EXECUTIVE FUNCTION SKILLS AND UNDERSTANDING OF PHYSICS CONCEPTS TO DESIGN A TEACHING GUIDE OF FORCE CONCEPTS AND MEASURING ITS EFFECTIVENESS.

ABSTRACT

The Executive Function (EF) is *"a set of processes that all have to do with managing oneself and one's resources in order to achieve a goal"* (Gioia, Isquith, Guy, & Kenworthy, 2015). EF has three main strands: metacognitive, behaviour regulation, and emotional regulation (Gioia et al., 2015), with a wide range of EF skills that fall under these three strands. There is a lack of instruments to measure the EF of Malaysian students and no model to refer to be integrated into teaching and learning of Force and Motion. EF levels of students differ, and the role of EF in teaching and learning physics concepts in Malaysia is minimal. Multiphase design of mixed-method research employed in this study. In the first phase, document analysis and interviews with teachers and students were conducted to explore the EF skills present among the Form Four physics students. Thematic analysis indicated 13 EF skills were present. In the second phase, EF Questionnaire was established and administered with 529 students. A model of EF and understanding physics concepts was established using structural equation modelling. In the third phase, a teaching guide embedding the EF model, the strategies proposed by The Four-Quadrant Model of Facilitated Learning, and the strategies to overcome the EF skills deficits was established. A force concept test (FCT) was established to measure the teaching guide's effectiveness in the fourth phase. The teaching guide was administered in two schools, and the teaching guide's effectiveness was measured using a t-test for the pre-test post-test design. The result indicated that there was a statistically significant increase in FCT scores for School A from Pre-test (M = 34.53, SD = 10.19) to Post-Test (M = 45.90, SD = 10.66), $t(61) = 15.11$, $p<.001$. For School B, there was a statistically significant increase in FCT scores from Pre-test (M = 34.80, SD = 12.70) to Post-Test (M = 44.84, SD = 13.56), $t(44) = 10.14$, $p<.00$. Interviews were then conducted with the teachers and students to identify the teachers' and students' perceptions of the teaching guide. Thematic analysis indicated that there were more advantages in using the teaching guide developed. Embedding the EF model in teaching physics is an alternative approach that the teachers can use. The teaching guide embedding the EF model incorporated the 21st-century science learning process and made learning physics to be fun and increased students' interest in physics subject.

CHAPTER 1

INTRODUCTION

1.1 Introduction

The Executive Function (EF) is *"a set of processes that all have to do with managing oneself and one's resources in order to achieve a goal. It is an umbrella term for the neurologically based skills involving mental control and self-regulation"* (Gioia, Isquith, Guy, & Kenworthy, 2015, p.2). There are three main strands in EF: metacognitive, behaviour regulation (BR), and emotional regulation (ER) (Gioia et al., 2015), and there is also a wide range of EF skills that fall under these three strands. Children who can use and strengthen these skills become proficient in a particular field/aspect (Dawson & Guare, 2010). For instance, a study conducted by Chen and Whitehead (2009) with 320 middle school pupils in Taiwan found that students with higher working memory (WM) capacity, a component of EF, can better understand physics ideas. Skills inherent to EF are potentially developed (Shonkoff, 2017), and for the EF of the brain of a child to function at a maximum capacity, EF can cultivate (Lockhart & DeCarli, 2014) as the brain function is very much environment-dependent (Shonkoff, 2017).

To cultivate EF, students' skills need to be context (Schwaighofer, Bühner, & Fischer, 2017) and content (Blair & Razza, 2007; Welsh, Nix, Blair, Bierman, & Nelson, 2010) specific. The context refers to the environment (learning context) where the students learn, while the content refers to the subject matter and the level. For instance, in acquiring physics concepts such as momentum, the skills should be specific to the Malaysian context and the subject matter (Force and Motion in physics). The context and content-specific skills derived from the wide range of skills encompass the three EF strands (metacognition, BR and ER). The skills in these three strands are required to understand concepts and lead to better physics achievement. For instance, goal-setting skill under metacognition increased the students' knowledge of science knowledge and content knowledge (Peters, 2012). Inhibition skill under BR predicted mathematical performance (Cragg & Gilmore, 2014). Attentional flexibility skill under ER enables a student to multitask or transit between activities without anxiety during teaching and learning (Dawson & Guare, 2010). Studies in the past showed the importance of strategies that address the EF skills in enhancing students' conceptual understanding, transfer and creative use of knowledge, and ability to self-reflect about the learning process (Brown, 1997; Deshler, Schumaker, Lenz, & Ellis, 1984; Pressley & Woloshyn, 1995). Hence, the information on the skills that explain Malaysian secondary school students learning of Force and Motion is essential. When the teaching is designed based on the EF skills constitute the learning of Force and Motion, the teaching expected to cultivate the skills subsequently improves learning the concepts in Force and Motion.

Thus, a model that explains the EF using the skills derived from the three strands, metacognition, BR, and ER, is necessary to guide the teachers in teaching the lessons on Force and Motion for Form Four students. Besides the types of skills, the individuals' level of skills influences learning (Kahn & Foster, 2013). Kahn and Foster (2013) further suggested using The Four-Quadrant Model of Facilitated Learning (4QM) approach to group the students into four quadrants. Quadrant 1 is for a low EF level, Quadrant 2 is for a moderately low EF level, Quadrant 3 is for a moderately high EF level, and finally, Quadrant 4 is for a high EF level. Each quadrant has appropriate teaching and learning strategies that suites the students' level of EF. The 4QM is the teaching-learning approach used in occupational therapy (Greber, Ziviani, & Rodger, 2007a). Hence, it is imperative to identify the EF skills that encompass Force and Motion learning, model the skills, and develop a teaching guide using the model for students with different EF skills levels.

This study aimed to measure the Form Four students' EF skills that constitute Force and motion learning derived from the three strands of EF: metacognition, BR, and ER. The structural equation modelling approach is used to develop a model that explains the EF skills needed to learn Force and Motion. The model then guided the development of a teaching guide on Force and Motion for students with different EF levels and classified according to 4QM.

1.2 Background of Study

Many studies have applied EF's concept without referring to it as EF (Posner & Peterson, 1990; Shure, 1992; Levine, Barak, & Granek, 1998; Greene, 2001). At the same time, there is no single definition of EF that is uniformly accepted up to this point in time. Due to this, there is a wide range of definitions of EF available. For instance, Hughes, Graham and Grayson (2005) defined EF as:

> "*the umbrella term that encompasses the set of higher-order processes (such as inhibitory control, WM and attentional flexibility) that govern goal-directed action and adaptive responses to novel, complex, or ambiguous situations*" (p.206).

According to Denckla (1994), *"EF is involved in the planning, organisation, regulation, and monitoring of goal-directed behaviour"* (p.2). Gioia, Isquith, Guy and Kenworthy (2000) defined EF as:

> "*collection of processes that are responsible for guiding, directing, and managing cognitive, emotional, and behavioural functions, particularly during active, novel problem-solving*" (p.3).

Gioia et al. (2000) further said that EF's term represents an umbrella construct that includes a collection of inter-related functions responsible for purposeful, goal-directed, problem-solving behaviour. There are three main domains involved in Gioia et al.'s (2000) definition: metacognition, behaviour, and emotion, and there is a collection of inter-related functions, which shows that there are a variety of EF skills involved.

Like the definition, many proposed EF models are available, but no model is accepted uniformly up to this point. Miyake, Friedman, Emerson, Witzki, Howerter and Wager (2000) proposed a model of EF that comprises three components: inhibition, working memory, and cognitive flexibility. Barkley (1997) suggested a hybrid EF model that consists of behavioural inhibition and was further divided into four components: WM, internalisation of speech, self-regulation of affect/ motivation/ arousal, and reconstitution.

Kaufman (2010) suggested that EF consists of two main domains: the metacognitive and social/ER domains. Metacognition is thinking about one's thinking. More precisely, it refers to the processes used to plan, monitor, and assess one's understanding and performance. Metacognition includes a critical awareness of one's thinking and learning and oneself as a thinker and learner. The metacognitive strand further comprises the cognitive and academic elements that play essential roles in comprehending the information and planning, starting, and completing tasks. Ten primary EF skills lie under the metacognitive strand in Kaufman's model: goal setting, planning/strategising, sequencing, organisation of materials, time management, task initiation, and executive/goal-directed attention, task persistence, WM, and set-shifting. These cognitive skills allow for the purposeful regulation of learning and production (Kaufman, 2010).

In goal-setting, people must first formulate the general goal and more specific objectives that they should accomplish. The clearer the goals, the easier to achieve the goals. The more precise goals establish the plans and strategies necessary to accomplish the desired ends if those ends are known (Kaufman, 2010). After the goal establishment, planning is necessary to accomplish the objectives. The specificity of the plans and strategies will determine whether people achieve their goals. The organisation of materials, which is heavily related to planning ability, is a much-needed skill to successfully carry out tasks such as project planning. There are plenty of students who develop nicely ordered plans for their work but fail miserably in the execution to study or write a paper due to their weakness in organisation of the materials (Kaufman, 2010).

Time management is among the most essential of the metacognitive executive skills, and it is very much related to goal-setting, planning skills, and anxiety/stress management (Misra & McKean, 2000). To complete tasks promptly, one must gauge with reasonable accuracy how long the task will take and then set aside the time to get it done (Kaufman, 2010). Task initiation involves the metacognitive skill to start the tasks promptly by avoiding procrastination. Students need to marshal their cognitive energy and organise their thinking to decide where and how to begin a task. This decision needs to be held and organised in WM while simultaneously initiating the outcome's mechanical aspects.

For attention skill, based on cognitive psychology and neuroscience research, there are two elements of attention. Firstly, the direct control attention (goal-directed or endogenous attention) and next, the involuntary attentional elements (Pessoa & Ungerleider, 2004). To be successful in school, students must develop a reasonable capacity to engage their attention selectively by choosing the correct direct control attention or the involuntary attentional elements. They also need to focus independently on important activities for critical periods and divide their attention as necessary between different essential elements of learning contexts (Pashler, Johnston, & Ruthroff, 2001). WM plays an essential role in the learning process, where it has an impact on the encoding and retrieval of information from LTM by serving as the essential bridge between short and LTM (Dehn, 2008). As the cognitive workspace, WM also serves as the cognitive "mixing bowl" in which new information is combined with background knowledge to comprehend spoken and written language (Kaufman, 2010).

Set shifting enables a person to move with relative ease between tasks and between steps within tasks. Due to different neuropsychological profiles, some children exhibit what Goldberg (2001) referred to as a specific stiffness of mind, in that they have a more incredible difficulty moving within and between tasks than would be expected for their age. For these students, prompts from parents or teachers to abandon a task (or even a part of a task) are torturous and completely unacceptable directions. Possessing balky cognitive shifters, these children become routine-, schedule-, and rule-bound, and generally require a considerable lead time and support to move onto other things before they are "done" (Kaufman, 2010).

Another EF domain in Kaufman's model is the social-emotional regulation strand with three EF skills: response inhibition/impulse control, emotional control, and adaptability. Psychologists refer to impulse regulation capacity as response inhibition. Some theorists considered response inhibition to be the primordial executive skill that precedes all other (Barkley, 1997). An essential aspect of the human condition is the ongoing struggle to check impulses to live amicably with others and achieve goals. People succeed and fail varied from day to day due to the management of a range of desires. Some might collapse on the spot due to the embarrassment that they had to face (Kaufman, 2010).

Emotional control refers primarily to the self-management of emotions. Emotional control skills may not prevent people from becoming enraged or despondent when stuck in a traffic jam, but they will determine how they vent out their frustration. Actions like taking some deep breaths while repeating a soothing mantra or a more maladaptive response enable emotional control (Kaufman, 2010). As Greene (2001) pointed out, children come into the world with varying potentials for coping with anger and frustration. Children who have less frustration management skills than their peers may struggle profoundly in family, school, and social contexts. Adaptability (similar to flexibility) is the social-emotional facet of the set-shifting skill. Just as the speed and ease can heavily influence success with academic activities with one transition within and between tasks, an individual’s success in social/behavioural domains is at least partially determined by how well he or she can adapt to changes in routine and cope with the many curveballs life throws at everyone daily (Dawson & Guare, 2010). Those who can cope with reasonable equanimity become more “together” and socially desirable than those who stubbornly insist on sameness and meltdown when their routines are disturbed (Kaufman, 2010). In this study, sequencing and task persistence skills were not included. Sequencing is part of WM, and task persistence relied heavily on self-monitoring in Gioia et al. (2015) model.

Gioia et al.'s (2015) EF model consists of three strands: the cognitive regulation index, ER index, and BR index. The cognitive regulation index consists of the initiate, WM, plan/organise, task monitor, organisation of materials, and task completion. The BR index is the representation of a child's ability to regulate and monitor behaviour effectively. There are two EF skills associated with this index, which are inhibition and self-monitor. The ER index represents a child's ability to regulate emotional responses, including changing situations. The ER index consists of shift and emotional control. All the skills are similar to Kaufman's model except for task monitoring, task completion, and self-monitoring.

Task monitor and self-monitor skills are grouped as one skill due to overlapping similar characteristics under self-monitor, pictured as the meta in metacognition by Kaufman (2010). Self-monitoring is the capacity to observe and evaluate one's behaviour as others experience it. Self-monitoring also includes an understanding of one's strengths and weaknesses, the ability to monitor the impact on others, awareness of one's effectiveness in problem-solving, and the ability to monitor other vital outcomes (Gioia et al., 2015). Successful students frequently gauge the quality of their attention, comprehension, and production in learning situations and adjust as necessary to maintain efficient input and productive output by self-monitoring (Kaufman, 2010). Task completion can be considered an outcome variable expressed either as a failure to complete a task or slow, inefficient task completion. Difficulties in this area often result from problems in other EF skills such as planning, organising, initiating, or sustaining WM (Gioia et al., 2015).

The skills in Kaufman (2010) and Gioia et al. (2015) are closely related to the Malaysian context since the EF skills are present in the Curriculum Standard Document and Assessment (CSDA) Physics Form Four (2018). For instance, goal-setting is essential in critical and creative thinking and reasoning skills (p.7). Planning skill is needed to select the best solution from several alternatives available (p.8).

Organisation skill is required to classify information based on specific criteria such as common characteristics or features (p.5). Time management skill is essential in conducting activities orderly and timely (p.18). Task completion skill is needed to complete a given project, such as building a cluster home model to overcome extreme temperatures (p.77). WM skill is required when a student forms a perception or mental image about an idea or concept (p.7). Shifting skill is required to quickly and flexibly process multiple representations, such as processing the experimental findings or observation data in various complex forms (p.15). In the form of reappraisal, emotional control skill was needed to record information objectively, which was not affected by feelings of illusions (p.18). Attention is much needed during experiments to be fully attentive to handling specimens correctly and carefully (p.10) to avoid any mistakes or injuries. Students need flexibility skill to adjust to changes, such as acknowledging that the knowledge of physics is temporary and evolving (p.2). Inhibition skill is required to perceive, feel, think, or act on the first impulse to solve complex problems (p.20). Self-monitor skill is required to self-assess where the students need to be responsible for their actions and consequences (p.21).

Apart from the CSDA Physics Form Four (2018), the EF skills in Kaufman’s (2010) and Gioia et al. (2015) models are also closely related to the Malaysian context in the teaching and learning Force and Motion subtopics. Thirteen EF skills are helpful to learn the physics concepts involved successfully. For example, to understanding the momentum concept, goal-setting skill is needed to set the goals to accomplish all the learning outcomes (Meltzer, 2010). Organisation skill is needed to perform tasks to contribute effectively (Northcott, 2011), such as successfully organising experiments related to momentum. Task initiation skill is needed to promptly start the task given independently or with the teacher's guidance. Time management and task completion skills are needed to successfully manage, complete the task, or solve the problems (Zelazo, 2013) pertaining momentum. Attention skill is needed to pay attention successfully when the teacher explains the content or when they read the content independently. Flexibility skill is required for the students to multitask or transit between many activities without anxiety (Dawson & Guare, 2010) when learning momentum. WM skill is needed to store concepts and formulas and recall them while solving them (Kincaid & Trautman, 2010). Shifting skills enable students to shift with relative ease between tasks and between steps within tasks given (Logue & Gould, 2013). A good planning skill enables the students to arrange the tasks given in order of importance to achieve their goals in completing the tasks given, such as homework or projects (Krishnan, Feller, & Orkin, 2010) pertaining momentum.

Emotional control skills enable the students to collaboratively work with their peers while keeping their emotions in control (Stein, 2010) when conducting experiments. Inhibition skill enables the students to suppress inappropriate impulses, thoughts, and actions to perceive, feel, think, or act on first impulse (McCloskey, Perkins, & Van Divner, 2009) during the teaching and learning sessions. Self-monitor skill enables the students to manage their cognitive and metacognitive processes to track their performance and outcomes (Zimmerman & Shunk, 2001) while learning momentum. The thirteen EF skills mentioned above to learn Force and Motion are grouped into three strands: metacognition, BR, and ER, similar to the strands in the Gioia et al. (2015) model.

Previous studies indicated that EF skills are needed to understand concepts. For instance, Rhodes et al. (2014) examined the relationship between EF's core aspects (inhibition control, mental set-shifting, WM, and planning) and biology's factual, conceptual learning. Results indicated that WM and planning significantly predicted the conceptual understanding of biology. Chen and Whitehead (2009) conducted a study to determine the relationship between WM capacity and learning physics using Taiwanese students aged 13-15. The outcome showed that students with higher WM capacities were consistent in understanding the physics concepts better. The author gave suggestions to teachers to be aware of the various capacities of students' WM, in which this variety makes their rate of development of understanding to be limited. Teachers also need to consider the students' limited WM capacity in deciding the teaching approach to deliver the content.

Based on the above studies, EF skills vary according to the concepts. Specific EF skills are involved in learning physics concepts, such as Force and Motion, and a model that explains the EF skills is necessary. The thirteen skills identified are modelled using structural equation modelling. CB-SEM is used to analyse the measurement model(as confirmatory factor analysis). PLS-SEM is used to analyse the structural model. PLS-SEM has many advantages in developing a model. PLS-SEM is robust to non-normality, can easily accommodate formative measures (Diamontopoulos, 2011), and PLS-SEM is preferred when the structural model has many constructs and indicators (Hair, Hult, Ringle, & Sarstedt, 2014b). Since there are thirteen skills (thirteen constructs) in this study, hierarchical component models (HCMs) will be used in PLS-SEM to reduce the number of relationships in the structural model and make the PLS path model more parsimonious and easier to grasp (Hair et al., 2014b). The HCMs established using the bottom-up approach, allowing several latent variables, the first-order EF skills constructs, combined into a single, more general construct. Several EF skills (first-order constructs) merged into second-order constructs, respectively, the metacognitive, BR, and ER. Then, these three second-order constructs merged into a third-order construct named EF. The model developed informs the EF skills that are required to learn physics. These skills categorised into the main three strands of EF: metacognitive, BR, and ER. The teaching guide design embeds the EF skills under the three strands. Simultaneously, the EF level among students needs consideration in designing the teaching guide.

Past studies do indicate that the EF-specific teaching approach played a vital role in delivering the concepts effectively. For example, a study examined the relationship between chemistry learning and verbal executive WM task performance. In the study, the new teaching material minimised any limitation to learning caused by WM space. The result showed a significant difference in average improvement in the experimental group compared to the control group, and there is a significant correlation between verbal WM and performance on the chemistry test. Based on the correlation, cognitive factors like WM capacity for learning were more meaningful in the learning approaches (Danili & Reid, 2004).

Different students have different EF levels (Kahn & Foster, 2013). Kahn and Foster (2013) further proposed that the 4QM approach can be adapted to suit the teaching and learning session for students with different EF levels. 4QM is an approach that grew out of cognitive psychology, provides a structure to enhance the knowledge when using learning strategies as part of a teaching-learning approach to intervention (Greber et al., 2007a). Kahn and Foster (2013) suggested that Quadrant 1 accommodates students with low EF levels, where the teaching and learning focused on directive strategies and are highly dependent on the facilitator. The directive strategies include explicit instruction and explanation, demonstration, and lower-order questions. Quadrant 2 is facilitator initiated and accommodates students with a moderately low EF level using indirect teaching and learning strategies. The indirect strategies suggested are higher-order questioning, feedback, prompts, and think-aloud modelling. Quadrant 3, which is learner-initiated, caters to students with a moderately high EF level. Direct teaching and learning strategies can be used, such as framing, mnemonics, verbal self-instruction, visual cues, and self-prompting. The final quadrant, Quadrant 4, is learner-initiated and accommodates students with a high EF level. The indirect strategies suggested for this quadrant are mental imagery, self-instruction, self-questioning, self-monitoring, problem-solving, and automaticity (Kahn & Foster, 2013).

1.3 Problem Statement

Past studies indicated that EF's role in teaching and learning in various science disciplines and countries other than Malaysia was investigated substantively. For instance, Bull and Scerif (2001), in their study with 93 school students from Scotland, found that EF correlated significantly with mathematical ability. Danili and Reid (2004) conducted a study with 105 Greek students and found that WM was related to chemistry performance. In another study by Rhodes et al. (2014) with 63 students from Scotland, planning skill predicted the factual assessment's performance. Planning and WM were predictive of performance on the conceptual assessment in learning biology. Latzman, Elkovitch, Young and Clark (2010) found that flexibility predicted performance in science in their study with 174 adolescents from the United States of America (USA). Abdullah, M.N.S. (2019) found that EF-based teaching strategy (focused on inhibition, WM, and shifting skills) enhanced students' understanding of Force and Motion subtopics in Malaysia. From the available studies on the EF and the learning of sciences, minimal literature is available on physics. Hence, there is a literature gap in fostering EF's role in teaching and learning physics. Similarly, minimal studies are available about EF and physics students in Malaysia.

EF's notion is context and content-specific, further depicts the need for EF information on learning physics in the Malaysian context (context-specific). A general instrument of EF is unable to capture the specific EF skills present. A context-specific instrument enables the measurement of EF skills levels accurately among the Form Four Malaysian physics students. However, there lacks an instrument to measure the EF of Malaysian students in learning physics. The available instruments are context-specific such as the Behaviour Rating Inventory of Executive Function (BRIEF) Parent and Teacher Reports. This inventory administered in 25 schools in the USA in Maryland (12 elementary, nine middle, and four high schools) rated parents' and teachers' views on the BR and metacognitive problems in children aged 5-18 years. The Barkley Deficits in Executive Function Scale—Children and Adolescents (BDEFS-CA) rated by the parent on EF behaviours in their children aged 6 to 17 years distributed across the USA's four regions (Barkley, 2012a). The Delis Rating of Executive Functions (D-REF) rated the EF in individuals aged 5–18, distributed across the USA's four regions with varying correspondence to the overall population (Delis, 2012). To serve the Malaysian context, only one instrument using the Executive Skills Questionnaire-Revised to measure executive dysfunction among employees in Malaysia was identified (Nasir, Tan & Pheh, 2021).

Since there is no instrument to measure and explicitly indicate the EF skills inherent to learn fundamental physics concepts in Force and Motion, integrating EF skills that might guide learning may hinder. The absence of an instrument to measure and informs the skills subsequently results in a lack of identification of the students' EF skills, and there is no model to be integrated into the teaching and learning of Force and Motion. This suggests a model is necessary to guide the teachers to perform the teaching. The model provides general information on the strands and EF skills needed in teaching and learning physics, but the EF level of students differs (Kahn & Foster, 2013). A guide to teaching the students with different EF levels using the 4QM and based on the needed model's skills to teach the physics concepts in Force and Motion.

As mentioned earlier, EF's role in teaching and learning physics concepts in Malaysia is minimal, which results in the teachers being less informed about using EF. Earlier studies focused on brain-based learning. For instance, Saleh (2012) found that the brain-based teaching approach has increased the students' motivation in learning physics. Another study examined the effects of brain-based teaching with i-Think maps and the brain gym approach towards the conceptual understanding of physics concepts. The result indicated that the conceptual understanding of Force and Motion topics among matriculation college students increased using this approach (Saleh & Mazlan, 2019). These studies merely introduced brain-based teaching strategies and measured their effectiveness. The EF skills that lie at the brain's frontal lobe, which is the primary concern of the neurocognitive approach that plays a predominant role in learning, were ignored in the above studies. Recent research by Abdullah, M.N.S. (2019) found that EF teaching-based strategies have enhanced students' understanding of Force and Motion, but the strategies focused solely on enhancing metacognition.

The teacher-centered approach currently dominates the teaching and learning of Force and Motion (Wieman & Perkins, 2005). According to Salmiza and Afik (2012), physics was still teacher-centered, although the teachers in Malaysia were knowledgeable about the teaching contents and used various teaching techniques. This teacher centered approach had made the students behave passively in the classroom. According to Wieman and Perkins (2005), lecture-based teaching results in less expert-like thinking. Apart from this, the students perceive physics as less connected to the real world, less exciting, and need to memorise without understanding. Wieman and

Perkins (2005) further concluded that the traditionally taught students learn by rote, memorising facts and recipes for problem-solving, and not gaining proper understanding. These students also assume that physics is boring and irrelevant to understanding the world around them (Wieman & Perkins, 2005). Even using 21st-century learning by focusing on student-centered, the average grade of physics subject in Malaysian Secondary Examination dropped (from 4.09 in 2017 to 4.27 in 2018) (Malaysia, 2019). Hence, a teaching guide based on a model that explains the EF skills inherent to teaching and learning of Force and Motion is required to deliver the lessons using the EF skills effectively.

1.4 Research Objectives

The objective of this research is to

1) explore the teaching and learning of physics to identify the components of EF that exist among the Form Four physics students.
2) explain the positive effects between the three strands of EFs (metacognitive, behavioural and emotional regulation) and understanding of physics concepts.
3) propose a teaching guide based on the EF model components developed and 4QM model for the two schools involved.
4) measure the effectiveness of the teaching guide on students' understanding of force and motion concepts for

   a) school A

   b) school B
5) explore the perception of the teachers and students in using the proposed teaching guide.

1.5 Research Questions

1) What are the EF skills that exist among the Form Four physics students?
2) Is there a significant positive effect between three strands of EF skills (metacognitive, behavioural, and emotional regulation) and understanding of physics concepts?
3) What is the teaching guide proposed from the EF model components developed and 4QM model for the two schools involved?
4) Is there any statistically significant difference between the pre and post-test mean scores of force concept test for:

   a) School A?

   b) School B?
5) What are the teachers' and students' perception in using the proposed teaching guide?

1.6 Research Hypothesis

Hypothesis which related to the problem were developed as follows:

1) H_1: There is a significant positive effect between metacognitive strand and understanding physics concepts.

2) H_2: There is a significant positive effect between emotional regulation strand and understanding physics concepts.

3) H_3: There is a significant positive effect between behavioural regulation strand and understanding physics concepts.

4) Ho_4: There is no statistically significant difference between the pre-test and post-test mean scores of the force concept test for School A.

5) Ho_5: There is no statistically significant difference between the pre-test and post-

test mean scores of the force concept test for School B.

1.7 Significance of the Study

The significance of this study is discussed based on different perspectives such as practionaire, students, policymakers, MMR, and theoretical significance. Firstly, for the practionaire, the teachers, integrating EF into the teaching and learning of physics is a new pedagogical approach to enhancing and understanding the students' physics concepts. According to Maknun (2020), reform effort is needed at all levels in education to uplift the students to compete successfully in the era of globalisation. Thus, the EF-based teaching strategy can be considered a reform to equip the physics students with all the skills needed to uplift them to compete successfully. Effective teaching and learning strategies based on EF must be implemented in the teaching and learning of physics to cater to all students with different EF levels. However, the teachers are currently not provided with a guide to measure the students' EF level. The EF Questionnaire proposed in this study is a tool for the teachers to assess EF's level among their students. Simultaneously, the teaching guide proposed in this study will help the teachers get an overview of EF-based teaching from the pedagogical perspective.

For the students, firstly, the teaching and learning sessions were catered according to their EF levels. The students were divided into four quadrants using 4QM, as Kahn and Foster (2013) suggested. Those in the low and moderately low EF level undergo teaching and learning sessions using facilitator-initiated strategies. In contrast, moderately high and high EF levels students undergo teaching and learning sessions using learner-initiated strategies. Simultaneously, their EF deficits were tackled during the teaching and learning sessions to utilise their EF skills fully. Thus, when the students learn in their respective quadrants, they can fully utilise their EF skills to grasp the knowledge and improve their understanding of the physics concepts.

Thirdly, for the policymakers, the teaching guide on Force and Motion subtopics in the current study provided a detailed description of implementing the EF-based teaching strategy. The teaching guide included the lesson plan, notes, activities, and supporting learning materials. Therefore, this teaching guide is informative to the Form Four physics curriculum developer (the Curriculum Development Centre (CDC), Ministry of Education Malaysia). CDC should suggest the teaching guide as an alternative to the current conventional teaching strategy. Simultaneously, the teaching guide's implementation in the current teachers' professional development courses and the pre-service teachers' curriculum should take place. Meltzer (2007) stressed that public education changes toward high-stakes testing had shifted the curriculum toward highly challenging, developmentally demanding goals that require students to access EF processes rapidly and efficiently. Thus, EF teaching strategies should emphasise the focus on the teaching and learning of physics.

This research suggests an EF Questionnaire to measure the Form Four physics students' EF level in Malaysia for the policymakers. Various instruments from other countries were adapted to produce thus EF questionnaire that suited the Malaysian context. Simultaneously, the EF and understanding of physics concepts model developed provides the information to the policymakers about the EF skills and EF strands needed to enhance students' understanding of physics concepts. This study's findings could also inform the policymakers on the effectiveness of the teaching guide developed to enhance the understanding of physics concepts among Form Four physics students. According to Beatriz, Deborah, and Hunter (2008), policymakers need the information to better address students' needs and improve the education policy. The information on the EF Questionnaire, EF, and understanding of the physics concepts model and the teaching guide could provide valuable information to the policymakers.

Fourthly, this research also contributes to the multiphase design study under mixed-method research. Not many studies in education apply multiphase design study. This research sets an example of how to incorporate a multiphase design study in the educational field. Finally, this study also contributes to the theoretical significance. This research can be used as a reference by researches who want to research EF, EF deficits, and physics understanding.

1.8 Delimitations of the Study

This study was conducted only among the form four Malaysian students in the Northern region. The minimum sample size is 189 for an effect size of .15 (the alpha error probability of .05, power of .95, and the number of predictors of 13 (using GPower). According to Hair, Black, Babin and Anderson (2014a), the preferable sample size is 100 or larger, or the minimum of having at least five times as many observations as the number of variables to be analysed. There are 55 items in this model. Based on the rule of having at least five times as many observations as the number of variables to be analysed, the sample in this study, which consists of 529 samples, is sufficient. Since the number of samples is sufficient, the findings can be generalised to form four Malaysian physics students.

There are various EF skills based on different models of EF. This study is limited to the EF skills that are present in the Form Four physics students based on the findings from document analysis of CDCA Physics From Four (2018), interview analysis of Form Four physics students, and teachers who are teaching Form Four students, and models proposed by Kaufman (2010) and Gioia et al. (2015). However, the EF skills identified were adequate to represent the skills in EF. The teaching guide was developed explicitly for the students who took part in the study. A different group of students will have different EF levels and EF deficits. Thus, the teaching guide cannot be generalised for all the Form Four students taking physics.

For the teaching guide's treatment, the students participated in teaching and learning sessions for five weeks. According to Creswell (2014), five weeks of duration for treatment is sufficient. However, the treatment should be conducted for a more extended period to observe the teaching guide's effectiveness. The topics for the teaching guide are limited to five subtopics under Force and Motion: Understanding Inertia, Analysing Momentum, Understanding the Effects of a Force, Analysing Impulse and Impulsive Force, and Understanding Gravity. Thus, the teaching guide does not represent the whole Force and Motion topic and Form Four physics topics. To measure the effectiveness of this study, having a paired t-test is appropriate at the research level. However, paired t-test alone has bias and type I error. For more advanced analysis, the use of ANOVA is necessary. In the analysis of the teaching guide's effectiveness, one group pre-test and post-test design were used. According to Bryman (2012), this design is sufficient for the analysis. However, for a better reflection, it is recommended to have a control group. A comprehensive comparison using the control group strengthens the findings in this study and is beneficial as a benchmark to measure other groups' results.

1.9 Operational Definitions

1. Executive Function

Executive functions are a collection of processes responsible for guiding, directing, and managing cognitive, emotional, and behavioural functions, particularly during active, novel problem-solving. EF represents an umbrella construct that includes a collection of inter-related functions responsible for purposeful, goal-directed, problem-solving behaviour (Gioia et al., 2015). In this study, EF referred to a collection of the process responsible for guiding, directing, and managing the metacognitive strand, BR strand, and ER strand. All these strands are necessary for novel problem solving, leading to a better performance in physics achievement. Simultaneously, there are inter-related functions, showing various EF skills involved are purposeful and goal-directed to achieve a good result in physics. Interviews with students and teachers assessed the EF skills present in Form Four physics students. Using EF Questionnaire and the students' year-end physics marks, a model of EF and understanding of physics concepts modelled. The EF Questionnaire also assessed the Form Four physics students' EF levels to group them into the correct quadrants in developing the teaching guide. The teaching guide developed on Force and Motion embeds the EF skills, EF strands, and EF skills deficits.

2. Metacognition

Metacognition in this study is the knowledge and cognition about cognitive phenomena (Flavell, 1979). Knowledge of cognition is what individuals know about their cognition and consists of three kinds of metacognitive awareness: declarative, procedural, and conditional knowledge (Brown, 1987; Jacobs & Paris, 1987; Schraw & Moshman, 1995). Cognition is the mental action or process of acquiring knowledge and understanding through thought, experience, and senses and encompasses many EF skills. In this study, most

EF skills fall under this metacognitive strand, which aligns with Kaufman's (2010) model and Gioia et al. (2015) model. There are eight skills under this strand: goal-setting, planning, organisation, time management, task initiation, task completion, WM, and shifting, and these eight skills are related to understanding physics concepts. These eight EF skills are measured by using the EF Questionnaire. The metacognition skills were also embedded in the teaching guide developed. For instance, the Graffiti Facts that consist of questions such as ‘What I Know’, ‘What I Want to Learn’, and ‘What I Learned’ were answered by students to assess their metacognition and facilitate their thinking throughout the lesson.

2a. Goal-Setting

Goal-setting is the ability to set specific, realistic objectives that can be achieved within a defined period based on an awareness of personal strengths and limitations and a clear vision of the desired result. To have a good achievement in physics, students need to have specific objectives to master the content of physics and to achieve it. They also need to know their strength and limitations. Four requirements are focused on by Krishnan et al. (2010) for students to set their goals. Firstly, students need to understand their learning strengths and weaknesses, as well as their learning profiles. Secondly, they also need to understand the “big picture” and envision a task's endpoint. Thirdly, students also need to value the task to engage actively in a task or assignment. The final requirement for students to set their goals is by recognising the goals that need to be attainable. In this study, the goal-setting skill was measured using the Goal Setting Questionnaire (2018 Version) (Gaumer Erickson & Noonan, 2018), a part of the EF Questionnaire.

2b. Planning

Planning refers to a complex, dynamic sequence of planned actions that must be continuously monitored, reviewed, and updated (V.Wild & Musser (2014). Planning needs a sequence of planned actions, which shows that students need to plan their tasks, be reviewed, monitored, and updated to get a positive outcome in their achievement. Items from BRIEF2 were adapted into EF Questionnaire and administered to assess the Form Four physics students' planning skills. Students who have weak planning skills were given a template to choose a formula before solving the questions. This template helps them plan first which formula to be chosen based on analysing the questions.

2c. Organisation

Organisation in this study is the ordering of a cohesive whole to collectively serve as a common goal (Krishnan et al., 2010). There are smaller segments in the organisation involved, such as material, methods, and strategies collectively grouped to serve a common goal. Students need to organise school materials, information, and ideas for greater independence in the academic setting. In this study, organisation skill was measured using EF Questionnaire, where the original items were adapted from BRIEF2.