The constructionism and neurocognitive-based teaching model for promoting science learning outcomes and creative thinking

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Received 28 Oct., 2016
Revised 25 Dec., 2016

Contents

Abstract

The aim of this study was to examine the effect, after intervention on both experimental and control groups, of constructionism and neurocognitive-based teaching model, and conventional teaching model, on the science learning outcomes and creative thinking of Grade 11 students. The researchers developed a constructionism and neurocognitive-based teaching model. The research sample consisted of 49 students in an experimental group and 34 students in a control group, randomly selected from 10 classes of Grade 11 students in one secondary school located in the northeast of Thailand. Researchers employed an experimental research pre-test and a post-test control group design. Results of this study showed that before intervention there was no significant difference between groups on the dependent variables, except science process skills. After intervention, all variables in the experimental group were significantly better than the control group. The developed teaching model was proven to successfully promote the students' science learning outcomes, including nanotechnology content knowledge, science process skills, scientific attitudes, as well as creative thinking.

Keywords: Constructionism and neurocognitive based teaching model, creative thinking, science learning outcomes, science process skills, scientific attitudes

Introduction

The current education system requires a high degree of flexibility and adaptability in facing economic, technological, social and personal challenges. Responding to the challenges of the twenty-first century, with its complex environmental, social and economic forces, requires students to be creative, innovative and adaptable, with the motivation, confidence and skills to use critical and creative thinking decisively. In particular, teaching and learning science in this new age requires a new teaching model. This means an interactive and creative education based on individual needs and abilities (Markovic, 2012).

Most teachers teach science primarily through lectures and textbooks that are dominated by facts and algorithmic processes, rather than by concepts, principles and evidence-based ways of thinking. This is despite ample evidence that many students gain little new knowledge from traditional lectures (Hrepic, Zollman &

Rebello, 2007). Reformers in science education have promoted the idea that students should be engaged in the excitement of science. They should be helped to discover the value of evidence-based reasoning and higher-order cognitive skills, and taught to become innovative problem solvers (Nelson, 2008; Perkins & Wieman, 2008).

The constructionism and neurocognitive-based teaching model utilizes two emerging fields, namely: neurocognitive learning theory and the constructivist philosophy of science teaching and learning. Neurocognitive learning theory is a synthesis of three traditionally separate components of inquiry such as (i) neurophysiology with an emphasis on the biological bases of brain and neutral activity; (ii) cognitive science with a focus on information processing and the internal presentation of experience, and (iii) learning theory that explains how we cumulatively interact with, and adapt to, our environment (Anderson, 2009).

According to Anderson (2009), the application of this teaching model to analyse inquiry based science learning has to go through the following process: (i) Action-reaction loops in brain functioning; (ii) Brain functional modules and their integrated activity during science learning; (iii) The role of attention and perception during inquiry learning; (iv) Knowledge networking and frontal lobe executive functions; (v) Scientific reasoning and frontal lobe activity; (vii) Inquiry learning cycle phases and frontal lobe cognitive functions, and (viii) A word about creativity, multi-modal representations and inquiry learning.

As indicated in the Framework for 21st Century Learning, learners must master a blend of content knowledge, specific skills, expertise and literacy in order to succeed in their work and life (http://www.p21.org/ourwork/p21-framework). Implementing all of these skills requires the development of core academic subject knowledge and understanding among all learners. In other words, those learners who can think critically and communicate effectively must build on a base of core academic subject knowledge. Within the context of core knowledge instruction, learners must also learn essential skills such as critical thinking, problem solving, communication and collaboration.

Creativity and innovation capabilities are recognized as fundamental to becoming successful learners by the Australian Council on Education (MCEETYA, 2008). According to the TAP Report (2005), science, as a major source of discovery and economic development, must be taught to cultivate the skilled scientists and engineers needed to create tomorrow's innovation; thus maintaining the country's competitiveness in the twenty-first century.

According to Gilbert (2005), former conceptions of knowledge, minds and learning no longer serve a world where what teachers know is less important than what teachers are able to do with knowledge in different contexts, and where their capacity for learning far outweighs the importance of their ability to follow rules. Therefore, schools and teachers need to thoughtfully and intentionally design learning environments and tasks in which teachers can explore issues that are relevant, and develop pedagogies that are effective for a knowledge era (Friesen, 2009). As a result, teachers need to develop new teaching strategies and acquire new expertise to design and facilitate meaningful learning, in particular, in sciences. Preparing science teachers for the 21st century requires a close look at what it means to teach and learn in increasingly networked, technology-rich, digital classrooms. If teachers have good science instruction they are able to teach science effectively, and process skills will be emphasized more in the classroom (Saribas & Bayram, 2009).

A construction education system encourages critical thinking and an inquiring mind, but the education system in Thailand is still not capable of offering these skills to students. This is because the classroom teaching remains very much teacher-centred, while learners are blamed for lacking talent and are denied the right to develop themselves (Chotiphatphaisal, 2014). The international study by the Office of the Education Council and Organization for Economic Cooperation and Development (OECD) in collaboration with the Program for International Student Assessment (PISA) in 2009 indicated that the average score for Thai students is 425, while the average international score is 501. This means that Thailand was ranked 47th out of a total of 65 countries (The Institute of the Promotion of Teaching Science and Technology-ISPT, 2010). On top of that, results of the Trends in International Mathematics and Science Study (TIMSS) revealed that Thai students scored 471 out of an international average score as 500 in terms of their knowledge and scientific skills at a basic educational level. In other words, Thai students were ranked 23rd out of a total of 50 countries (The Institute of the Promotion of Teaching Science and Technology-ISPT, 2009).

Constructionism and Neurocognitive-based Teaching Model

The medical definition of neurocognitive is related or involved cognitive functioning, and is associated to the structures and processes of the central nervous system (http://www.meriam-webster.com/medical/neurocognitive). Neurophysiology is focused on the biological aspects of brain and neural activity, while cognitive science highlights information processing and internal representation of experience. In addition, learning theory is used to explain how students cumulatively interact and adapt to their environments. Anderson (2009) proposed that neurocognitive learning theory is a synthesis of neurophysiology, cognitive science and learning theory. To what extent do these three components provide mutually reinforcing explanations of students' learning? As a result, teachers are able to understand and predict to enhance students' learning.

Hence, a neurocognitive model is defined as an information processing learning theory that is used to explain in terms of neurocognitive science. According to Anderson (2009), neurocognitive-based learning covers the following procedures. Firstly, perceptions of sensory input from students' five senses formed by their prior experiences, and modified in relation to prior stored information in their long term memory. The affective states influence how the incoming sensory data are perceived and integrated with prior knowledge, thus the working memory takes responsibility in doing these processes. Secondly, the brain processes multiple information inputs almost at the same time. Thirdly, decision making and response patterns are weighted by emotion, and finally the appropriate response is selected and actualized by motor pathways. According to this neurocognitive based teaching model, teachers have to: promote their students' affective states in order to keep their continual attention; focus on the appropriate connection between prior knowledge and new knowledge; promote executive function, especially working memory, for shaping and reworking in relation to their prior stored information; and use multi-sensory media or hands-on experiments as much as possible.

On the other hand, a constructionism learning theory is defined as one where students construct mental models in order to understand the world around them. Therefore, constructionism is connected with experiential learning and builds upon Jean Piaget's epistemological theory of constructivism (Cakir, 2008). In this sense, constructionism advocates student-centred, discovery learning where students use information they already know to acquire more knowledge (Alesandrini& Larson, 2002). Alesandrini and Larson further emphasized that students learn through their involvement in project-based learning where they make connections between different ideas and areas of knowledge facilitated by teachers through coaching rather than using lectures or step-by-step guidance. Further, constructionism holds that learning can happen most effectively when students are active in making tangible objects in the real world.

Constructionism has been introduced to Thai teachers as one of the learning centred teaching paradigms. Although, as mentioned by Israsena et al. (2014), the constructionism approach has been implemented in some schools, villages and organizations in Thailand since 1997, it is unpopular in most ordinary Thai schools. Israsena et al. theorized a transformative learning model consisting of five main components such as curiosity, motivation, planning, execution and conclusion, after experiencing this approach for more than 15 years.

Anderson (1992) proposed the interrelationships between the constructivist models of learning and current neurobiological theory, with implications for science education. Anderson, Love and Tsai (2014: 467) concluded that integrating a neuroscience, cognitive science and constructivist perspectives into science and mathematics learning had a significant impact. Since Papert's constructionism was rooted from Piaget's constructivism, but focused on the art of learning, or 'learning to learn', and on the significance of making things in learning (Ackermann, 2004), constructionists believe that students themselves are able to construct knowledge and understand the environment. They have experiences and use tools (i.e. computers) in learning to make them understand better (Ackermann, 2001).

Since the intention is to promote the ability for creative thinking, the best way to know whether or not students can construct their own knowledge, is by the active construction of something, using certain useful technology in today's digital world. Therefore, researchers gave students in both groups the opportunity to begin an interesting project by themselves, the opportunity to present ideas and creations, and the time to continue their projects. In this way, the constructionism idea was selected to develop our teaching model. Scott, Leritz and Mumford (2004) found that effective creative training programmes focused on the development of cognitive skills and skills in real life application. Consequently, a neurocognitive learning model can be a base for developing our students' cognitive skills. In this study, the researchers developed this constructionism and neurocognitive-based teaching model by using constructionism based on neurocognitive learning theory as one of the ways to implement educational neuroscience to improve students' learning outcomes, and one that enhances students to be creative thinkers with the ability to create innovation.

The main ideas used as the basis in this model were:

I. Student-centred paradigm - students construct their own knowledge and learn together from people and the environment. Students do hands-on activities, interact with the external meaningful environment, make a connection between pieces of prior knowledge and newly-learned knowledge to construct their own new knowledge, and exchange their knowledge with others;
II. Use of technology as a tool to seek out information and construct their knowledge;
III. Less stress or more enjoyable learning (emotional conditions influencing the selection and format of the response), multi-sensory learning, and the importance of executive function.

Aim of the Study

This study aimed to examine the effects of the constructionism and neurocognitive-based teaching model on students' science learning outcomes and creative thinking.

Method

Research Design and Study Samples

The study was based on a 2x2 (time x group) design. Participants' science learning outcomes (nanotechnology content knowledge, science process skills, scientific attitudes), and creative thinking were measured both before and after interventions. The participants were two classes of Grade 11 students in one secondary school in the northeast of Thailand, simple random sampling from 10 classes, which were re-sampled into one experimental group (n=49) and one control group (n=34).The intervention was applied in nanotechnology: a Grade 11 supplementary science course.

The constructionism and neurocognitive-based teaching model developed by the researchers was used to teach the experimental group, and the conventional teaching model was used for the control group. The syntax of constructionism and the neurocognitive-based teaching model consists of six steps as follows:

(i) Boost attention: Teacher prepares students to be ready for the new lesson. Teacher stimulates students' learning interest through their presentation. Teacher makes the students interested in receiving data, motivated to learn, and stimulated their brain. Together, teacher and students shared and defined individual learning and workloads;

(ii) Gather information: Teacher practices students' divergent thinking and abilities to search information via information technology. Teacher provides opportunities for students to seek knowledge through new sources of learning. Teachers have to prepare materials such as study materials, computer programs or a real object;

(iii) Understanding: Teacher helps students to construct their own knowledge. Students have to review or rethink their assignment. Students find out the relationship between seeking information and constructing their knowledge;

(iv) Thoughts organized: Teacher insists students construct their own knowledge by organizing their ideas. Students are encouraged to share, analyse and debate their projects and find out more information;

(iv) Idea clarification/looking for something new: Teacher continues to encourage students to construct their own knowledge by brainstorming, sorting, and making connections between prior knowledge and new knowledge. Teacher promotes divergent thinking, imagination and creation of something new;

(v) Idea tested: Teacher performs a test or proof of the new invention. Students review the objectives and carefully consider their work.

Finally, students compared significant positive and negative effects and made a presentation (refer to Appendix A and B).

Similarly, the conventional teaching model was used to teach the control group. The syntax of the conventional teaching model is comprised of three steps, namely: introduction, instruction and conclusion. This conventional teaching model is a teacher centred approach and is very common in education. The conventional teaching model disregards the students consequently the mental level of interest of the students**.** It involves coverage of the context and rote memorization on the part of the students. It did not involve students in creative thinking and participation in the creative part of activities. Most of the time, during the teaching and learning process, instruction remains lateral, which is considered to be accepted activity (Khalid &Azeem, 2012).

Pre-test and post-test was measured on science learning outcomes, namely: nanotechnology content knowledge, science process skills, scientific attitudes, as well as creative thinking before and after intervention. Two sets of lesson plans were developed, one for the experimental group and the other for the control group. Each set of lesson plans consisted of nine lesson plans for two hours per week, giving a total of 24 hours. There were eight subtopics and the time allocated for each subtopic was: (i) basic knowledge of nanotechnology (two hours); (ii) nanotechnology in nature (two hours); (iii) activated carbon with nanotechnology (two hours); (iv) nano products inventing tools (two hours); (v) how to invent nano products (eight hours); (vi) uses of nanotechnology (two hours); (vii) understanding nanotechnology (two hours), and (viii) nanotechnology products (four hours).

Research Instrument

Research instruments were mainly used as tests to measure science learning outcomes and creative thinking. A total of four types of instrument were utilized in this study (refer to Appendix C). The Nanotechnology Content Knowledge Test was used to measure the science learning outcome of nanotechnology content knowledge. It comprised 30 multiple choice items that were selected from the school item bank. The reliability (KR20) was 0.87; the discrimination index was 0.21 to 0.64, and the difficulty index was 0.21 to 0.85.

The Science Process Skills Test was used to measure the science learning outcome of science process skills, which consisted of 45 multiple choice items. This instrument was adopted from Bunterm, Lee, Ng, Srikoon, Vangpoomyai, Rattanavongsa and Rachahoon (2014). Thirteen different science process skills were assessed by this Science Process Skills Test, namely: observing, measuring, using numbers and calculating, classifying, space/space relationship and space/time relationship, communication, inferring, predicting, controlling variable, formulating hypotheses, defining operationally, experimenting, and interpreting data and conclusion. The reliability (KR20) was 0.88; the discrimination index was 0.21 to 0.72, and the difficulty index was 0.22 to 0.93.

The Scientific Attitudes Rating Scale was adopted from Bunterm et al. (2014). It was used to measure the science learning outcome of scientific attitudes. This 25-item task rating scale was designed to evaluate the six traits of scientific attitudes, namely: curiosity, reasonableness, responsibility and perseverance, organization and carefulness, honesty, and open-mindedness. The reliability value (α) of this Scientific Attitudes Rating Scale was 0.83.

The Torrance type scientific creative test created by Wongpratum (2000) was adapted and its characteristics were re-examined before it was utilized to measure the creative thinking of students. Three categories of creative thinking were considered, namely: fluency, flexibility, and originality. The total score of creative thinking was cumulated from these three categories. The reliability (Hoyt's analysis of variance) value originally reported was 0.792. The re-examined reliability was 0.772.

Researchers took one to two hours per week to collect data for the four instruments, before and after the intervention as pre-tests and post-tests, respectively. Firstly, the participants were given a duration of 50 minutes to attend the creative test. This was followed by a 40 minute Nanotechnology Content Knowledge Test, and a 10 minute Scientific Attitudes Rating Scale. Finally, a 50 minute Science Process Skills Test was conducted. All of these tests were conducted on different days within a week.

Data Analysis

Repeated measures of multivariate analysis of variance (Repeated MANOVA) were used to analyse the effect of time, teaching model, and interaction between time and teaching model on the four dependent variables: nanotechnology content knowledge, science process skills, scientific attitudes, and creative thinking. Wilks' lambda, a direct measure of the proportion of variance in the combination of dependent variables that is unaccounted for the group variable (Everitt & Dunn, 1991), was used to test whether there were differences between the means of identified groups of subjects on a combination of dependent variables. However, if some violated assumptions are found, such as if the covariance matrices of the dependent variables were not equal across the group (the Box's M was significant**),** this implies a Type I error should be considered, the Pillai's trace, which is the most robust (Olson,1976) will be used instead. Or if the Levene's Test of Equality of Error Variances showed the difference of error variance across groups, the nonparametric test will be used instead for that variable. Furthermore, if some variables are not equal before treatment, researchers will compare the after treatment dependent variables using MANCOVA with the unequal pre-test variables as the covariates.

The adjustment for the pre-test score in MANCOVA has produced two benefits. The first one is to make sure that any post-test differences truly result from the treatment of the teaching model, and are not some left-over effect of (usually random) pre-test differences between the groups. The other benefit is to account for variation around the post-test means that comes from the variation in where the students started at pre-test.

Results

The results of this study are presented in accordance with the research aim indicated above. The findings are presented in two parts, namely: descriptive and inferential findings. The initial findings highlight the science learning outcomes and creative thinking of Grade 11 students before and after a constructionism and neurocognitive-based teaching model, and a conventional teaching model, were used in their educational instruction. This is followed by evaluating the impact of these two teaching models on the Grade 11 students' science learning outcomes and creative thinking. Finally, the different impacts of the two teaching models are measured.

The descriptive statistics of pre-test vs. post-test of nanotechnology content knowledge, science process skills, scientific attitudes, and creative thinking of both the experimental and control groups for the Grade 11 students are presented in Table 1. All post-test results show an increment compared to the pre-test results after utilizing any of the two teaching models.

A 2x2 repeated MANOVA was utilized to analyse the effect of the two teaching models on all of the four dependent variables. The Box's M was significant implied that the covariance matrices of the dependent variables were not equal across the groups**.** Therefore the Type 1 error should be considered. The results revealed that there was a significant multivariate effect for interaction between teaching models and time. Pillai's trace value = .531, $F(4, 74) = 20.982$, $p = .000$; partial $\eta^2 = .531$ showed that this interaction could explain 53.1 percent of variance in the dependent variables. Power to detect the effect was 1.000, which showed that the sample size was adequate. However, the Levene's Test of Equality of Error Variances showed the difference of error variance across groups on pre-test science process skills, $F(1, 77) = 13.389$, $p = .000$, and violated the assumption.

Table 1. Descriptive statistics of pre-test vs post-test

Dependent variables	Experimental group (N=45)				Control group (N=34)			
	Pre-test		Post-test		Pre-test		Post-test	
	M	*SD*	*M*	*SD*	*M*	*SD*	*M*	*SD*
NT. content knowledge	11.40	2.43	22.40	2.99	11.59	2.61	16.79	3.22
Sci. process skills	30.18	5.61	33.71	4.16	28.29	3.11	30.35	3.02
Scientific attitudes	92.89	9.79	104.09	8.66	95.15	10.84	96.24	9.65
Creative thinking	174.24	39.42	220.38	66.55	150.41	42.72	163.50	58.24

On this line of reasoning, researchers used the nonparametric method for testing this variable. The Mann-Whitney U test showed that before the intervention, science process skills were significantly different between groups (U = 560.000, $p = .420$). The analysis design was then changed to see whether or not these two groups were equal, and in which particular variables, before intervention, and used those variables as the covariates. A one-way MANOVA for the other three remaining pre-test variables showed that there was no significant difference between groups, $F(3, 75) = 2.720$, $p = .050$, with Box's M = 3.931, $p = .709$, and all the Levene's Test of Equality of these three variables were not significant. Therefore, the covariance variable in the post-test analysis was only the pre-test of the science process skills score.

A one way MANOVA for the four dependent variables after intervention (Box's M = 8.881, p = .503) revealed a significant multivariate main effect for teaching models, Wilks' λ =.423, $F(4, 74) = 25.207$, $p = .000$; the teaching model could explain 57.7 percent of variance in the dependent variables, partial $\eta2 = .577$; power to detect the effect was 1.000. Given the significance of the overall test, the univariate main effects were examined. Significant univariate main effects for teaching models were obtained for all dependent variables as shown in Table 2 below.

Since the pre-test of science process skills differed between groups, a MANCOVA design was applied to make sure that post-test differences truly resulted from the treatment, and were not from some other left-over effect of pre-test differences between the groups. The results revealed a significant multivariate main effect for teaching models, Wilks' λ =.440, $F(4, 73) = 23.243$, $p = .000$; the ability to explain variance in dependent variables showed a small decrease, partial $\eta^2 = .560$; power to detect the effect was 1.000. All the assumptions were met. Significant univariate main effects for teaching models were obtained for all dependent variables as indicated in Table 2 below.

Table 2. Summary of univariate tests results for the two models

Variables	No covariate	With covariate
Nanotechnology content knowledge	$F(1,77) = 63.643$ $p = .000$ $\eta_p^2 = .453$	$F(1,76) = 57.528$ $p = .000$ $\eta_p^2 = .431$
Science process skills	$F(1,77) = 16.256$ $p = .000$ $\eta_p^2 = .174$	$F(1,77) = 12.917$ $p = .000$ $\eta_p^2 = .145$
Scientific attitudes	$F(1,77) = 14.440$ $p = .000$ $\eta_p^2 = .158$	$F(1,77) = 14.319$ $p = .000$ $\eta_p^2 = .159$
Creative thinking	$F(1,77) = 15.727$ $p = .000$ $\eta_p^2 = .170$	$F(1,77) = 16.320$ $p = .000$ $\eta_p^2 = .177$

Discussion

The results of this study showed that there was no significant difference between groups on the dependent variables, except science process skills before the intervention. However, after the intervention, all dependent variables, namely the three science learning outcomes and creative thinking in the experimental group, were significantly higher than the control group. On this line of reasoning, the developed teaching model is found to have a more significant effect on the overall science learning outcomes and creative thinking of students than the traditional model. The results of this study are found to be consistent with several previous findings about constructivism (Ayaz & Sekerci, 2015; Bogar, Kalender & Sarikaya, 2012; Qarareh, 2016) and also the constructionism learning model (Triantafyllou & Timcenko, 2013; Stager, 2005).

The results of this study indicated that there was a significant different effect from the two teaching models. As a result, great emphasis has been placed on science teachers to use effective teaching models to improve students' learning and creative thinking. With the passage of time, the importance of science teachers' teaching styles is being rolled-out perhaps and they are taking initiatives to improve their teaching strategies, using an appropriate teaching model, to improve students' learning and thinking skills (Jalbani, 2014).

Science teachers used to give instruction via the conventional teaching model, while the role of science teachers in the constructionism neurocognitive-based teaching model is to create a productive context for learning, including preparing multisensory material, scaffolding, consulting, giving time, collaboration, and doing ahead with the coming needs of student as suggested by Stager (2010). The students' role in the constructionism neurocognitive-based teaching model is to share their ideas with each other and cooperate in making something shareable, thus involving in open inquiry learning. While their roles in the conventional teaching model is doing an experiment in-group following workbook instruction or learning via structured inquiry. This result is supported by previous researchers who found advantages in utilizing the open inquiry learning approach (Bunterm et al., 2014; Rachahoon, Bunterm, Wattanathorn & Muchimapura, 2011; Rattanawongsa, Bunterm, Wattanathorn & Muchimapura, 2013; Vangpoomyai, Bunterm, Wattanathorn & Muchimapura, 2012) and the multi-sensory approach (Wannathong, Bunterm & Wannanon, 2013).

The common features seen to promote creativity were flexibility in the pedagogical environment, where the teacher creates an environment that provides students opportunities for ideas and expression, and promotes good attitudes towards creative thinking, particularly an open-mindedness to receive new initiatives. This result is supported by Davies et al. (2013) who emphasized an important feature of the pedagogic environment, which can promote creativity, is the nature of the relationship between teachers and students, including high expectations, mutual respect, modelling of creative attitudes, flexibility and dialogue.

The current situation of research on neurocognitive-based learning is still at an initial stage. Though there are many studies about Brain-Based Learning, some researchers prefer not to use this term as it is tied to more over claim believes that still not proof in neuroscience or sometimes misconceptions and seem to be more business. Many studies have found the effects of cognitive functions such as working memory, attention and executive functions on learning outcomes (Dehn, 2008). Further studies are now discovering how the brain works in processing information. Most are done by neuroscientists or neurocognitive psychologists. Ridderinkhof, van den Wildenberg, Segalowitz and Carter (2004), from departments of psychology in four universities made a review of recent progress in cognitive neuroscience and examined some of the main constituent processes of cognitive control involved in dynamic decision making: goal directed action selection, response activation and inhibition, performance monitoring, and reward-based learning. However, teachers still know little of how to apply this knowledge of neuroscience in their classrooms.

In Thailand, this field of study is at an early stage. Some educational researchers have tried to develop teaching models that incorporate the concepts of working memory, attention and executive functions in their teaching models. The results confirmed that students in experimental groups who learned science via a teaching model based on some concepts from a neurocognitive-based learning theory performed better than students in a control group (Srikoon & Bunterm, 2016; Uppasai & Bunterm, 2015; Wannatong, Bunterm & Wannanon, 2013).

It is concluded that the developed constructionism and neurocognitive based teaching model, which is based on the theoretical foundation of neurocognitive learning theory and constructionism learning theory, is able to enhance the science learning outcomes and creative thinking of Grade 11 students. As a high-impact educational practice shown in this study, the benefits of these two learning theories are being recognized as an important teaching model. Maintaining a productive constructionism and neurocognitive-based teaching model requires not only the dedication of the participating science teachers, but also the establishment of a culture across schools that encourages the application of these two learning theories and provides a network of support for the teaching community. The constructionism and neurocognitive-based teaching model proposed in this paper and used in the case study, show a positive impact on students' science learning outcomes and their creative thinking. Further work that includes developing this teaching model with more direct and indirect assessment is a necessity.

Conclusion

As a conclusion, the developed teaching model, based on the ideas of constructionism and neurocognitive science, was found to be beneficial to students learning science. It should be clear that Thailand is currently engaged in teacher quality policies that have been influenced by effective research into teacher training, but with the absence of much of the research knowledge that would help the training development of teachers.

The current era of information and communication technology influences the growing pressure to reform, and to differentiate higher accountability of educational programmes that ensure students acquire skills rather than memorize content (Wannapiroon, 2014; Wilkin, 2014). As a result, science teachers should consider neurocognitive and constructionism learning theories when they design their lesson plans to enhance better outcomes in science education. Since this constructionism and neurocognitive teaching model was to promote science learning outcomes, including nanotechnology content knowledge, science process skills and scientific attitudes, as well as creative thinking, science teachers are encouraged to use this teaching model. Moreover, the results of this study also indicated that science learning outcomes and creative thinking are important in enhancing students to embed knowledge in their long-term memory. On this line of reasoning, science teachers should provide sufficient opportunities to conduct student-centred learning to develop these domains.

Recent international surveys such as the OECD’s PISA showed a discouraging result in students’ achievement scores, and offered support for the translation of an innovative teaching model such as constructionism and the neurocognitive-based teaching model. Indeed, what may now finally emerge is a ‘learning level’ paradigm that has numerous possibilities for improving Thai educational processes and outcomes through focusing on teaching. Finally, results of this study provide further evidence in support of the need to develop science teachers’ abilities to deliver and guide students using the constructionism approach, as well as how to apply neurocognitive science with educational practice as a new concept for Thai teachers. An effective training programme that is related to constructionism and neurocognitive-based teaching, including open inquiry teaching, is suggested to the Thailand Ministry of Education.

However, there are some limitations to this study. This study was held in the school's own supplementary science class, not in the basic science class that is required to be the same in all schools. As a supplementary course, its time is not fixed. The teachers were not anxious as they feel they will not have time to finish all of the content required in curriculum. This study showed that there is a real effect from using the teaching method, but how to implement this in a basic science class is still to be discovered. It is recommended that future studies of how to implement this model of teaching in basic science courses should be carried out for further benefit of its application.

Acknowledgement

This work was supported by the Higher Education Research Promotion and National Research University Project of Thailand, Office of the Higher Education Commission, through the Cluster of Research to Enhance the Quality of Basic Education.

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Appendix

Appendix A

The six steps of developed teaching model
and
How the six steps related to or guided by the neurocognitive theory and constructionism learning theory?

The six steps of developed teaching model

1. **Boost attention**: Teacher prepares students to be ready for the new lesson. Teacher stimulates students' learning interest through their presentation. Teacher makes the students to be interested in receiving data, motivated them to learn and stimulated their brain. Teacher and students shared and defined individual learning and workload together.
2. **Gather information**: Teacher practices students' divergent thinking and abilities to search information via information technology. Teacher provides opportunities for students to seek knowledge through new sources of learning. Teachers have to prepare materials such as study materials, computer programs or a real object.
3. **Understanding**: Teacher helps students to construct their own knowledge. Students have to review or rethink about their assignment. Students find out the relationship between seeking information and constructing their knowledge.
4. **Thoughts organized**: Teacher insists students to construct their own knowledge by organizing their ideas. Students are encouraged to share, analyze, and debate about their projects and find out more information.
5. **Idea clarification/looking for something new**: Teacher still continues to keep the students to construct their own knowledge by brainstorming, sorting, making the connection between the prior knowledge and new knowledge. Teacher promotes divergent thinking, imagination and creation of something new, and
6. **Idea tested**: Teacher performs a test or proof of the new invention. Students review the objectives, and consider their works carefully.

Finally students compare the significant positive and negative effect and make a presentation.

How the six steps guided by the neurocognitive and constructionism learning theory?

Constructionism/constructivism ideas (Anderson, 2009; Ackermann, 2004)	**Implication for Education**	**Implication for developed teaching model**
Knowledge is actively created through interaction with sensory experience and is in part to the cultural and educational history of the individual, by relating new information to pre-existing information in memory. Students are active creators of their own knowledge.	The importance of learning environment and experience. Students construct their own understanding in their own ways through experiencing things and reflecting. To do this, they have to ask questions, explore, and assess what they know.	Encouraging students to ask question, do hands-on activities and then reflect on and talk about what they are doing and how their understanding is changing, need to provide activities which engage the mind as well as the hands.
Knowledge construction is mediated through social dialogue whereby linguistic communities, often with a common cultural heritage, share information thus arriving at a consensus explanation of experiences and sensory phenomena. We create knowledge through dialogue and consensus-making. Learning is the effect of interaction with people and environment.	The teacher or other facilitator is essential to enhance passage through a zone of proximal development by engaging the learner in challenging discourse.	“Hands-on. minds-on”; scaffolding; time for discourse.
Percepts are constructed by dynamic interaction between existing knowledge and sensory input. When we meet something new, we have to merge it with our previous ideas and experience, maybe changing what we believe, or may be neglected the new information that unrelated.	The importance of preexisting conceptions in learning.	Make sure that the activities are based on students' preexisting conceptions; let the students to interact with the external meaningful environment, help them to make the connection between pieces of prior knowledge and new learned knowledge to construct their own new knowledge and exchanging their knowledge with others.
We are not merely shaped by our environment, but we are active participants in defining who we are through building explanations of ourselves, our communities and the natural environment surrounding us.	This affirms the capacity of learners to take hold of their own learning, to become self-directive and increasingly mature in their educational development, and to pro-actively develop learning	Active learning

	strategies rather than being passive recipients of information.	
The best way to know whether the students can construct their own knowledge or not is by the active construction of something.	The creation of the product, allows the learner to develop a deeper understanding of the concept being studied.	Have the opportunity to create or construct something.
Using some useful technology in today digital world.	Education in digital world	Provide facility for using internet.

Neurocognitive learning theory (Anderson, 2009; Goswami, 2015).	**Implication for Education**	**Implication for developed teaching model**
Brain plasticity. The brain changes as a result of learning, and remains 'plastic' throughout life.	The brain will learn from every experienced event.	Prepare the appropriate learning environment for experiencing.
The brain will record multiple representations of experience. Learning depends on neural networks distributed across multiple brain regions. The basis of cognition is indeed in sensory-motor learning. Perceptions of sensory input from five senses are formed by prior experiences and modified in relation to prior stored information in long term memory, the brain processes multiple information inputs almost at the same time. Much of the knowledge that we think of as cognitive seems to develop initially via the way that our perceptual systems operate.	The benefits of multi-sensory approaches /multi-sensory media to education.	Use multi-sensory mediaand "hands-on/minds-on" approach Learning by doing and thinking
The affective states influence how the incoming sensory data are perceived and integrated with prior knowledge, the working memory takes the responsibility in doing these processes. Decision making and response patterns are weighed by emotion, the appropriate response is selected and is actualized by	The importance of stress in learning; the importance of affective states in learning; the importance of working memory, attention, and executive function in learning.	Reduce stress in learning. Have to promote the students' affective states for continuing their attention, focus on the appropriate connection between prior knowledge and new knowledge, promote executive function especially working memory for shaping and reworking in relation to prior stored information.

motor pathways. Moderate stress is beneficial for learning, while mild and extreme stress are detrimental to learning.		
Children with poor working memory will struggle to remember the teacher's instructions, and will forget where they are in a piece of work, perhaps continually losing their place. Executive function abilities have important links to success in school. Language plays a key role in cognitive development. Children with good metacognitive skills can improve their own learning and memory, for example by adopting effective cognitive strategies and by being aware of when they don't understand something and seeking more guidance.	The development of working memory and executive functionis important for the development of metacognition and the development of reading and academic progress. The conception of "Learn how to learn"	Try to promote working memory and executive function. Emphasis on reading comprehension and interaction between people.

Relations between Constructionism, neurocognitive learning theory, and the developed teaching steps

The basic stages in all teaching models are at least 3 stages: (i) introduction stage to bring the students to engage in the lesson, (ii) teaching or instruction stage, and (iii) summary and evaluation stage to summarize and examine whether students have learned something or not. In this constructionism and neurocognitive-based teaching modelfor promoting science learning outcomes and creative thinking, we identify the teaching steps in this model into 6 steps. Activities in each step is based on constructionism and neurocognitive science knowledge about learning theory added with promoting students' divergent thing as possible as shown below. For more details please see example of lesson plan in Appendix B.

Developed teaching steps	Constructionism	Neurocognitive
1. **Boost attention**: For bringing thestudents to active engage in the lesson and ask the question about what they want to learn, and for checking students' prior	Appropriate learning environment/ Knowledge isconstructed from own prior knowledge/Students have to ask questions, explore, and assess what they know.	Multi-sensory approach: stimulate every part of the brain; Attention; The affective states /Moderate stress is beneficial for learning, while mild and extreme stress are

knowledge.		detrimental to learning.
2. **Gather information**: Beginning to find information / maybe using internet	The best way to know whether the students can construct their own knowledge or not is by the active construction of something.	The brain will learn from every experienced event. Learning by doing. The importance of working memory, attention, and executive function in learning.
3. **Understanding:** Helps students to construct their own knowledge. Students have to review or rethink about their assignment. Students find out the relationship between seeking information and constructing their knowledge.	The best way to know whether the students can construct their own knowledge or not is by the active construction of something.	Learning by doing and thinking. The importance of working memory, attention, and executive function in learning.
4. **Thoughts organized**: Insists students to construct their own knowledge by organizing their ideas. Students are encouraged to share, analyze, and debate about their projects and find out more information.	Knowledge construction is mediated through social dialogue whereby linguistic communities, often with a common cultural heritage, share information thus arriving at a consensus explanation of experiences and sensory phenomena. We create knowledge through dialogue and consensus-making. Learning is the effect of interaction with people and environment.	Language plays a key role in cognitive development. The importance of working memory, attention, and executive function in learning. Have to promote the students' affective states for continuing their attention, focus on the appropriate connection between prior knowledge and new knowledge, promote executive function especially working memory for shaping and reworking in relation to prior stored information,
5. **Idea clarification and looking for something new**: Continues to keep the students to construct their own knowledge by brainstorming, sorting, making the connection between the prior knowledge and new knowledge, promotes divergent thinking, imagination and creation of something new.		
6. **Idea tested**: Students review the objectives, and consider their works carefully, compare the significant positive and negative effect and make a presentation.	Students have to ask questions, explore, and assess what they know	Successful done made the desirable affective states. Children with good metacognitive skills can improve their own learning and memory.

Appendix B
Compared of grade 11th Lesson plan

Traditional teaching model	The developed teaching model
Topic: Producing nano-products. **Time : 4 hours**	
Main concept Cotton and many types of natural fiber fabrics or fiber textiles have a property of water and liquid absorption. This made our clothing to be easy to wet and the embedded dirty stain fabrics occurs. So nano-technology has been applied in the production of many types of clothing. By mimicking the natural principle of Lotus leaf, using simple manufacturing processes to make the non-wet or waterproofing clothing.	
Learning Outcomes : Students are able to • Describe how to produce nano-technology products. • Design and do an experiment on the topic of properties of nano-fabrics.	
Class management: Learning in small group Asks the students to be grouped in 3-5 persons per group. Each comprised mixed level of achievement ability: weak, medium, and talented students. Each group selects their group leader and group secretary.	
Traditional teaching model **Phase 1: Introduction**	**Developed teaching model** **Step 1: Boost attention**
• The teacher introduced many kinds of fabrics such as cotton, silk, nano-fabrics, etc. • Asks the students to observe and compare these fabrics. (The students may observe the fiber, testing the water absorption, etc.) • Asks the students to record what were observed.	The same as in traditional teaching model *(The purpose of this step is to prepare students to be ready for the new lesson.)*
	Step 2 : Gather information • Students read the Nano-textiles content sheet • Asks the students to search the properties of each type of fabric that observed in step 1 as most properties as they can. Using the learning resources provided including books, media, and internet. *(The purpose of this step is to promote the divergent thinking and practice for searching information via information technology.)*

	Step 3 : Understand • Asks each group sharing their ideas, analyzing about the properties of each type of fabric. • Students conclude the properties of each type of fabric.
Phase 2 : Instruction • **Learning from instructional worksheets** Students read the Nano-textiles content sheet • **Learning by doing the experiment** o Asks each group to do the activities assigned in worksheet 1: cloth that not wet. o Asks the students to discuss for planning and doing their experiment following the worksheet 1. o Each group records data. o Each group analyzes the recorded data, discusses and makes a conclusion. o Each group presents the findings to class. **Worksheet 1: cloth that not wet** **Objectives** • Understand the principle about how to make the not wet clothes. • Know the different types of structures or chemical that can make clothes not wet. • Understand the procedures required in producing fabrics that is not wet. • Understand and can apply the benefit non-wet fabrics. **Content** Some plants' leaves have fat or wax coated their surface. When dropping water on these plants' leaves, water droplets will notbe absorbed but will travel together in the middle of the leaves. If we can coat our clothes with some substances that have the same properties of thin wax, our clothes will not wet. Substances commonly used in coating the fabric for non-wet property are Teflon substance or fluorocarbon and silicone substance. **Materials** 1. Hair dryers. 2. Iron 3. Glass bowl 4. Gloves 5.Cotton (10 cm x 10 cm) 2 pieces 6. Cloth Ironing Board **Chemical Substance** Teflon substance **Methods**. • Put chemical substance into the glass bowl.	**Step 4: Thoughts Organized** • Asks each group to discuss about fabric properties, and give reason for their decision that which type of fabric is the best. • Asks each group to do the activities assigned in worksheet 1: cloth that not wet, (the same as in control group, but let them use less time than the control group since they have to do more activity in worksheet 2 too) *(The purpose of step3 and 4 is to keep the students to construct their own knowledge.)*

- Bring one piece of cotton dipped in chemicals.
- Squeeze, damp
- Use hair dryer to dry that piece of cotton.
- Ironing with medium heat iron over and over several times.

Record

Fabric Type	Characteristics of water droplets.	Characteristics of fabrics
1. Cotton that does not coating.		
2. coating cotton		

Data Analysis and Summary
…………………………………………………...
…………………………………………………..
…………………………………………………..

Phase3 : Conclusion
T: Why the cloth is not wet?
S: It is coated.
T: What kind of substances can use to coat?
S: Wood rubber, Wax,...
T: A substance that they is coated on a fabric has low surface tension than water. So the water droplets on fabric cannot be dissolved. It is often FAT type substance.

Step 5: Idea clarification
T: Why the cloth is not wet?
S: It is coated.
T: What kind of substances can use to coat?
S: Wood rubber, Wax,...
T: A substance that they is coated on a fabric has low surface tension than water. So the water droplets on fabric cannot be dissolved.It is often FAT type substance.
T: I will give you these worksheet 2. You have to brainstorm, share your ideas to plan and do the activities.
(The purpose of step5 is to keep the students to construct their own knowledge. By using the questions and activities to allow the students to share and clarify their ideas. Make the connection between the prior knowledge and new knowledge, and promote the divergent thinking.)

Worksheet 2:
Brainstorm for cloth that not wet
Group …………
Participants

- ………………….
- …………………
- …………………
- …………………
- …………………

List of waterproof substance :

……………………………………….
……………………………………….
The best substance to use for making the cloth that not wet here is ……………….............
Because …………………………….
Testing the idea (you can do this in your science club if necessary)
……………………………………….
……………………………………….
Conclusion
……………………………………….

Step 6: Idea tested and looking for something new

- Each group presents ideas to class.
- Students participate in discussing each group idea.
- The teacher provides information to bring back to develop the further concept. (In this case the teacher asks for coating the fruits skin, and some students think about using the gelatin from fruit yam to coat the fruits skin.)

(The purpose of step 6 is to keep the students to construct their own knowledge. Make the connection between the prior knowledge and new knowledge, andlooking for something new)

4. Instructional Media

i) Nano-textiles content sheet

- Worksheet 1: Cloth that not wet.

Nano-textiles Content sheet

In nature, there are a large number of surfaces that are not wet. The obvious examples are the Lotus leaves and Elephant ear leaves.

		Lotus leaves
		Elephant ear leaves

(Elephant ear is called Bonn in Thai. Its scientific

4. Instructional Media

i) Nano-textiles content sheet
ii) Online computer
iii) Worksheet 1: Cloth that not wet.
iv) Worksheet 2: Brainstorm for cloth that not wet

name is Colocasiaesculenta (L.) Schott)
When dropping water on these plants' leaves, will notbe absorbed but will travel together in the middle of the leaves. When pouring water out, it will be found that these leaves will not get wet at all. This is because there is a type of fat or wax coated outside on the surface of the leaves of these plants. The surface tension of these fat substances is lower than the surface tension of water, so the water drops cannot permeate into these plants' leaves. This property can be applied to everyday products, such as clothing or fiber fabric that protection against water drips or not to absorb liquid. By arranging the structure like water or hydrophobicity of the substance that is coated onto the fabric on the nanometer level, combined with the knowledge about the surface tension of water droplets to protect the water droplets to permeability. So when there are water droplets drip on to the fabric, it will not seep into the fabric. Make the lining or wipe off easily.

Substances commonly used in these processes are Teflon-type substance or fluorocarbon and silicone substance, both have less surface tension than water, and are used in the production of water reflection clothing to date.

5. Measurement and Evaluation

5.1 Observing from students' discussion, how they do experiment, and their communication competency.

5.2 Checking their worksheets

Appendix C: Examples of item in each instrument

Instrument	Example item
Creative Thinking (5 items/50 minutes)	Figure out how to make flyer cotton which has a weight of 1 g going as far as possible. You can use the devices to help (except to move by human-raised). Try to find out the strange and new methods, and as most answers as possible.

	Sample answers: (1) use the mouth blow it, (2) attach to rocks and then throwing, (3) etc.
Nanotechnology content knowledge Test (30 items /40 minutes)	What is the nano ingredient in sunscreens? 1. Calcium carbonate 2. Titanium dioxide 3. Zinc oxide 4. Sulfur dioxide
Scientific attitudes (six traits/25 items/ 10 minutes)	*Curiosity*: I read science magazines. *Reasonableness*: I believe that people's lives are control by fate. *Responsibility and perseverance*: If I am given an easy task, I do it immediately but if the task is very difficult, I will pass it to someone else. *Organisation and carefulness*: I check the apparatus before doing experiment. *Honesty*: Even if my results are not as same as another group, I will not change it. *Open-mindedness*: I am willing to listen to the opinions of others even if they do not agree with mine.
Science process skills (13 skills/45 items/50 minutes)	*Observing:* Sam's home power outage, he lit the candle. Which data is from observing? 1. Candles are made with whale fat. 2. The filling of the candles made from white yarn. 3. Candles are yellow sticks. 4. This candle can be lit about 15 minutes. *Measuring:* If you want 3.0 cubic centimeters of sodium chloride solution, which device is most appropriate? 1. A small test tube 2. A science lab syringe, 5 cubic centimeters. 3. A graduated cylinder, 20 cubic centimeters. 4. A beaker, 25 cubic centimeters. *Using number and calculating:* "There is water in human body, 2/3 of the body weight is water" If Tom has a 42 kg of body weight, how much water in his body? 1. 20 kg 2. 24 kg 3. 28 kg 4. 32 kg *Classifying:* There are six kinds of animals: ant, fish, chicken, shrimp, shellfish, and cat. What is the criteria to classify these six animals into two groups, each group contains three animals? a. Habitats: Land animal and aquatic animal b. Blood Temperature: Warm-blooded animal

(Homoeothermic) and cold blooded animal (poikilothermic)

c. Hair: Animals that have fur and hairless animals
d. Reproduction method: Oviparous animal (animals that lay eggs)and Viviparous animal (animals that give birth to young ones)

Space/space relationship and space/time relationship:

You go to school in the morning, the Sun is in front of you. In the evening when you back home, where is the Sun?

1. Back of you
2. In front of you
3. Left of you
4. Right of you

Communication:

Which form of presentation will make your friends understand the growth of a bird from egg until an adult most clearly?

1. The table
2. The bar chart
3. The cycle chart
4. The picture chart

Inferring:

Consider a glass of fruit juice. Which statement is inferring?

1. Red
2. Soft scent
3. Both sour and candies taste
4. Have a scent and sour taste like Roselle

Predicting:

John collected data from his experiment and found the relationship between the amount of batteries and the extension of the elastic as in Table

Battery (pieces)	elastic’s extension(cm)
2	0.8
4	1.6
6	2.4
8	3.2

If using 9 pieces of battery, what will be the magnitude of elastic’s extension?

1. 3.4 cm.
2. 3.6 cm.
3. 3.8 cm.
4. 4.0 cm.

Controlling variable:

What should be measured if a researcher would like to know whether driving at different speeds would result in different amount of fuel being consumed?

a. time
b. quantity of gasoline
c. distance

d. speed

Formulating hypotheses:

A student used loose soil and clay planting one type of tree by controlling other variables. After one month, it appears that these 2 set of trees have not equal growth. Which statement should be the hypothesis of this experiment?

1. The type of soil affecting the growth of the tree.
2. The quantity of soil affecting the growth of the tree.
3. The amount of water affecting the growth of the tree.
4. The quantity of fertilizer affecting the growth of the tree.

Defining operationally variable:

What is the meaning of "hard water" that can be observed and measured?

1. Consumer water
2. Water that does not have the disease.
3. Water that does not make bubbles with soap.
4. Water that is not suitable for drinking.

Experimenting:

If you want to prepare a solution of concentrated alcohol 60%, 50 cubic centimetres, you will use the devices in each choice.

1. Beaker and test tube
2. Glass measuring cylinder and beaker
3. Dropper and syringe
4. Syringes and test tube

Interpreting data and conclusion:

This table shows the temperature at various locations.

Location	Temperature (oC)
Pattaya	30
Bangkok	33
Pu Shefah	20
DoiIntanont	8

From the table, which is the correct conclusion?

a) The higher location, the lower temperature.
b) The higher location, the higher temperature.
c) Weather in Pattaya is comfortable.
d) At Bangkok, it’s hot and humid