EXECUTIVE FUNCTION-BASED TEACHING STRATEGY'S EFFECT ON SECONDARY SCHOOL STUDENTS' UNDERSTANDING OF FORCE AND PHYSICS METACOGNITION

by

MOHD NOR SYAHRIR ABDULLAH

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LIST OF ABBREVIATIONS

BSE	Between Search Errors
CANTAB	Cambridge Neuropsychological Test Automated Battery
EF	Executive Function
FCT	Force Concept Test
IC	Inhibition Control
IE/ED Task	Intra/Extradimensional Set Shift
KBSM	Kurikulum Bersepada Sekolah Menengah
MMR	Mixed-Method Research
MoCA	Montreal Cognitive Assessment
MSS	Mental Set-Shifting
MT	Metacognitive Theories
NCM	Neurocognitive-constructivist Model
SPM	Sijil Pelajaran Malaysia
SSRT	Stop Signal Reaction Time
SST	Stop Signal Task
SWM	Spatial Working Memory
WM	Working Memory

LIST OF APPENDICES

KESAN STRATEGI PENGAJARAN BERASASKAN FUNGSI EKSEKUTIF TERHADAP PEMAHAMAN KONSEP DAYA DAN METAKOGNISI FIZIK DALAM KALANGAN PELAJAR SEKOLAH MENENGAH

ABSTRAK

Kajian terdahulu mencadangkan bahawa fungsi eksekutif (EF) otak berperanan terhadap metakognisi dan juga proses pengajaran-pembelajaran konsep daya dalam fizik. Oleh itu, kajian ini dijalankan dengan bertujuan memperkenalkan strategi pengajaran berasaskan fungsi eksekutif untuk mengajar konsep daya serta mengkaji kesannya ke atas pemahaman pelajar sekolah menengah terhadap konsep daya dan juga metakognisi fizik. Sebelum itu, hubungan antara tiga komponen utama EF dan pemahaman terhadap konsep daya diukur dahulu untuk mencadangkan strategi pengajaran yang unik ini. Kajian ini menjalankan kajian reka bentuk gabungan dan intervensi di mana data kualitatif digabungkan dan dihubung jalin bersama data kuantitatif. Kajian ini dijalankan dalam dua peringkat melibatkan 61 orang pelajar Tingkatan Empat. Pada peringkat pertama, hubungan antara tiga komponen EF dengan pemahaman terhadap konsep daya dikaji. Untuk tujuan ini, *Cambridge Neuropsychological Test Automated Battery (CANTAB)* dan Ujian Konsep Daya telah dijalankan untuk melihat hubungan antara tiga komponen EF (Ingatan Kerja, Kawalan Sekat-lakuan & Perubahan Mental) dan pemahaman konsep daya. Analisis korelasi Paerson menunjukkan terdapat hubungan korelasi yang signifikan terhadap Ingatan Kerja dan pemahaman konsep daya. Dapatan temu bual dan juga analisis dokumen mendedahkan bahawa EF memainkan peranan penting terhadap pengajaran dan pembelajaran topik daya. Hasil daripada penemuan kuantitatif dan kualitatif ini

digunakan untuk mencadangkan strategi pengajaran berasaskan fungsi eksekutif untuk mengajar topik daya. Pada peringkat kedua, strategi pengajaran berasaskan fungsi eksekutif ini dijalankan untuk mengajar topik daya. Kesan strategi pengajaran ini terhadap pemahaman pelajar terhadap konsep daya dan metakognisi fizik telah dikaji. Sebanyak 10 aktiviti menggunakan strategi pengajaran ini telah diguna pakai untuk mengajar topik-topik daya. Ujian Konsep Daya dan juga soal selidik Inventori Metacognisi Fizik telah dilaksanakan pada ujian pra, ujian pasca 1 dan ujian pasca 2. Tambahan lagi, temu bual dan analisis dokumen dijalankan untuk menyokong dapatan data kuantitatif terhadap pemahaman konsep daya dan juga metakognisi fizik. Pengukuran ulangan ANOVA dan MANOVA dilaksanakan untuk melihat perubahan yang berlaku terhadap pemboleh ubah bergerak balas dalam kajian ini. Keputusan analisis menunjukkan terdapat perubahan yang signifikan terhadap pemahaman konsep daya ($F = 87.773$, $p = 0.00$). Keputusan juga menunjukkan terdapat perubahan yang signifikan terhadap metakognisi fizik secara keseluruhan dan keuda-dua konstruknya ($F = 31.8$, $p = 0.00$, $\eta^2 = 0.52$). Dapatan temu bual dan analisis dokumen juga menyokong dapatan kuantitatif. Dapatan dari kajian ini menunjukkan peranan EF dalam pemahaman konsep daya dan strategi pengajaran berasaskan fungsi eksekutif merupakan satu pendekatan yang dapat meningkatkan pemahaman pelajar terhadap konsep daya dan juga meningkatkan metakognisi fizik dalam kalangan pelajar.

EXECUTIVE FUNCTION-BASED TEACHING STRATEGY'S EFFECT ON SECONDARY SCHOOL STUDENTS' UNDERSTANDING OF FORCE AND PHYSICS METACOGNITION

ABSTRACT

Literature suggests that executive function (EF) of the brain has a role in metacognition and teaching-learning of force concept in physics. In line with suggestion this study was conducted with the aim of introducing EF-based teaching strategy to teach force concepts as well as to evaluate the effectiveness of EF-based teaching strategy on the secondary school students' understanding of force and physics metacognition. This study employed intervention mixed method design connecting and embedding both quantitative and qualitative data. The study was performed in two stages involving 61 Form Four students. At first stage the relationships between three core components of EF with the understanding of force was measured. For this purpose, cognitive task using Cambridge Neuropsychological Test Automated Battery (CANTAB) and Force Concept Test (FCT) was administered to identify the relationship between EF (working memory, inhibition control & mental set-shifting) and understanding of force. The Pearson correlation analysis performed indicates that the significant correlation exists between working memory and understanding of force. The interviews and document analysis revealed that EF play an important role in the current teaching-learning of force. The results of quantitative and qualitative findings on the status of EF were used to suggest EF-based teaching strategy to teach force. At the second stage, EF-based teaching strategy was used to teach force concepts simultaneously the effect of this strategy on students' understanding of force and physics metacognition was assessed. A total 10 activities using EF-based teaching strategy were adopted to teach force topic. Pre-test, post-test1 and post-test2 were administered for the quantitative survey on force concept test (FCT) and physics metacognition inventory (PMI). Furthermore, interviews and document analysis were used to support the outcome of the quantitative findings on students' understanding of force and physics metacognition. Repeated measure ANOVA and MANOVA were performed to look into the changes in the independent variables. For understanding of force, significant changes ($F = 87.773$, $p = 0.00$) were obtained. For physics metacognition significant changes ($F = 31.8$, $p = 0.00$, $\eta^2 = 0.52$) were obtained in the overall physics metacognition and all its two subscales. Interviews and document analysis results further assist in understanding the quantitative findings. The findings obtained from this study indicated the role of EF on understanding of force and EF-based teaching strategy is an approach that could be used to enhance students' understanding of force and physics metacognition.

CHAPTER 1

INTRODUCTION

1.1 Introduction

Contemporary findings in cognitive neuroscience studies have provided various insights into educational practices. This includes the role of Executive Function (EF) of the brain on the academic achievement. EF is presented as consist of three main cores: working memory, inhibition control and mental set-shifting (also called cognitive flexibility) (Diamond, 2013). EF is also described as a term referring to the underlying processes responsible for children's ability to direct, maintain and focus their attention, manage impulses, self-regulate behaviour and emotion, plan ahead and demonstrate flexible approaches to problem-solving (Howard-Jones, 2010). These abilities subsequently determine the metacognition and cognition ability of the students (Diamond, 2013; Raver & Blair, 2014). Teaching strategies that target on the EF of the individual brain reported to significantly improve students to perform better cognitively and affectively (Danili & Reid, 2004; Kaufman, 2010; McCloskey, Perkins, & Van Diviner, 2008). Many available studies in literature depict the relationship between EF and science learning namely biology (Rhodes et al., 2014) and chemistry (Danili & Reid, 2004).

In the context of learning physic concepts, the nature of EF as mentioned by Howard-Jones (2010) is a process responsible for students to regulate their behaviours, manage impulses and focuses attention plays an imperative role. However, conclusive evidence on the role of EF in teaching and learning of physics is lacking as there are available studies on chemistry and biology. Particularly, in learning the concepts of force, EF in the form of the three components is perceived imperative as frequently the concepts related to force are viewed as isolated pieces of information unrelated to the real world. As a result of viewing force concepts in compartmentalised and fragmented manner, the concepts are learned through memorization, and the notion physics involves problem-solving 'recipes' that apply to highly specific situations is prevalent (Wieman & Perkins, 2005). The tendency to apply recipe like problem-solving techniques is usually linked with the metacognitive strands (Phang, Siallagan, Odubunmi, & Rochford, 2010) of an individual. The above literature suggests that EF has a role in teaching and learning of force concepts in physics. Hence, this study aimed at proposing EF-based teaching strategy to teach force concepts. However, prior to embarking on suggesting the unique teaching strategy, the relationship between three core components of EF with the understanding of force was measured. The findings obtained were used as a guide in suggesting the teaching strategy. Subsequently, the effectiveness of EF-based teaching strategy in improving understanding of force and physics metacognitive skills were measured. Additionally, how the strategy influenced the understanding, and metacognitive skills were explored as well using mixed method intervention design (Creswell, 2015).

1.2 Background of the Study

Physics is frequently considered as one of the most challenging subjects to understand among other science subjects (Chen & Whitehead, 2009; Mohd Salleh, 2004; Saleh, 2012). Chen and Whitehead (2009) surveyed to identify difficult topics in the Taiwanese middle school physics, and they identified a few topics in the physics that students found difficult to understand. Among the topics are electricity, electrical circuits, heat and temperature, and how light travels. In this study, students were invited to make verbal comments on the topics they found difficult. Their comments were: do not understand, hard to understand, too many concepts, complicated diagrams, and applying knowledge is difficult.

A similar scenario happens to the Malaysia context. According to the report of the quality of the answer on SPM 2014 reported by Malaysia Examination Syndicates, the students were unable to provide accurate definition and explanation of specific physics concept (Lembaga Peperiksaan Malaysia, 2016), including force concept. The report also revealed that the students could not explain the law, principle and the theory of physics correctly. The students also could not use the correct formula in answering the questions which means they have low ability in solving physics problems (Lembaga Peperiksaan Malaysia, 2016).

Force is one of the sub-topics in physics Form Four in secondary school that most students have a poor understanding (Salleh & Phang, 2012). This is because it involves learning abstract concepts which students face difficulty to learn (Alias & Ibrahim, 2015) and due to misconceptions that students have about force (Chambers & Andre, 1997; Hammer, 1996). Researchers also found that students' level of the understanding of the concept of force is low because students only remember but do not understand the concepts (Alias & Ibrahim, 2015). Understanding of force concept is essential because the force concept is the basic concept that students need to master in order to understand the more complex concept in physics such as mechanics.

Due to the weak understanding about force, many attempts were made using various strategies to improve the understanding about force (Mohd Zaid & Ahmad, 2007; Saleh, 2012; Salleh & Phang, 2012; Salleh & Tai, 2010). For instance, Saleh (2012) employed a study to assess the effectiveness of the Brain-Based Teaching Approach on the conceptual understanding of Newtonian physics of Form Four students in secondary science school and also their learning motivation towards the subject of physics. The result obtained from this study revealed that the Brain-Based Teaching Approach enhanced students' conceptual understanding of Newtonian physics and also increased their learning motivation towards the subject of physics. In another study conducted by Salleh and Phang (2012) to investigate the effectiveness of teaching strategy using Free-body Diagram on the students' ability to solve problems related to force. The result of this study showed that teaching strategy using Free-body diagram could improve student's ability to solve problems related to force significantly.

Even though various teaching strategies have been introduced to increase students' understanding, traditional teaching approach such as teaching using chalk and talk; textbook and lecturing method still dominates the physics classroom. In the traditional classroom, students are more passive learners and not encouraged to ask questions, and the relationships between students and teacher are too formal. While in the laboratory setting, the traditional approach involves students follow the procedures to perform experiments to prove the physics concept taught and does not take into account the development of students thinking skills and cognitive ability (Wieman & Perkins, 2005).

These conditions made students unable to master physics concepts, and they were quickly bored with the lessons. Physics Nobel Laurette, Carl Wieman suggested that teaching physics should be slowing down, minimising jargon and explicitly structuring and 'chunking' of material to reduce the cognitive overload and helps students learn more deeply (Oliver, 2011). This assertion is parallel with Kaufman (2010) suggestion that students can perform well in the learning and social environments that are matched to their executive skills. Therefore, teaching strategy that considers students' EF should be implemented in the classroom especially in physics teaching and learning to help enhance physics understanding.

Metacognition also plays an important role in solving physics problems (Phang et al., 2010). Metacognition is seen as an important element that could influence the problem-solving process (Flavell, 1979). For example, a study conducted by Anandaraj and Ramesh (2014) on the relationship between metacognition and problem-solving ability of physics major students shows that there is a significant relationship between metacognition of the physics major students and their problem-solving ability. It shows that how important metacognition knowledge and skills on problem-solving ability among the students. This is because metacognition helps the students to give the knowledge about what, why and how they learn, which is helps the students for constructive learning (Anandaraj & Ramesh, 2014).

Research conducted by Phang et al. (2010) investigated the patterns of physics problem-solving and metacognition among Malaysian students and compared with the UK's patterns. The problem-solving processes are "observed" using thinking-aloud technique followed by retrospective interviews. The results of this study revealed that

Malaysia students do not reflect on their thoughts and decisions in solving physics problems because of their inability to express their metacognitive skills.

Previous studies indicated that metacognition and EF are important in the prediction of educational achievement. For instance, a study conducted by Roebers, Cimeli, Röthlisberger, and Neuenschwander (2012) investigated the relationship among metacognitive monitoring, metacognitive control, EF and educational achievement in seven to eight years old students. In this study, they found out that metacognitive control and EF contribute to language abilities. Another study conducted by Bryce, Whitebread, and Szücs (2015) investigated the relationship between cores of executive functions (inhibitory control and working memory) and metacognitive skills from two groups of children (5 and 7-year-old children). The result of the study showed that metacognitive monitoring processes relate to inhibitory control and working memory showed reliable associations with metacognitive control only in the younger group.

According to Kaufman (2010), EF has two core strands: metacognitive strand and the social/emotional strand. The metacognitive strand of EF is further divided into cognitive and academic elements. Both these elements play key roles in the comprehension of information and the planning, starting and completion of the task (Kaufman, 2010). Metacognitive strand includes various skills. Kaufman (2010) proposed goal setting, planning/strategising, sequencing, organisation of materials, time management, task initiation, executive/goal-directed attention, task persistence, working memory and set-shifting as metacognitive skills whereas the skills for the social/emotional strand are responses to inhibition/impulse control, emotional control and adaptability (Kaufman, 2010).

On the contrary, there are researchers who have suggested that EF believed to be a compendium of constructs comprising of three core dissociable components: working memory, inhibition control and mental set-shifting (Rhodes et al., 2014; Diamond, 2013, Lehto et al., 2003; Miyake et al., 2000). Diamond (2013) further argued that the inhibition control construct of EF could be further explained using self-control (behaviour inhibition) and interference control (selective attention and cognitive inhibition) and cognitive flexibility also called mental set-shifting, mental flexibility, or mental set-shifting and closely linked to creativity. Previous studies reported that these three cores of EF are fundamental for building higher order skills such as reasoning, problem-solving and planning (Collins & Koechlin, 2012; Diamond, 2013; Lunt et al., 2012).

Among the three core constructs of EF, the role of working memory in science learning is mostly researched in the past studies (Rhodes et al., 2014). This is because, despite Diamond's claim that the three cores are dissociable, the cores in separation has identified influence learning (e.g., Lehto, Juujärvi, Kooistra, & Pulkkinen, 2003; Miyake et al., 2000). Specifically, among the three cores, Rhodes et al., (2014) asserted that working memory as the best predictor of problem-solving and science grade. For example, Chen and Whitehead (2009) examined the relationship between working memory capacity and learning physics in Taiwanese people aged 13-15 years. This research studied the impact of working memory capacity on the students' understanding of physics. The outcomes of this study showed that students with higher working memory capacities were found consistently to understand the physics concepts better. The authors also suggested that teachers need to be aware that students' working memory capacities vary and that this makes their rate of development of understanding to be limited. The findings of this study suggest teachers should consider limited working memory capacity of the students in deciding the teaching approach to be used in delivering the content.

In another study, Danili and Reid (2004) examined the relationship between chemistry learning and performance on verbal executive working memory task. The authors reported a significant correlation between verbal working memory and performance on the chemistry test. In this study, they constructed new teaching materials to minimise any limitation to learning caused by working memory space. The use of new materials was compared to the normal teaching process. The result showed that there was a significant difference in average improvement in the experimental group compared to the control group. It is suggested that approaches to learning must consider cognitive factors like working memory capacity for the learning to be much more meaningful (Danili and Reid, 2004).

In another study, involving young adolescent (aged 12-13 years) that examined the relationship between core aspect of executive functions (inhibition control, mental set-shifting, working memory and planning) and the factual and conceptual learning of biology showed that conceptual understanding of biology is significantly predicted by executive functions abilities of working memory and planning (Rhodes et al. 2014). Besides, through this study, Rhodes et al. (2014) heightened the role of executive functions in understanding and applying knowledge about what is learned within science teaching.

In the Malaysia Education Blueprint 2013-2025 report, one objective of this report stated that the implementation of the education for the 21st century which includes enhancing students higher order of thinking skills. Since EF encompasses the higher order thinking skills and plays an important role in understanding science concept and also metacognition, it is important to study the role of EF in the understanding of force concept as well as to design EF-based teaching strategies to enhance students understanding of force and physics metacognition.

As stated above, EF encompasses cores that built higher-order skills like metacognitive skills, planning, reasoning and problem-solving. These skills are needed for 21st-century global society to meet the demand of 21st-century global society (Choi, Lee, Shin, Kim, & Krajcik, 2011). Choi et al. (2011) have developed a framework of scientific literacy for 21st-century skills that includes five dimensions: content knowledge (big ideas), habits of mind (systematic thinking), character and values, science as a human endeavour, and metacognition and self-direction. Among those dimensions, metacognition and self-direction are the major dimensions of global scientific literacy. Therefore, developing teaching and learning approach based on students' EF capacities is in line with the framework of scientific literacy for of 21st-century skills. However, research on the role of EF in learning science especially in physics and students' physics metacognition is still lacking.

1.3 Problem Statement

Physics always being labelled as a subject that is difficult, dry and dull. A few studies have shown that among science subjects chemistry and biology, physics is the most difficult subject to understand (Mohd Salleh, 2004). Force is one of the topics that most students found difficult to understand. This is because it involves learning abstract concepts. The difficulty in learning force has resulted in students developing misconceptions about force (Chambers & Andre, 1997; Hammer, 1996). Past research also found that students' level in the level of understanding of the physics concepts related to force is low (Alias & Ibrahim, 2015). This study specifically reported that students failed to determine the direction of the force which acted on the object, force relative magnitude and also failed to visualise the force that acts on counter direction together with the force which acted on the balanced body. This mainly happens because rote memorisation the facts and not completely understanding the fundamentals.

The quality of the answers provided by students in the Sijil Pelajaran Malaysia (SPM) 2014 revealed that students unable to provide accurate definition and explanation of certain physics concepts including force (Lembaga Peperiksaan Malaysia, 2016). The report also revealed that some students only able to partially correct explanation for the law, principle and theory of physics. The report indicated that students' ability to solve physics problems appeared moderate. This is because students did not use the correct formula in answering the questions (Lembaga Peperiksaan Malaysia, 2016). This means that students still have poor understanding of physics concepts.

Metacognition is an important element that influences students' problem-solving skills, especially in physics. This is because metacognition awareness permits the students to use appropriate strategy in learning a task and solving the problem (Bogdanovic, Obadovic, Cvjeticanin, Segedinac, & Budic, 2015). A study conducted by Phang et al. (2010) to identify the pattern of physics problem-solving and metacognition among the UK and Malaysian secondary school students have reported that Malaysia students lack in metacognition skills in solving physics problems.

Considering the importance of metacognition skills, this skills has been recognised as one of the elements of 21st-century scientific literacy (Choi et al., 2011). In 2013, Ministry of Education Malaysia had introduced Malaysia Education Blueprint 2013-2025 in order to improve and strengthen the national education system. This includes to improve science and mathematics education and also to enhance higher order thinking skills among the students including metacognitive skills. However, specific strategies focus on imparting this skill particularly in physics is lacking.

Some studies have examined that metacognitive skills closely related to EF (Bryce et al., 2015; Fernandez-Duque, Baird, & Posner, 2000; Hofmann, Schmeichel, & Baddeley, 2012). But most of the studies investigated metacognition and EF as two different separate non-related entity (Roebers et al., 2012). The empirical study testing the effect of EF on metacognition and physics understanding is still minimal in the literature despite the claim that EF closely related to metacognition and academic achievement.

EF of the brain is an imperative tool that fundamentally influences students understanding. Rhodes et al. (2014) suggested that different aspect of EF might be important in the learning of different science subjects. For instance, in a recent finding, working memory and planning were reported as predictive of conceptual understanding of biology. Another finding highlighted the role of inhibition control and mental set-shifting in relation to generic science achievement (Latzman, Elkovitch, Young, & Clark, 2010) and conceptual learning of chemistry (Rhodes et al., 2012). Following these importance, studies have been conducted to rule out the relationship between EF (or components of EF) and science learning in biology

(Rhodes et al., 2014), chemistry (Danili & Reid, 2004 & Rhodes et al., 2012) and generic science (Latzman et al., 2010). However, up to this end literature on the relationships between EF components and learning of physics concepts is lacking.

Many researchers suggest that EF has three separable, yet interrelated, core components: working memory, inhibition control and mental set-shifting (Diamond, 2013; Miyake et al., 2000; Rhodes et al., 2014; Rhodes et al., 2016). Most research that has examined executive functions and science learning has focused on the role of working memory (Rhodes et al., 2014). For instance, Danili and Reid (2004) studied the role of working memory capacity in chemistry performance have found that there is significant relationship exist between working memory capacity and pupils' performance. In this study, they developed teaching materials which were specifically designed to minimise the impact of limitations in working memory space, and the result showed that the new teaching strategy could enhance students' performance in chemistry. However, besides in separation, collectively how all the constructs of EF function influences learning is still minimal.

Many studies focus on the role of EF in academic achievement at elementary students (e.g. Espy et al., 2004; Monette, Bigras, & Guay, 2011; Nayfeld, Fuccillo, & Greenfield, 2013; Ramirez, Gunderson, Levine, & Beilock, 2013). Despite the development of EF is reported from early childhood until early adolescent (Best, Miller, & Naglieri, 2011), not much study has been conducted between the age of 15 to 16 years old. For instance, Espy et al. (2004) conducted a study to determine whether executive functions were related to emergent mathematical proficiency in preschool children (age between two and five years). The result of this study showed that components of EF like working memory, inhibition control and mental set-shifting were related to emergent mathematical proficiency in preschool children.

Many attempts were made using various strategies to improve understanding of force (Alias & Ibrahim, 2015; Mohd Zaid & Ahmad, 2007; Salleh & Phang, 2012; Salleh & Tai, 2010). However, traditional teaching approaches such as using chalk and talk; textbook and lecturing method still dominates the physics classroom. Researchers also indicated that students could perform well in learning if the academic and social contexts are aligned to their executive functioning needs (for example, working memory, inhibition control, and mental set-shifting) (McCloskey et al., 2008). Therefore, this study is attempted to investigate the relationship between EF and understanding of force among students at the age of 15 to 16 years old. Based on the identified relationship, EF-based teaching strategy will be adopted from various sources and used in the lessons of force. Then, the effect of this teaching strategy on students' understanding of force and physics metacognition were investigated.

1.4 Research Objectives

The objective of this research is to investigate the relationship between the three core components of executive functions and understanding of force. Based on the relationship between the three components of EF and understanding of force an effective EF-based teaching strategy will be suggested to teach force. Additionally, the effectiveness of this teaching strategy in improving students understanding of force and physics metacognition will be measured. The specific research objective of this study includes:

1. To investigate the relationships between EF components (working memory, inhibition control and mental set-shifting) and students' understanding of force. Specifically:

i. To investigate the relationship between EF components of working memory and students' understanding of force.

ii. To investigate the relationship between EF components of inhibition control and students' understanding of force.

iii. To investigate the relationship between EF components of mental set-shifting and students' understanding of force.

2. To explore how the three core components of EF: working memory, inhibition control and mental set-shifting are considered in the current situation of teaching and learning of force.

3. To suggest an EF-based teaching strategy to teach force based on the findings on the objective 1 and objective 2.

4. a) To investigate the effectiveness of EF-based teaching strategy on students' understanding of the force.

4. b) To explore and understand how EF-based teaching strategy resulted in students' understanding of force.

5. a) To investigate the effectiveness of EF-based teaching strategy on students' physics metacognition and its subscales (knowledge of cognition and regulation of cognition). Specifically:

i. To investigate the effect of EF-based teaching approach on students' knowledge of cognition.

ii. To investigate the effect of EF-based teaching approach on students' regulation of cognition.

5 b) To explore and understand how EF-based teaching strategy resulted in students' physics metacognition.

1.5 Research Questions

1. Does any significant relationship exist between EF components (working memory, inhibition control and mental set-shifting) and students' understanding of force?
2. How do EF components were considered in the current teaching and learning of force?
3. How the EF-based teaching strategy to teach force was suggested based on the findings obtained from RQ1 and RQ2?
4. a) Does EF-based teaching strategy have any significant effect on students' understanding of force?

   b) How does EF-based teaching strategy influence students' understanding of force?
5. a) Does EF-based teaching strategy have any significant effect on students' physics metacognition and its subscales (knowledge of cognition and regulation of cognition)?

   b) How does EF-based teaching strategy influence students' physics metacognition?

1.6 Hypothesis

The hypothesis which related to the problems were developed as follows:

i. H_{01}: There is no significant correlation between EF components and understanding of force. Specifically:

   a. H_{01a}: There is no significant correlation between EF components of working memory and understanding of force.

   b. H_{01b}: There is no significant correlation between EF components of inhibition control and understanding of force.

   c. H_{01c}: There is no significant correlation between EF components of mental set-shifting and understanding of force.

ii. H_{02}: There is no significant difference in the pre-test, post-test I and post-test II mean scores of forces understanding test of form four students after conducting a series of EF-based teaching strategy to teach force.

iii. H_{03}: There is no significant difference in the pre-test, post-test I and post-test II mean values of physics metacognition subscales of form four students after conducting a series of EF-based teaching strategy. Specifically:

   - There is no significant main effect of the physics metacognition subscales.
   - There is no significant main effect of the test time.
   - There is no significant interaction of physics metacognition subscales x test time.

1.7 The significance of the Study

This study suggested a new teaching strategy which considers students' EF of the brain capacity. This teaching strategy also tailored to KBSM physics curriculum. Furthermore, the teaching strategy implemented in this study also provided the students with the metacognition skills which is the important skills for 21st-century scientific literacy. Therefore, this new teaching strategy would be informative to the teacher to implement it in the classroom in order to improve students' understanding of force concept as well as physics metacognition.

The finding obtained through this study is resourceful for the curriculum planners and policymakers. The finding on the role of EF on the understanding of force has implications on teaching science, especially in physics. The finding can inform the policymakers and the curriculum planners that science learning, especially physics, should be tailored to accommodate developmental restrictions in EF to ensure optimal learning. The manual on EF-based teaching strategy used in this study provides detail description on how the strategy implemented in the physics curriculum, which would be informative to the curriculum planners. The manual could be used as a guide in planning and integrate 21st-century skills into physics curriculum. This could be exemplary for the planners to develop a more specific manual to be implemented on a larger scale.

The finding of this study also could be used to advise the policymakers on the importance of teaching strategy that tailored based on students' EF capacity to enhance their understanding of the physics concepts and physics metacognition. The students' experiences while engaging in the teaching strategy would also be useful to advise the policymakers on the urgency in implementing 21st-century skills needed for 21st-century scientific literacy.

The finding on the role of EF on the understanding of force and the effect of EF-based teaching strategy on students' understanding of force and physics metacognition also resourceful for the teachers' educators. The teachers' educators can inform the in-training teachers the importance of teaching strategy that considers students' limited capacity of EF in enhancing students understanding of physics concept as well as physics metacognition.

The skills that implemented in the teaching strategy also can help students to understand better the concepts of physics in the classroom. Students also can apply the skills in learning other concepts in physics as well as in other subjects. The teaching strategy also can help the students to enhance their 21st-century learning skills such as metacognition skills.

On top of that, this research also added value to the models used in framing the research. It filled the gaps and provided the evidence that EF components which are working memory (explained using EF Model) play an important role in students understanding of force concept. Furthermore, the EF-based teaching strategy able to be framed and explained using Neurocognitive-Constructivist Model. For example, Neurocognitive-Constructivist Model explained the wholes seven strategies of an EF-based teaching strategy that have been conducted to teach force. The EF-based teaching strategy link with the Neurocognitive-Constructivist Model and provided the students with meaningful learning experiences in the topic of force. This provided informative evidence to support the feasibility of conducting EF-based teaching strategy using the model provided in Neurocognitive-constructivist Model. Evidence from research become useful information to enhance the usage of Neurocognitive-Constructivist Model to explain the process of EF-based teaching strategy in the secondary physics classroom. Such information would be helpful for future researchers to frame their science teaching strategies that consider students' EF capacity.

1.8 Limitation of the Study

In this study, only three components of EF: working memory, inhibition control and mental set-shifting were used to investigate the relationship of these three components of EF on the understanding of force. However, many other researchers acknowledge that these three components of EF are the main cores for the EF (Diamond, 2013; Lehto et al., 2003; Miyake et al., 2000; Rhodes et al., 2014; Rhodes et al., 2016). Therefore, using these three components of EF in this study to investigate the relationship between EF and understanding of force is sufficient.

For the cognitive test, CANTAB were used to assess students' working memory, inhibition control and mental set-shifting. However, the use of this instrument is limited because only one CANTAB available and the tests took about 30 minutes for each student. It took a lot of time to test the students. However, CANTAB was chosen because the tasks in CANTAB have been extensively validated in both child and adult populations (Curtis, Lindeke, Georgieff, & Nelson, 2002; Luciana & Nelson, 1998; Rhodes et al., 2014; Rhodes et al., 2016). Furthermore, all the tasks used in this study are non-verbal executive function skills and performed via a touch-screen computer.

In this study, EF-based teaching strategy was conducted in the teaching of force topic in physics curriculum form four. One of the limitation that this study exhibit was that the study is only focusing on the force concept within the subject of physics. According to Meltzer, Pollica, and Barzillai (2007), EF-based teaching strategy instruction should be directly linked to the curriculum. Therefore, the implementation of this teaching strategy in the force topic is still applicable and manage to provide a significant result because it linked with the physics curriculum. EF-based teaching strategy is a versatile strategy; perhaps it is also possible to implement in other physics concept or other science subjects such as chemistry and biology.

For the purpose of this study, 61 students from one school participated. This creates the limitation in terms of generalising the finding. However, according to (Gay, Mills, & Airasian, 2011), a minimum sample size of 30 is noted to be appropriate for the experimental research. As such involvement of 61 samples in this study is appropriate. Due to the nature of this setting, the intact group selection method was used during the sampling period. Intact group sampling reduces disruption to the sample. To have better control of the external variables and to improve the internal validity, it is advisable to include more schools and more students with a diverse background (Price & Murnan, 2004) to yield the same results.

This study used an intervention mixed method design which involved quantitative and qualitative studies. For the quantitative phase, one-way repeated measures design was used. There are several advantages of using repeated measures design. One of the major advantages is that the participants serve as their own controls, thus reducing the error variance and increasing the statistical power of the test (Ellis, 1999). Another benefit of this design is it can use few participants be recruited, trained, and compensated to complete an entire experiment and to detect the desired effect size (Howitt & Cramer, 2011). However, this design has several limitations such as order and sequence effects. According to Ellis (1999), these effects can largely be controlled by random administration of dependent variables and allowing time between treatments. In this study, the items in force concept test (FCT) and physics metacognition inventory (PMI) were being randomised for each test to avoid the familiarisation of the tests among the students. The period between pre-test, post-test 1 and post-test 2 is about three weeks. Thus, it is allowing time between treatments and reducing the order effects of repeated measures design. Furthermore, the qualitative findings also help to understand the quantitative findings. Both quantitative and qualitative phases in this study are sufficient to answer the research questions of this study.

1.9 Operational Definition

Executive Functions

Executive Function (EF) is a term referring to the underlying processes responsible for children's ability to direct, maintain and focus their attention, manage impulses, self-regulate behaviour and emotion, plan ahead and demonstrate flexible approaches to problem-solving (Howard-Jones, 2010). In other words, EF determines one's cognitive and affective ability (Curtis et al., 2002; Luciana & Nelson, 1998; Rhodes et al., 2014; Rhodes et al., 2016). In this study, EF is described using three core elements: monitoring and manipulation of information in working memory, suppression of distracting information (inhibition control) and the ability to shift from concept to concept (mental set-shifting) underlie in determining the students' ability to understanding force and also physics metacognition.

Working Memory

Working memory is the part of the brain where we hold information, work on it, organise it and shape it, before storing it in the long-term memory for further use (Baddeley, 1996). In the learning process, working memory plays important role in encoding and retrieval of information from long-term working memory by serving as the essential bridge between short- and long-term memory (Dehn, 2008). Average adult working memory capacity can keep the information in short-term memory roughly 7 units and approximately 20-30 seconds before the information begins to fade away (Miller, 1956). If ongoing attempts are made to keep things in working memory for longer periods via some types of recall strategy such as purposely picturing the information (using free-body diagram/systematic note taking), the material will remain in consciousness for a longer period of time and has a greater chance of being stored in long-term memory (Dehn, 2008). In this study, working memory is described as where the learner thinks, understand and make sense of information about force concepts. For instance, when learners learn about the force concepts, they can understand the concepts learned and organise the information systematically (using systematic note-taking or free-body diagram), so they can recall back when they need it. When the learners were solving problems on the force, the learners able to recall back information learned in the class to solve the problems on the force. The learners also able to apply some strategies such as draw free-body diagrams to overcome their working memory limitation to solve problems on the force.

Inhibition Control

Inhibition or inhibitory control is the ability to control attention, behaviour, thoughts, and/or emotions to override a strong internal predisposition or external lure, and instead, do what more appropriate or needed (Kaufman, 2010). In this study, inhibition refers to the students' ability to have the discipline to stay on task despite distraction during learning and completing tasks despite temptations to give up while learning about force.

Mental Set-Shifting

Mental set-shifting is one core of executive functions that involves the ability to change perspectives or approaches to a problem, flexibly adjusting to new demands, rules, or priorities (as in switching between task) (Diamond, 2013). In this study, mental set-shifting is described as students' ability to manipulate information they learn, and also flexible enough to adjust the change in demands or priority on what they learn in order to enhance their understanding about force.

EF Based Teaching Strategy

EF-based Teaching Approach is teaching strategies that take consideration of students' working memory capacity, inhibition control and mental set-shifting of the students. In this study, EF-based Teaching Strategy specifically tailored to teach force by taking consideration on students' working memory capacity, ability to mentally set-shifting and also able to control attention, behaviour and thoughts in order to enhance students understanding of force and physics metacognition. This teaching approach based on the seven EF-based teaching strategies proposed by Kaufman (2010). For example, in one of the activities implemented in this study, students are asked to dramatise a story to illustrate a variety of forces using things around them. By using real objects or things around them to relate to the concept learning, it can minimise students working memory demand. Thus, it will enhance their understanding. Then, students were asked to write down a systematic note on the concept they have learned to organise the information they learned systematically so that their working memory was not overload. Throughout the activity, teachers also facilitate the students to explain the force involved and monitor their attention frequently to make them focus on their task. At the end of the lesson, students were given a worksheet consisted of the problems related to the topic. Students were trained to solve the problems systematically. Such as, identify the key information first; then identify whether the forces are balanced or unbalanced; then draw a free-body diagram; then solve the problems. After the students solved the problems, they were asked to check back their answer and the steps of calculation to make sure they solved the problems correctly. At the end of the activity, students were asked to write down reflective journal to reflect back what they have learned, what problems they have after the lesson and what are the strategies they will employ to encounter the problems.