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The Effect of Design-Based Learning Integrated with Educational Neuroscience Instructional Model on Students' Learning Outcomes, Executive Functions, and Learning Stress

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ABSTRACT

The investigation examined the consequences of design-based learning integrated with the educational neuroscience instructional model (DEN) and conventional instructional model (CIM) for tenth-grade students' learning outcomes, executive function, and learning stress. Since the physics curriculum is planned to prepare students for discovering complex scientific concepts through real-life experience, the use of the DEN model is necessary to measure its efficiency. The cluster random sampling method was used to select 63 out of 494 tenth-grade students from Numsomphittayakhon School, Thailand. The researcher administered seven tests and employed the pre-test and post-test control group research design. The experimental and control groups were taught using DEN and CIM, respectively. The data were analyzed by repeated measures of multivariate analysis of variance to study the consequences of both instructional models. The results indicated that students from both groups seemed to demonstrate no significant difference in all the pre-tests on the dependent variables before the treatment with the instructional models. However, MANOVA analysis discovered that the experimental group's physics learning outcomes and executive functions were better than the control group. Moreover, students from the experimental group seemed to have a lower learning stress level than those from the control group. The results have successfully contributed to contemporary awareness of

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the efficiency of the DEN model to promote student learning outcomes and executive functions and reduce students' learning stress.

Keywords: Conventional instructional model, educational neuroscience instructional model, executive functions, learning outcomes, learning stress

INTRODUCTION

The physics curriculum is one of three science subjects offered at the high school level in the Thai education system. It is intended to prepare students to understand how the universe works so that they can discover complex scientific concepts and create real-work relationships to recognize its impact on daily life (Chiou et al., 2013). According to Tornee et al. (2017a), Thailand's science education is planned to support the relevance of the science curriculum with students' realistic involvement. Therefore, students are anticipated to achieve universal scientific literacy: science process skills, and a scientific mind because the science subject is compulsory from first to twelfth grade in Thailand's basic education core curriculum (Yuenyong & Narjaikaew, 2009). In this line of reasoning, the concept of developing students (Chinnery, 2014) and a systematic process to assist students' memory through a teaching plan and learning activities (Isman, 2011) have become essential principles in developing an instructional design model (Srikoon et al., 2018).

Design-based learning is defined as an investigation style of education or instruction. It is based on incorporating the project idea, and its layout has been progressively introduced into the classroom at the K-12 and post-secondary levels (Cobb et al., 2003). Cobb et al. further justified that design-based learning balances instructive experimental investigation with the theory-focused model of studying settings. Hence, it is a vital method for realizing when, why, and how instructive innovations should be implemented. On the other hand, Vaninsky (2017) referred to educational neuroscience as the processes that initiated and governed the flow of the biopotentials and sought to develop precise domains in the brain so that students can achieve the desired educational results.

An instructional model was developed by researchers whereby design-based learning and educational neuroscience were amalgamated in teaching physics lessons. Despite these two approaches having differences in their theory and method, they share pedagogy as a common field of applications. The instructional model is the so-called educational neuroscience instructional model (DEN), which was created by integrating design-based learning and educational neuroscience. This model is composed of five phases as follows: (i) identifying the learning problems; (ii) associating with knowledge; (iii) leading to solving problems; (iv) checking together; and (v) summarizing and evaluating.

In identifying the learning problems phase, students identify the learning problems according to their teachers' problem situation. The problem is related to students' daily life situations and can trigger five sensory aspects of their brain to cultivate a new sensory memory. It will ultimately enable them to make a new association to expand their prior knowledge to an extended knowledge. When the new information stimulates the brain's memory region, it will distribute across other brain regions. Hence, it corresponds to the multi-sensory plates (Anderson, 2009; Goswami, 2008). It is followed by creating attention and providing a better command to the prefrontal brain to increase its perception of the task of top-down attention and, ultimately, the construction of a better consolidation process (Cohen et al., 2021).

Students must explore and search for associated knowledge with technological assistance in the associating with knowledge phase. First, students decide how to identify the knowledge and use it. Next, they find the issues that affect the problem situation and retrieve additional knowledge from the network to form the associated schemas to solve the problem situation (Noesselt et al., 2012). It is followed by the third phase leading to solving problems. Students are encouraged to use their five senses to design, create, and develop inventions or innovations to solve the problem situation by working together with their team members during this phase. At this point, students are allowed to maximize the utilization of their five senses to receive multiple channels of information. For example, they can consistently shake, smell, listen to the sound, or touch an object. This information will then transform the neurotransmitters linking and activating neurons in the area, such as the multi-sensory superior temporal sulcus complex (MSTS-c) and the superior colliculus with the prefrontal cortex. It will enable the students to use their knowledge to design, create, and develop inventions or innovations to solve problems (Engel et al., 2012).

In the checking together phase, students are provided with opportunities to present their solutions collaboratively using a variety of formats, such as competition artifacts. According to Spalding et al. (2015), students' prefrontal cortex, as a key structure for the performance of executive functions, will use coordinated operation of higher-order thinking whenever the checking together activity is guided and discussed properly with their teachers. Next, in the summarizing and evaluating phase, the students must reflect on their solutions and the learning process to evaluate quickly and efficiently. The final phase involves many brain areas, such as the posterior cortical regions, ventromedial prefrontal cortex (vmPFC), the hippocampus, and the angular gyrus (Spalding et al., 2015).

The conventional instructional model (CIM) is the standard method for teaching science subjects in Thailand. It was employed to teach the control group. The Institute for the Promotion of Teaching Science and Technology (IPST) (2012) endorsed CIM as a standardized instructional model in Thailand. The CIM entails five phases: engage, explore, explain, elaborate, and evaluate. Generally, the model permits teachers and students to practice ordinary activities, develop students' abilities based on their previous understanding and skills, create connotations, and persistently evaluate their comprehension of an idea. In the engagement phase, teachers provide activities that encourage students to think about the learning outcomes. Hence, students will be psychologically engaged in the concept or skills they are learning. It is followed by the explore phase, which offers students a familiar foundation of practices. Students will vigorously explore their learning situation or employ resources to develop concepts, processes, and skills. In the explain phase, teachers assist students by explaining what they explored in the previous phase so that they can express their conceptual knowledge or prove the skills that they have learned. The fourth phase is the elaborate phase whereby students are inspired to broaden their conceptual understanding and apply their skills. The final phase of CIM is the evaluation phase. Teachers evaluate students' understanding and capabilities as their key learning of concepts and development of skills.

Previous researchers have found that design-based learning and a neurocognitive-based instructional model can encourage and significantly affect students' learning outcomes (Srikoon et al., 2017; Sripongwiwat et al., 2016; Tornee et al., 2017b; Uopasai et al., 2017, 2018). These research results indicated how students' learning outcomes, such as academic achievement, science process skills, and a scientific mind, can be advanced if an appropriate instructional model is used. In addition, Jordan et al. (2011) found that a functioning instructional model can assist students' scientific literacy, such as science process skills and a scientific mind, and their learning outcomes are closely related to their teacher's determinations.

Executive function is collectively referred to as cognitive processes, such as attention and working memory, required for intellectual influence on performance (Diamond, 2013). Meltzer (2010) stated that executive function constitutes one of the cognitive components, namely, biological and sociodemographic factors, which need further investigation. Moreover, Gilbert and Burgess (2008) described the concept of executive functions as a group of intellectual capabilities that can influence and adjust other cognitive processes, for example, attention, memory, and motor skills. According to Srikoon et al. (2017), schools can only build an executive function culture in their classroom after teachers empower students to discover 'how to solve problems flexibly' and 'how to learn.' These cognitive procedures are essential for working memory and attention to accomplishing a task. Similarly, Yang and Chang (2015) defined attention as the crucial development of intelligence that includes coordinating data into a comprehensible composition and elevating intangible knowledge. Working memory is an operational approach to collecting data and knowledge management, crucial for the accurate operation of additional complicated intellectual tasks (Jacob & Silvanto, 2015; Sanchez-Torres et al., 2015). Furthermore, Yang and Chang (2015) found that attention can influence working memory learning outcomes.

Vogel and Schwabe (2016) emphasized the complexity of learning stress. It can have enhanced or damaging consequences on remembrance, differing according to the particular memory procedure or phase specifically influenced by anxiety and the action of the main functional anxiety reaction system. Nevertheless, Sripongwiwat et al. (2018) found that the method students handle demanding events varies considerably depending on whether and how they identify and respond to the situation. Sripongwiwat et al. (2018) conducted a sequence of cross-sectional surveys with 925 secondary school students in northeast Thailand. Their results showed that the students' lower secondary and higher secondary groups exhibited significant differences in all six types of learning stressors. However, males and females had significant differences only for academic-related stressors.

The above literature review highlights the significant effects of effective instructional models on students' learning outcomes (Srikoon et al., 2018; Tornee et al., 2017b; Uopasai et al., 2018), their executive functions (Srikoon et al., 2017; Uopasai et al., 2017), and their learning stress (Sripongwiwat et al., 2018) in science subjects. Therefore, researchers have concluded a significant relationship between the instructional model used by science teachers and students' learning outcomes, executive functions, and learning stress. However, considering the limitations of the previous studies, the current study used a two-way factorial design to investigate the effectiveness of DEN and CIM intervention delivered in two different ways to two groups of students to examine their impacts on learning outcomes, executive functions, and learning stress. This study was designed to examine the DEN model's effect by seeking to address the following research purposes using this line of reasoning. The researchers investigated the mean differences between the experimental and control groups on their learning outcomes in physics test achievement, science process skills, and scientific mind, their executive functions regarding attention and working memory, and their learning stress.

MATERIALS AND METHODS

Research Design

A pretest and posttest control group was employed as a true experimental research design. This design was chosen to assess the two groups and evaluate any transformation arising from the treatment investigated. The subjects of this study were randomly assigned to the two groups. Both were presented with two different instructional treatments, namely DEN and CIM, for the experimental and control groups. The researchers considered the randomized design, in which they compared the post-test scores of the experimental and control groups while monitoring for pre-test differences, as proposed by Bellini and Rumrill (2009). In other words, the randomized layout meant that the random assortment and allocation of subjects to the two groups would subsequently result in the random assignment of groups to treatments. The measurement of change (post-test scores–pre-test scores) provides a method for assessing the effectiveness of the two instructional models. Therefore, a two-way method was utilized - DEN versus CIM; time of measure: pre-test versus post-test.

Population and Samples

Random cluster sampling was employed in which the subjects of the population were randomly selected from the existing groups and called a 'cluster.' The cluster in this study refers to a natural but heterogeneous, intact cluster of tenth-grade students from 15 classes in Numsomphittayakhom School, Udon Thani province, Thailand, in the 2019 academic year. A total of 63 samples were selected from a population of 494 and appointed to the experimental group (n = 35) and the control group (n = 28), respectively.

Research Instruments

The researchers employed seven types of instruments in the format of tests to collect, measure, and analyze the data relevant to the study's aim: learning outcomes, executive functions, and learning stress. A total of seven types of tests were employed to evaluate the respective dependent variables, namely, a physics achievement test, a science process skills test, a scientific mind scale, an attention battery test, a working memory battery test, a stress test (ST5), and a learning stressor questionnaire.

Students' learning outcomes were measured using three research instruments: a physics achievement test, a science process skills test, and a scientific mind scale. The physics achievement test was a multiple-choice test that covered questions normally found in typical school examinations. The initial physics achievement test consisted of 60 questions and was sent to three science experts for validity checking. Two experts specialized in science education and were affiliated with the Faculty of Education of a public university in Thailand and had teaching experience in physics subjects for more than ten years in higher secondary schools. The third expert was a science expert teacher of a level equivalent to an associate professor in a university. This expert worked in a secondary school, and their highest academic qualification is a master's degree in science education. The three experts advised removing some questions. The final version of test comprised 40 questions (KR20 = 0.95; discrimination index = 0.40 to 0.87; and difficult index = 0.40 to 0.80).

The science process skills test was adapted from Tornee (2014) and comprised 45 multiple-choice items with 13 science process skills as follows: measuring, using numbers and calculating, observing, communication, classifying, space/space relationship and space/time relationship, predicting, inferring, formulating hypotheses, controlling variables, experimenting, defining operationally, and interpreting data and conclusion. The science process skills test was piloted. The reliability value was KR-20 = 0.81, the difficult index = 0.29–0.78, and discrimination index = 0.21–0.73.

The scientific mind scale evaluated six traits: reasonableness, curiosity, perseverance, responsibility, honesty, organization and carefulness, and open-mindedness. The scientific mind scale consisted of 25 items to which students were required to react according to a five-point Likert scale. The reliability value (α) of this scientific mind scale was 0.82.

Two set of battery tests were used to measure executive functions, namely attention and working memory abilities, in terms of their accuracy and time reaction. Both sets of tests were originally presented in the Thai language and adopted from Bunterm et al. (2015). The two battery tests comprised eight attention tasks and 17 working memory tasks. The eight attention battery tasks covered: (i) SR-dot; (ii) SR-letter; (iii) Focus-dot; (iv) Focus-letter; (v) Sustain-dot; (vi) Sustain-letter; (vii) Select ch-letter Thai (20), and (viii) Select ch-letter Thai (21). The 17 working memory tasks included: (i) stoop; (ii) flanker-arrow; (iii) odd-even; (iv) vowel-consonant; (v) left-right; (vi) up-down; (vii) switch-up-down-left-right; (viii) switch-Thai Letter Number; (ix) two-word span; (x) three-word span; (xi) four-word span; (xii) zero-number updating; (xiii) 1-number updating; (xiv) 2-number updating; (xv) 0-back; (xvi) one-back, and (xvii) two-back.

Each student was given ten trials for every task, making 80 and 170 trials for the respective attention and working memory tasks. The reaction times of less than 200 milliseconds were omitted, and data were scrutinized in the range of $\bar{x}$±3S.D. The eight tasks of the attention battery test and the 17 tasks of the working memory battery test were assessed by Bunterm et al. (2015) for construct validity using the goodness of fit test. Furthermore, the test-retest reliability values of attention and working memory tasks ranged from 0.822 to 0.979 and 0.939 to 0.998, respectively. Therefore, it can be concluded that both battery tests have passed the tests of validity and reliability, and therefore they are considered good measures (Sekaran, 2003).

The researchers adapted the Thailand Secondary School Stressor Questionnaire from Sripongwiwat et al. (2018). The latter modified and converted it from English to the Thai language from the original instrument developed by Yusoff (2011, 2016). The stress test (ST5) and learning stressor components covered in this instrument measure students' responses to the intensity of stress experienced. At the same time, they were treated with two different instructional models in their physics learning process. The instrument consisted of 39 items with a response range of 0 to 5. Hence, in this order, the students' responses ranged from no stress-causing lowest, mild, moderate, high, and highest stress. The reliability values of the ST5 and the learning stressor instrument were found to be α = 0.91 and, hence, reflected a good measure of learning stress.

Data Analysis

The researchers examined three major constructs encompassing eight factors: academic achievement in physics, scientific mind, science process skills, working memory accuracy and reaction time, attention accuracy and reaction time, and learning stress. In addition, repeated MANOVA testing was utilized to analyze the impact of time, instructional model, and interaction between instructional model and time on learning outcomes, executive functions, and learning stress as dependent variables. According to Hair et al. (2013), employing MANOVA assessed whether there were any significant mean differences in the experimental and control groups from an identical sample dispersal. Moreover, Everitt and Dunn (1991) clarified that Hotelling's trace is a direct degree of the amount of variance in the mixture of dependent variables encountered for the collection variable. Therefore, it examines the mean differences between the two experimental and control groups toward a mixture of dependent variables.

RESULTS

The results of this study are described in the following section. Before applying the treatments to the experimental or control groups, the researchers conducted a preliminary study to ensure that all the experimental or control group students were no different in terms of their age and handedness. The preliminary tests showed that there were no significant differences for students' age ($t(63) = 0.949$, $p>.05$) or handedness ($t(63) = 0.678$, $p>.05$) between the groups. Hence, both the control and experimental groups had a similar sample dispersion and were identical. The researchers could then continue with the treatment of the instructional model.

The initial findings discuss the differences in the learning outcomes, executive functions, and learning stress of tenth-grade students before and after treatment with the DEN and CIM models. It is followed by an assessment of the effect of these models on the students' learning outcomes, executive functions, and learning stress. Lastly, the different impacts of the two instructional models were measured.

Results for Learning Outcomes

The impacts of the DEN and CIM models on the students' learning outcomes were measured using a two-way MANOVA test. Before the researchers began to evaluate the effects of the instructional models, Box's M test for equality of variance-covariance matrices was used to ensure that the assumption of homogeneity across the group was met. The result showed that Box's M= 10.195, F= 2.341, df_1=21, df_2=12302.44, Sig=.141; $p>0.05$ is not significant; hence, these results supported the assumption that both experimental and control groups were homogeneous. The repeated-measures MANOVA analysis confirmed a significant multivariate effect of the interaction between the groups and reaction time: Hotelling's trace $T^2 = 259.00$, $F(3, 59)= 5093.75$, $p< 0.01$, partial $\eta^2 = 0.996$. Moreover, the results also indicated that there was a significant multivariate effect between the learning outcomes of the physics subject that encompassed students' achievement in physics tests, science process skills, and scientific mind across the groups, regardless of their reaction time, as well as across within-subjects time point regardless of student group: Hotelling's trace $T^2 = 8.08$, $F(3, 59) = 159.04$, $p< 0.01$, partial $\eta^2 = 0.890$ (refer to Table 1).

The univariate tests showed that students from the experimental group gained higher scores in all three aspects of learning outcomes. Specifically, the overall results of the learning outcomes showed that student's achievement in the physics subject ($F(1,62)= 1105.22$, $p < 0.01$, partial $\eta^2 = 0.948$), science process skills ($F(1,62)= 1008.27$, $p< 0.01$, partial $\eta^2= 0.845$), and scientific mind ($F(1,62)= 132.83$, $p<0.01$, partial $\eta^2= 0.535$) were higher than students from the control group regardless of time point.

Students' learning outcomes in physics were measured from three aspects, namely, test achievement, science process skills, and scientific mind. Table 2 illustrates the pre-test versus post-test learning outcomes

Table 1
MANOVA and univariate results of learning outcomes (LO)

Effect		Hotelling's trace T^2	F	Df_1	Df_2	partial η^2
Between-subjects	Group	259.00	5093.75**	3	59	0.996
	Time*LO	32.27	634.71**	3	59	0.970
	Group*LO	8.08	159.04**	3	59	0.890

Univariate test

Learning outcomes	Exp. (n = 35)		Ctrl. (n = 28)		F	*p*	partial η^2
	M	*SD*	M	*SD*			
Achievement in physics test	28.86	2.79	15.14	2.10	1105.22**	0.000	0.948
Science process skills	38.80	3.06	26.75	5.05	1008.27**	0.000	0.845
Scientific mind	3.79	0.27	3.54	0.39	132.83**	0.000	0.535

Note: **p<.01

Table 2
Mean score and standard deviation of learning outcomes

Learning outcomes	Exp. (n = 35)		Ctrl. (n = 28)		t-value
	M	*SD*	M	*SD*	
Achievement in physics test					
Pre-test	9.94	1.91	9.64	2.42	0.55
Post-test	28.86	2.79	15.14	2.10	21.56**
Science process skills					
Pre-test	11.91	3.18	11.25	3.10	0.83
Post-test	38.80	3.06	26.75	5.05	11.71**
Scientific mind					
Pre-test	3.25	0.27	3.60	0.45	1.62
Post-test	3.79	0.27	3.54	0.39	2.89**

Note: **p<.01

in the physics achievement test, scientific mind test, and science process skills test of the control and experimental groups before and after treatment with the DEN and CIM models. All post-tests improved the students' learning outcomes after the treatment compared to the pre-tests, whether they were taught using DEN or CIM.

Results for Executive Function

Both executive functions of attention and working memory were assessed concerning the students' accuracy and reaction time (in milliseconds, ms). The impacts of the DEN and CIM models on the students' executive functions were measured using a two-way MANOVA test. A repeated measure of time acted (before and after treatment) as the independent variables and the accuracy percentage of executing the eight attention tasks, comprising SR-dot, SR-letter, Focus-dot, Focus-letter, Sustain-dot, Sustain-letter, Select ch-letter Thai (20), and Select ch-letter Thai (21), were dependent variables. The results confirmed a significant multivariate effect between subjects of the combined accuracy of performing the 17 tasks across student groups irrespective of time point: Hotelling's trace $T^2 = 1378.37$, $F(8, 54)= 9303.96$, $p< 0.01$, partial $\eta^2 = 0.999$. It can be concluded that there is a significant multivariate effect within-subjects time point irrespective of student group: Hotelling's trace $T^2 = 17.82$, $F(8, 54)= 120.27$, $p< 0.01$, partial $\eta^2 = 0.947$. Therefore, the result further showed that there is a significant multivariate effect across the interaction between student groups and time points: Hotelling's trace $T^2 = 3.70$, $F(8, 54)= 24.97$, $p< 0.01$, partial $\eta^2 = 0.787$ (refer to Table 3).

Table 3
MANOVA and univariate results of executive function (Accuracy of attention test AA)

Effect		Hotelling's trace T^2	F	Df_1	Df_2	partial η^2
Between-subjects	Group	1378.37	9303.96**	8	54	0.999
	Time*AA	17.82	120.27**	8	54	0.947
	Group*AA	3.70	24.97	8	54	0.787

Univariate test (Post-test)

Attention tasks	Exp. (n = 35)		Ctrl. (n = 28)		F	*p*	partial η^2
	M	*SD*	M	*SD*			
SR-dot	38.60	4.73	35.00	4.51	19.47**	0.000	0.242
SR-letter	44.06	3.98	28.18	5.08	37.23**	0.000	0.379
Focus-dot	9.37	0.65	8.61	0.50	14.32**	0.000	0.190
Focus-letter	9.34	0.68	8.21	0.63	20.89**	0.000	0.255
Sustain-dot	9.00	0.77	8.25	0.59	4.53*	0.037	0.069
Sustain-letter	9.57	0.56	8.86	1.08	9.71**	0.003	0.137
Select ch-letter Thai (20)	45.37	6.83	39.93	2.40	11.56**	0.001	0.159
Select ch-letter Thai (21)	18.94	0.91	16.96	2.46	34.11**	0.000	0.359

Note: *p<.05 and **p<.01

While univariate tests were executed on the dependent variables, the results indicated that the accuracy percentage of executing the attention tasks described above in the experimental group was more accurate than the control group at a significant level of 0.01. In other words, they obtained higher attention accuracy in almost all the attention tasks except the sustain-letter attention task compared to students in the control group. Table 4 shows the mean score and standard deviation of attention accuracy for each attention task between the control group and experimental group before and after treatment of DEN and CIM.

On the other hand, when students were performing the eight attention tasks, they acted as dependent variables for the reaction time of attention. In contrast, a repeated measure of time (before and after treatment) acted as the independent variable. The two-way MANOVA results confirmed a significant multivariate effect across the interaction between the student group and time point: Hotelling's trace T^2 = 655.67, F(8, 54)= 4425.79, *p*< 0.01, partial η^2 = 0.998. It can be concluded that there is a significant multivariate effect between subjects of the combined reaction time for the eight tasks across student groups irrespective of time point: Hotelling's trace T^2 = 19.87, F(8, 54)= 134.24, *p*< 0.01, partial η^2 = 0.952. The result further showed that there is a significant multivariate effect within-subjects time point irrespective of student group: Hotelling's trace T^2 = 6.34, F(8, 54)= 42.79, *p*< 0.01, partial η^2 = 0.864 (refer to Table 5).

Table 4
Mean score and standard deviation of executive function (Accuracy of attention test)

Attention tasks		Exp. (n = 35)		Ctrl. (n = 28)		t-value
		M	*SD*	M	*SD*	
SR-dot	Pre-test	31.77	5.80	31.29	4.53	0.363
	Post-test	38.60	4.73	35.00	4.51	3.063**
SR-letter	Pre-test	27.31	10.54	25.57	9.37	0.685
	Post-test	44.06	3.98	28.18	5.08	13.913**
Focus-dot	Pre-test	8.29	0.71	8.25	0.70	0.200
	Post-test	9.37	0.65	8.61	0.50	5.156**
Focus-letter	Pre-test	7.23	0.81	7.14	0.71	0.443
	Post-test	9.34	0.68	8.21	0.63	6.741**
Sustain-dot	Pre-test	7.43	0.81	7.18	0.67	1.308
	Post-test	9.00	0.77	8.25	0.59	4.272**
Sustain-letter	Pre-test	9.43	0.78	9.46	0.84	0.175
	Post-test	9.57	0.56	8.86	1.08	3.395**
Select ch-letter Thai (20)	Pre-test	36.43	1.70	35.89	1.81	1.206
	Post-test	45.37	6.83	39.93	2.40	4.019**
Select ch-letter Thai (21)	Pre-test	15.40	2.92	16.07	2.61	0.950
	Post-test	18.94	0.91	16.96	2.46	4.412**

Note: **p<.01

Table 5
MANOVA and univariate results of executive function (Reaction time of attention test RT)

Effect		Hotelling's trace T^2		F		Df_1	Df_2	partial η^2
Between-subjects	Group	655.67		4425.79**		8	54	0.998
	Time*RT	19.87		134.24**		8	54	0.952
	Group*RT	6.34		42.79**		8	54	0.864
Univariate test								
Attention tasks	Exp. (n = 35)		Ctrl. (n = 28)		F		*p*	partial η^2
	M	*SD*	M	*SD*				
SR-dot	368.74	43.06	409.83	66.03	27.69**		0.000	0.312
SR-letter	502.41	71.22	529.88	76.14	36.16**		0.000	0.372
Focus-dot	372.11	47.27	418.23	69.67	66.19**		0.000	0.520
Focus-letter	381.99	66.22	485.35	79.42	71.94**		0.000	0.541
Sustain-dot	401.90	48.06	437.01	76.41	23.31**		0.000	0.276
Sustain-letter	457.59	55.23	525.11	58.45	27.15**		0.000	0.308
Select ch-letter Thai (20)	444.02	35.58	516.65	49.70	95.18**		0.000	0.609
Select ch-letter Thai (21)	483.78	41.16	545.40	37.07	34.92**		0.000	0.364

Note: **p<.01

When univariate tests were executed on the dependent variables, the results indicated that the reaction times of the experimental group when performing the eight attention tasks were significantly shorter than the control group, irrespective of the time point at a significant level of 0.01. In short, students from the experimental group had a shorter reaction time when executing all the attention tasks than students from the control group. The mean scores and standard deviation of the reaction times of the eight attention tasks before and after treatment are shown in Table 6.

Working memory was another component of executive function measured by its accuracy and reaction time. A repeated measure of time before and after instructional model treatments acted as the independent variable and the accuracy percentage of executing the 17 working memory tasks comprising stoop, flanker-arrow, odd-even, vowel-consonant, left-right, up-down, switch-up-down-left-right, switch-Thai letter number, two-word span, three-word span, four-word span, zero-number updating, one-number updating, two-number updating, zero-back, one-back, and two-back working memory tasks acted as dependent variables. The two-way MANOVA results confirmed that there is a significant multivariate effect between subjects of the combined accuracy while they were conducting the 17 working memory tasks across student groups irrespective of time point: Hotelling's trace T^2 = 1093.62, F(17, 45)= 2894.87, p< 0.01, partial η^2 = 0.999. Moreover, the results showed that there is a significant multivariate effect across within-subjects time point irrespective of student group: Hotelling's trace T^2 = 47.21, F(17,

Table 6
Mean score and standard deviation of executive function (Reaction time of attention test)

Attention tasks		Exp. (n = 35)		Ctrl. (n = 28)		t-value
		M	*SD*	M	*SD*	
SR-dot	Pre-test	426.92	57.08	432.55	67.59	0.358
	Post-test	368.74	43.06	409.83	66.03	2.977**
SR-letter	Pre-test	551.50	72.79	547.32	76.50	0.830
	Post-test	502.41	71.22	529.88	76.14	2.897**
Focus-dot	Pre-test	434.30	60.84	432.55	67.59	0.451
	Post-test	372.11	47.27	418.23	69.67	1.167**
Focus-letter	Pre-test	474.69	64.07	474.69	64.07	0.140
	Post-test	381.99	66.22	485.35	79.42	1.111**
Sustain-dot	Pre-test	450.30	49.87	449.55	75.66	0.220
	Post-test	401.90	48.06	437.01	76.41	1.808**
Sustain-letter	Pre-test	511.51	63.06	534.92	62.35	0.351
	Post-test	457.59	55.23	525.11	58.45	2.236**
Select ch-letter Thai (20)	Pre-test	564.04	53.08	540.51	45.94	0.217
	Post-test	444.02	35.58	516.65	49.70	1.447**
Select ch-letter Thai (21)	Pre-test	625.02	44.08	611.83	36.51	0.144
	Post-test	483.78	41.16	545.40	37.07	1.575**

Note: **p<.01

45)= 124.97, $p < 0.01$, partial $\eta^2 = 0.979$. It can be concluded that there is a significant multivariate effect across the interaction between student groups and time points: Hotelling's trace $T^2 = 7.91$, $F(17, 45) = 20.92$, partial $\eta^2 = 0.888$ (refer to Table 7).

When univariate tests were performed on the dependent variables, the results indicated that the experimental group performed the 17 working memory tasks more accurately than the control group at $p < 0.01$. This result implies that the DEN model has significantly affected the students' working memory. In terms of accuracy, it is greater than the effect of the CIM in all the working memory tasks except the flanker-arrow task. Table 8 shows the mean scores and standard deviation of accuracy percentage of the 17 working memory tasks before and after treatment.

In addition, the researchers continued to examine students' reaction times while they were executing the 17 working memory tasks as dependent variables, and a repeated measure of time before and after instructional model treatment acted as the independent variables. The two-way MANOVA results indicated a significant multivariate effect across the interaction between the student group and time point: Hotelling's trace $T^2 = 3237.59$, $F(17, 45) = 8570.07$, $p < 0.01$, partial $\eta^2 = 0.999$. Furthermore, the results showed that there is a significant multivariate effect between-subjects (of the combined reaction time of ten tasks) across student groups

Table 7
MANOVA and univariate results of executive function (Accuracy of working memory test AWM)

Effect		Hotelling's trace T^2	F	Df_1	Df_2	partial η^2
Between-subjects	Group	1093.62	2894.87**	17	45	0.999
	Time*AWM	47.21	124.97**	17	45	0.979
	Group*AWM	7.91	20.92**	17	45	0.888

Univariate test (Post-test)

Working memory tasks	Exp. (n = 35)		Ctrl. (n = 28)		F	*p*	partial η^2
	M	*SD*	M	*SD*			
Stoop	82.74	6.07	82.74	6.07	19.11**	0.000	0.239
Flanker-arrow	84.86	7.03	84.86	7.03	22.49**	0.000	0.269
Odd-even	37.46	7.01	37.46	7.01	6.45**	0.014	0.096
Vowel- consonant	44.94	3.60	44.94	3.60	5.62**	0.021	0.084
Left-right	55.60	6.28	55.60	6.28	10.34**	0.002	0.145
Up-down	58.09	2.76	58.09	2.76	25.29**	0.000	0.293
Switch-up-down-left-right	42.69	3.70	42.69	3.70	8.32**	0.005	0.120
Switch-Thai Letter Number	36.11	3.59	36.11	3.59	18.15**	0.000	0.229
2-word span	4.40	0.55	4.40	0.55	23.42**	0.000	0.277
3-word span	13.49	1.22	13.49	1.22	26.86**	0.000	0.306
4-word span	3.69	0.47	3.07	0.54	47.28**	0.000	0.437
0-number updating	4.51	0.51	3.32	0.48	21.26**	0.000	0.258
1-number updating	10.20	1.86	10.20	1.86	11.14**	0.001	0.154
2-number updating	4.71	0.46	4.71	0.46	25.56**	0.000	0.295
0-back	4.31	0.53	3.18	0.53	11.13**	0.001	0.154
1-back	3.32	0.48	2.82	0.61	22.62**	0.000	0.271
2-back	2.89	0.63	2.36	0.49	12.05**	0.001	0.165

Note: **p<.01

Table 8
Mean score and standard deviation of executive function (Accuracy of working memory test)

Working memory tasks		Exp (n = 35)		Ctrl (n = 28)		t-value
		M	*SD*	M	*SD*	
Stoop	Pre-test	68.14	9.33	71.07	10.49	0.781
	Post-test	82.74	6.07	82.74	6.07	5.530**
Flanker-arrow	Pre-test	79.20	9.14	78.89	9.01	0.639
	Post-test	84.86	7.03	84.86	7.03	2.951**
Odd-even	Pre-test	28.94	11.20	26.93	6.00	1.571
	Post-test	37.46	7.01	37.46	7.01	6.307**
Vowel- consonant	Pre-test	36.17	10.49	36.07	4.67	1.798
	Post-test	44.94	3.60	44.94	3.60	8.516**
Left-right	Pre-test	47.66	9.14	47.00	8.83	1.112

Table 8 *(continue)*

Working memory tasks		Exp (n = 35)		Ctrl (n = 28)		t-value
		M	*SD*	M	*SD*	
	Post-test	55.60	6.28	55.60	6.28	4.513**
Up-down	Pre-test	47.29	6.59	50.89	5.31	0.773
	Post-test	58.09	2.76	58.09	2.76	6.933**
Switch-up-down-left-right	Pre-test	22.71	6.67	36.89	4.79	0.072
	Post-test	42.69	3.70	42.69	3.70	5.414**
Switch-Thai Letter Number	Pre-test	11.06	4.14	28.36	5.53	1.433
	Post-test	36.11	3.59	36.11	3.59	6.721**
2-word span	Pre-test	3.06	0.76	3.32	0.48	0.726
	Post-test	4.40	0.55	4.40	0.55	8.178**
3-word span	Pre-test	11.26	1.69	11.57	1.62	0.556
	Post-test	13.49	1.22	13.49	1.22	5.347**
4-word span	Pre-test	2.94	0.59	2.64	0.56	0.891
	Post-test	3.69	0.47	3.07	0.539	8.038**
0-number updating	Pre-test	3.31	0.47	3.61	0.57	0.060
	Post-test	4.51	0.51	3.32	0.475	6.695**
1-number updating	Pre-test	6.86	1.68	8.71	1.78	1.194
	Post-test	10.20	1.86	10.20	1.86	3.210**
2-number updating	Pre-test	3.57	0.65	3.68	0.67	1.907
	Post-test	4.71	0.46	4.71	0.46	7.272**
0-back	Pre-test	3.06	0.80	3.36	0.56	0.591
	Post-test	4.31	0.53	3.18	0.53	6.055**
1-back	Pre-test	2.94	0.73	2.82	0.61	0.707
	Post-test	3.32	0.48	2.82	0.61	5.603**
2-back	Pre-test	2.37	0.49	2.36	0.49	0.115
	Post-test	2.89	0.63	2.36	0.49	5.801**

Note: ** p<.01

irrespective of time point: Hotelling's trace T^2 = 63.87, F(17, 45)= 169.06, p< 0.01, partial η^2 = 0.985. This implies that there is also a significant multivariate effect within-subjects time point irrespective of student group: Hotelling's trace T^2 = 14.93, F(17, 45)= 39.63, p< 0.01, partial η^2 = 0.937 (refer to Table 9).

When univariate tests were executed on the dependent variables, the researchers found that students from the experimental group could perform the 17 working memory tasks comparatively shorter than the students from the control group, regardless of the time point at p < 0.01. In other words, the DEN model significantly caused the students to react faster in performing the 17 working memory tasks than the students who were taught with the CIM. Table 10 shows the reaction time results between the experimental and control groups while performing the 17 working memory tasks before and after treatment.

Table 9
MANOVA and univariate results of executive function (Reaction time of working memory test RTWM)

Effect		Hotelling's trace T^2	F	Df_1	Df_2	partial η^2
Between-subjects	Group	3237.57	8570.07**	17	45	0.999
	Time*RTWM	63.87	169.06**	17	45	0.985
	Group*RTWM	14.93	39.63**	17	45	0.937

Univariate test (Post-test)

Working memory tasks	Exp. (n = 35)		Ctrl. (n = 28)		F	*p*	partial η^2
	M	*SD*	M	*SD*			
Stoop	512.67	39.12	562.98	66.85	25.38**	0.000	0.294
Flanker-arrow	523.56	45.18	542.22	59.05	9.74**	0.003	0.138
Odd-even	535.37	34.67	590.25	109.71	93.36**	0.000	0.605
Vowel- consonant	505.67	50.28	592.70	45.55	57.16**	0.000	0.484
Left-right	457.19	46.10	496.10	67.77	35.38**	0.000	0.367
Up-down	456.56	52.25	524.62	65.55	85.58**	0.000	0.584
Switch-up-down-left-right	458.34	81.38	485.07	99.15	1.37	0.246	0.022
Switch-Thai Letter Number	536.98	62.19	604.22	54.82	45.12**	0.000	0.425
2-word span	3777.59	389.72	4071.20	589.97	0.002	0.962	0.000
3-word span	4613.80	73.85	4931.88	450.83	6.63*	0.012	0.098
4-word span	4165.12	297.81	4251.44	254.52	0.005	0.944	0.000
0-number updating	1507.54	166.12	1520.64	190.46	4.09*	0.047	0.063
1-number updating	2556.77	46.17	3270.64	451.76	88.38**	0.000	0.592
2-number updating	961.83	180.27	1059.92	116.28	49.44**	0.000	0.448
0-back	369.29	42.25	414.77	45.37	12.45**	0.001	0.170
1-back	338.47	51.25	447.08	72.55	6.82*	0.011	0.101
2-back	365.04	17.69	431.20	32.80	35.32**	0.000	0.367

Note: *p<.05 and **p<.01

Table 10
Mean score and standard deviation of executive function (Reaction time of working memory test)

Working memory tasks		Exp (n = 35)		Ctrl (n = 28)		t-value
		M	*SD*	M	*SD*	
Stoop	Pre-test	577.88	50.26	585.79	65.17	0.544
	Post-test	512.67	39.12	562.98	66.85	3.729**
Flanker-arrow	Pre-test	556.11	46.49	559.92	57.38	0.291
	Post-test	523.56	45.18	542.22	59.05	1.422**
Odd-even	Pre-test	606.16	38.56	606.91	112.30	0.037
	Post-test	535.37	34.67	590.25	109.71	2.795**
Vowel- consonant	Pre-test	574.93	42.65	575.97	42.59	0.096
	Post-test	505.67	50.28	592.70	45.55	7.115**
Left-right	Pre-test	513.37	56.86	515.12	71.04	0.109
	Post-test	457.19	46.10	496.10	67.77	2.706**
Up-down	Pre-test	550.13	64.25	540.67	66.28	0.573

Table 10 *(continue)*

Working memory tasks		Exp (n = 35)		Ctrl (n = 28)		t-value
		M	*SD*	M	*SD*	
	Post-test	456.56	52.25	524.62	65.55	4.588**
Switch-up-down-left-right	Pre-test	581.34	91.77	588.17	93.82	0.291
	Post-test	458.34	81.38	485.07	99.15	1.175**
Switch-Thai Letter Number	Pre-test	613.80	73.85	623.98	43.63	0.645
	Post-test	536.98	62.19	604.22	54.82	4.492**
2-word span	Pre-test	4413.46	450.05	4701.59	806.92	1.794
	Post-test	3777.59	389.72	4071.2	589.97	2.370**
3-word span	Pre-test	5550.76	668.93	5472.56	663.24	1.794
	Post-test	4613.80	73.85	4931.88	450.83	2.370**
4-word span	Pre-test	4405.54	339.65	4486.26	364.82	0.907
	Post-test	4165.12	297.81	4251.44	254.52	1.218**
0-number updating	Pre-test	1878.35	297.48	1776.99	349.80	0.243
	Post-test	1507.54	166.12	1520.64	190.46	2.456**
1-number updating	Pre-test	1119.52	225.49	1137.05	112.78	0.441
	Post-test	2556.77	46.17	3270.64	451.76	3.123**
2-number updating	Pre-test	448.46	71.67	446.37	80.26	0.375
	Post-test	961.83	180.27	1059.92	116.28	2.492**
0-back	Pre-test	506.69	78.92	508.90	85.27	0.110
	Post-test	369.29	42.25	414.77	45.37	4.108**
1-back	Pre-test	434.32	25.11	440.51	22.31	0.107
	Post-test	338.47	51.25	447.08	72.55	6.954**
2-back	Pre-test	3345.75	219.92	3321.66	211.98	1.021
	Post-test	365.04	17.69	431.20	32.80	10.230**

Note: ** p<.01

Results for Learning Stress

The researchers evaluated the stress and learning stress of both experimental and control groups using pre-test versus post-test. In addition, a two-way MANOVA test was used to examine the effects of the two instructional models on learning stress. The results showed that students from the experimental group maintained almost the same stress level both pre-test and post-test, but students from the control group experienced an increase in their stress level post-test. Moreover, the results indicated decreased learning stress in the experimental group but increased learning stress in the control group. In short, students who are taught using the DEN model have less learning stress than students who are taught using the CIM.

Box's M test for equality of variance-covariance matrices was insignificant (Box's M= 15.52, F= 1.439, df_1=10, df_2=15859.24, Sig=.156; $p>0.05$) and implied that the assumption of homogeneity across the group was met. Repeated-measures MANOVA analysis confirmed a significant multivariate effect of the interaction between the groups and reaction time: Hotelling's trace T^2 = 43.813, F(2, 60)= 1314.40, *p*< 0.01, partial η^2 = 0.978. Moreover, the results indicated that there is a significant multivariate effect between stress, which encompassed the experience of ST5 and learning stress across the groups regardless of their reaction time: Hotelling's trace T^2 = 1.528, F(2, 60)= 45.82, *p*< 0.01, partial η^2 = 0.604. It can be concluded that there is a significant multivariate effect across within-subjects time point regardless of student group: T^2 = 0.643, F(2, 60)= 19.298, *p*< 0.01, partial η^2 = 0.391 (refer to Table 11).

When univariate tests were performed on the dependent variables, the results indicated that the ST5 score of the experimental group was higher than the control group regardless of time point, F(1,62)= 9.539, *p* < 0.01, partial η^2 = 0.135; and learning stress was also higher than for the control group, F(1,62)= 75.513, *p* < 0.01, partial η^2= 0.553. Table 12 illustrates the details of students' stress and learning stress as reflected in their pre-tests and post-tests before and after the treatments with the two instructional models.

Table 11
MANOVA and univariate results of learning stress (LS)

Effect		Hotelling's trace T^2	F		Df_1	Df_2	partial η^2
Between-subjects	Group	43.813	1314.40**		2	60	0.978
	Time*LS	1.528	45.82**		2	60	0.604
	Group*LS	0.643	19.298**		2	60	0.391
Univariate test (Post-test)							
Learning stress	Exp. (n = 35)		Ctrl. (n = 28)		F	*p*	partial η^2
	M	*SD*	M	*SD*			
Stress	4.17	1.97	6.00	2.48	9.532**	0.002	0.135
Learning stress	80.34	20.26	96.64	16.80	75.513**	0.001	0.553

Note: **p<.01

Table 12
Mean score and standard deviation of learning stress

Dependent variables		Exp (n = 35)		Ctrl (n = 28)		t-value
		M	SD	M	SD	
Stress	Pre-test	6.17	2.18	4.17	1.97	0.11
	Post-test	6.18	2.78	6.00	2.48	3.25**
Learning stress	Pre-test	120.74	22.98	80.34	20.25	2.62
	Post-test	106.28	19.79	96.64	16.79	3.49**

Note: ** p<.01

DISCUSSION

The study's results have provided a better understanding of the fundamental device of the DEN model for the enhancement of tenth-grade students' learning outcomes, executive functions, and decrement of learning stress. Therefore, the overall results have the potential to make a substantial contribution to teacher education. Furthermore, consistent with past research results (Srikoon et al., 2017; Sripongwiwat et al., 2016; Tornee et al., 2017; Uopasai et al., 2017, 2018), our results showed similar outcomes for optimizing an appropriate instructional model treatment to assist the devices of education and growth associated with group differences in educational accomplishment, particularly in teaching science or applied science subjects.

The contemporary era of information and communication technology has the effect of increasing the burden of educational transformation. Therefore, it is necessary to distinguish the advanced responsibility of the science curriculum to ensure that students gain skills rather than remember the lesson content (Wilkin, 2014). Furthermore, all basic education institutions face many challenges brought about by the COVID-19 pandemic. Hence, science teachers should consider design-based learning and educational neuroscience learning theories when developing lesson plans to produce better learning consequences and develop their students' executive functions to sustain the subject's relevance in the 'new normal' era. In conclusion, the results of this study implied that physics learning outcomes and executive functions are essential in improving students' long-term skills. Finally, the researchers would like to encourage physics teachers to explore and use the DEN model to develop outstanding human capital in the future.

CONCLUSION

The impetus for the current study was to report the effectiveness of DEN model intervention on tenth-grade students' learning outcomes, executive functions, and learning stress in Thailand. However, despite meaningful results for the efficiency of the DEN for promoting students' learning outcomes and executive functions and reducing students' learning stress, the study has its limitations. It is because a true experimental design that allowed students to assign multiple intervention conditions randomly would have been useful. Therefore, the researchers recommended longitudinal interventions for future studies.

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REFERENCES

Anderson, O. R. (2009). Neurocognitive theory and constructivism in science education: A review of neurobiological, cognitive and cultural perspectives. *Brunei International Journal of Science & Mathematics Education, 1*(1), 1-32.

Bunterm, T., Ketchatturat, J., Samranjai, J., Methaneethorn, J., Wattanathorn, J., Muchimapura, S., Wannanon, P., Uopasai, S., Srikoon, S., & Werachairatana, S. (2015). *The development of cognitive function battery test: Thai version*. National Research Council of Thailand.

Bellini, J. L., & Rumrill, P. D. (2009). *Research in rehabilitation counseling: A guide to design, methodology, and utilization* (2nd ed.). Charles Thomas.

Chinnery, A. (2014). Teaching concept and model. In *Encyclopedia of educational theory and philosophy* (pp. 792-796). SAGE Publications, Inc. https://doi.org/10.4135/9781483346229

Chiou, G. L., Lee, M. H., & Tsai, C. C. (2013). High school students' approaches to learning Physics with relationship to epistemic views on Physics and conceptions of learning Physics. *Research in Science & Technological Education, 31*(1), 1-15. https://doi.org/10.1080/02635143.2013.794134

Cobb, P., diSessa, A., Lehrer, R., & Schauble, L. (2003). Design experiments in educational research. *Educational Researcher, 32*(1), 9-13.

Cohen, I., Berkov, T., & Gilboa, G. (2021). Total-variation mode decomposition. https://guygiboa.net.technion.ac.il/files/2021/05/ssvm_Cohen_Berkov_Gilboa.pdf

Diamond, A. D. (2013). Executive functions. *Annual Review of Psychology, 64*, 135-168. https://doi.org/10.1146/annurev-psych-113011-143750

Engel, A. K., Senkowski, D., & Schneider, T. R. (2012). Multisensory integration through neural coherence. In M. M. Murray & M. T. Wallace (Eds.), *The neural bases of multisensory processes*. CRC Press/Taylor & Francis.

Everitt, B. S., & Dunn, G. (1991). *Applied multivariate data analysis* (2nd ed.). Edward Arnold.

Gilbert, S., & Burgess, P. (2008). Executive function. *Current Biology, 18*(3), R110-R114.

Goswami, U. (2008). *Cognitive development: The learning brain*. Psychology Press.

Hair, J. F., Back, W. C., Babin, B. J., & Anderson, R. E. (2013). *Multivariate data analysis* (7th ed.). Pearson.

Institute for the Promotion of Teaching Science and Technology. (2012). *Science measurement and assessment*. V. Print.

Isman, A. (2011). Instructional design in education: New model. *The Turkish Online Journal of Educational Technology*, *10*(1), 136-142.

Jacob, C., & Silvanto, J. (2015). How is working memory content consciously experienced? The 'conscious copy' model of WM introspection. *Neuroscience and Biobehavioral Reviews, 55*, 510-519. https://doi.org/10.1016/j.neubiorev.2015.06.003

Jordan, R. C., Ruibal-Villasenor, M., Hmelo-silver, C. E., & Etkina, E. (2011). Laboratory materials: Affordances or constraints. *Journal of Research in Science Teaching, 48*(9), 1010-1025.

Meltzer, L. (2010). *Promoting executive function in the classroom*. The Guilford Press.

Noesselt, T., Bergmann, D., Heinze, H. J., Münte, T., & Spence, C. (2012). Coding of multisensory temporal patterns in human superior temporal sulcus. *Frontiers in Integrative Neuroscience, 6*(1), 64-78.

Sanchez-Torres, A. M., Elosua, M. R., Lorente-Omenaca, R., Moreno-Izco, L., & Cuesta, M. J. (2015). A comparative study of the working memory multicomponent model in psychosis and healthy control. *Comprehensive Psychiatry, 61*, 97-105.

Sekaran, U. (2003). *Research methods for business: A skill building approach* (4th ed.). John Wiley and Sons.

Spalding, K. N., Jones, S. H., Duff, M. C., Tranel, D., & Warren, D. E. (2015). Investigating the neural correlates of schemas: Ventromedial prefrontal cortex is necessary for normal schematic influence on memory. *The Journal of Neuroscience: The Official Journal of the Society for Neuroscience, 35*(47), 15746-15751.

Srikoon, S., Bunterm, T., Nethanomsak, T., & Tang, K. N. (2017). A comparative study of the effects of the neurocognitive-based model and the conventional model of learner attention, working memory and mood. *Malaysian Journal of Learning and Instruction, 14*(1), 83-110.

Srikoon, S., Bunterm, T., Nethanomsak, T., & Tang, K. N. (2018). Effects of 5P model on academic achievement, creative thinking, and research characteristics. *Kasetsart Journal of Social Sciences, 39*(3), 488-495.

Sripongwiwat, S., Bunterm, T., Srisawat, N., & Tang, K. N. (2016). The construction and neurocognitive-based teaching model for promoting science learning outcomes and creative thinking. *Asia Pacific Forum on Science Learning and Teaching, 17*(2), 9.

Sripongwiwat, S., Bunterm, T., & Tang, K. N. (2018). An investigation of learning stressors among secondary school students: A case study in northeast Thailand. *Kasetsart Journal of Social Sciences, 39*, 197-206. https://doi.org/10.1016/j.kjss.2017.06.002

Tornee, N. (2014). *Development of chemistry teaching model based on constructivism and educational neuroscience for optimizing cognitive ability, problem-solving, and innovation development ability* [Unpublished Doctoral dissertation]. Khon Kaen University.

Tornee, N., Bunterm, T., & Tang, K. N. (2017a). The impacts of inquiry-based learning model on teaching science subject: A case study in Thailand. *Turkish Online Journal of Educational Technology,* (Special Issue for INTE), 395-402.

Tornee, N., Bunterm, T., Muchimapura, S., & Tang, K. N. (2017b). The neurocognitive constructivist guided-inquiry based teaching model for promoting attention abilities. *Turkish Online Journal of Educational Technology,* (Special Issue for INTE), 475-483.

Uopasai, S., Bunterm, T., Muchimapura, S., & Tang, K. N. (2017). The effect of working memory training on the behavioral, electrophysiological and achievement change. *Turkish Online Journal of Educational Technology,* (Special Issue for INTE), 331-339.

Uopasai, S., Bunterm, T., Muchimapura, S., & Tang, K. N. (2018). The effect of constructivism, metacognitive and neurocognitive-based teaching model to enhance veterinary medicine students' learning outcomes. *Pertanika Journal of Social Sciences & Humanities, 26*(4), 2313-2331.

Vaninsky, A. (2017). Educational neuroscience, educational psychology, and classroom pedagogy as a system. *American Journal of Educational Research, 5*(4), 384-391. https://doi.org/10.12691/education-5-4-6

Vogel, S., & Schwabe, L. (2016). Learning and memory under stress: Implications for the classroom. *NRJ Science of Learning, 1*, (16011), 1-10. https://doi.org/10.1038/npjscilearn.2016.11

Wilkin, C. L. (2014). Enhancing the AIS curriculum: Integration of a research-led, problem-based learning task. *Journal of Accounting Education, 32*(2), 185-199. https://doi.org/10.1016/j.jaccedu.2014.04.001

Yang, H. Y., & Chang, C. C. (2015). The effect of attention cueing on science text learning. *Tech Know Learn, 23,* 357. https://doi.org/10.1007/s10758-015-9264-6

Yuenyong, C., & Narjaikaew, P. (2009). Scientific literacy and Thailand science education. *International Journal of Environmental & Science Education, 4*(3), 335-349.

Yusoff, M. S. B. (2011). The validity and reliability of secondary school stressor questionnaire (3SQ) in identifying stressor among adolescents in secondary school. *International Medical Journal, 18*(2), 99-105.

Yusoff, M. S. B. (2016, August 10). *The medical student stressor questionnaire: A valid screening tool to discover sources of stress of medical students* (Paper presentation). The Innovative Practices in Higher Education Expo 2016 (I-PHES), Kuala Lumpur, Malaysia.