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คณะศึกษาศาสตร์ มหาวิทยาลัยศรีนครินทรวิโรฒ ปีที่ 13 ฉบับที่ 1 มกราคม – มิถุนายน 2562

แนวทางการจัดการเรียนรู้แบบวัฏจักรการเรียนรู้ 7 ขั้น และการนำไปใช้ในการจัดการเรียนรู้ เรื่องความรู้เบื้องต้นของนาโนเทคโนโลยี

อัญชฎา พัวไพบูลย์

โรงเรียนสาธิตมหาวิทยาลัยศรีนครินทรวิโรฒ ปทุมวัน

**Corresponding author e-mail: unchada@satitpatumwan.ac.th*

บทคัดย่อ

การวิจัยครั้งนี้มีจุดมุ่งหมายเพื่อสร้างและพัฒนา แผนการจัดการเรียนรู้ (LPLA) เรื่อง ความรู้เบื้องต้นของนาโนเทคโนโลยี (FKN) โดยทำการวิเคราะห์หาประสิทธิภาพของแผนการจัดการเรียนรู้ แผนจัดการเรียนรู้นี้ถูกสร้างตามการจัดการเรียนรู้แบบวัฏจักรการเรียนรู้ 7 ขั้นของไฮเซนคราฟ (Eisenkraft) และนำไปพัฒนาด้วยการหาประสิทธิภาพของแผนการจัดการเรียนรู้กับนักเรียนชั้นมัธยมศึกษาปีที่5 ของโรงเรียนมัธยมแห่งหนึ่งในภาคตะวันออกของประเทศ หลังจากนั้นนำแผนจัดการเรียนรู้ที่พัฒนาแล้ว นำไปทดลองกับกับนักเรียนชั้นมัธยมศึกษาปีที่5 ของโรงเรียนมัธยมแห่งหนึ่งในภาคกลางประเทศ ทำการเลือกนักเรียน 60 คน จากนักเรียน จำนวน 216 คน แล้วนำมาแบ่งเป็นกลุ่มทดลอง 30 คน และกลุ่มควบคุม 30 คน ด้วยวิธีการจับคู่ (Matching) โดยแต่ละคู่ของนักเรียนกลุ่มทดลอง-กลุ่มควบคุม จะมีคะแนนทดสอบก่อนเรียนเท่ากัน ผลการวิจัยพบว่า ผลสัมฤทธิ์ทางการเรียนหลังเรียนของนักเรียนที่ได้รับการสอนแบบวัฏจักรการเรียนรู้ 7 ขั้น เรื่อง ความรู้เบื้องต้นของนาโนเทคโนโลยี สูงกว่านักเรียนที่ได้รับการสอนแบบปกติ อย่างมีนัยสำคัญทางสถิติที่ระดับ .01 ผลสัมฤทธิ์ทางการเรียนหลังเรียนของนักเรียนที่ได้รับการสอนแบบวัฏจักรการเรียนรู้ 7 ขั้น เรื่อง ความรู้เบื้องต้นของนาโนเทคโนโลยี สูงกว่าก่อนเรียน อย่างมีนัยสำคัญทางสถิติที่ระดับ .01

คำสำคัญ : รูปแบบการสอนแบบ 7 ขั้น, วัฏจักรการเรียนรู้, ทฤษฎีการสร้างสรรค์ความรู้, นาโนเทคโนโลยี

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A 7E LEARNING CYCLE APPROACH AND USABILITY INSTRUCTION OF FUNDAMENTAL KNOWLEDGE ON NANOTECHNOLOGY

Unchada Phuapaiboon

Patumwan Demonstration School Srinakharinwirot University

**Corresponding author e-mail: unchada@satitpatumwan.ac.th*

Abstract

The aims of this research were to develop and construct Fundamental Nanotechnology Knowledge (FKN) lesson plans for learning activities (LPLA) and to analyze the effectiveness of the product, i.e, LPLA. Lesson plans were created using the Eisenkraft 7E learning-cycle and developed together with Grade 11 students at a secondary school in the Eastern Region (E). The lesson plans were then tried on Grade 11 students at a secondary school in the Central Region (M). From a population cohort, of 216 students, 60 students were chosen by random matching to form an experimental group (n = 30) and a control group (n = 30). Students in the control and experimental groups performed similarly in a pre-achievement test. The results showed that the student achievement after participating in the designed LPLA was significantly greater than that of those who studied under the regular lesson plans at the .01 level of significance: post-LPLA scores showed a significant improvement over pre-LPLA scores.

Keywords : 7E Learning Model, Learning Cycle, Constructivism, Nanotechnology

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Introduction

Nanotechnology has become a significant field of research and is having an increasing impact on our daily life. Thus, nanoeducation should be included in our national curricula at the high school level. To facilitate the integration of nanotechnology teaching, we developed and constructed lesson plans for learning activities (LPLA) to teach Fundamental Nanotechnology Knowledge (FKN).

The National Research Council in the United States published two books “How People Learn” (Bransford et al., 1999) and “How Students Learn” (Donovan & Bransford, 2005) that describe how teachers can encourage children to think for themselves and acquire knowledge on any subject. Children follow a step-by-step learning process, studying independently to construct knowledge, and are able to demonstrate understanding of the core concepts of learning materials (Selahattin & Serhat, 2010; Arslan, Geban, & Sağlam, 2015). As a result, learners can transfer their knowledge to more complex materials. DEMİRDAĞ et al. (2011) suggest that the 7E learning cycle approach is an appropriate process to help students to construct knowledge. The 7E learning cycle model extends the 5E learning cycle model by expanding the engagement element into two components (elicit and engage), and expanding the two stages of elaboration and evaluation into three components (elaborate, evaluate, and extend). The elicitation phase intends to investigate prior knowledge and informs teachers of student needs before beginning the lesson. The extension phase encourages learners to transfer and apply knowledge, facilitating more effective learning (Eisenkraft, 2003).

The researcher created LPLA by applying the 7E learning cycle, which is based on Piaget’s cognitive development and constructivism theories. Students undergo intellectual development and are able to apply their newly constructed knowledge to their daily life and to society (Ajaja, 2013). To increase teaching effectiveness, instructors need to develop lesson plans that stimulate and encourage learner thinking processes and enable each child to learn more effectively and truly understand the contents. We compared experimental and control group post-LPLA scores, and we also compared the pre- and post-LPLA scores for the experimental group alone.

Research Objectives

The research questions comprised 2 questions, as follows:

1. Are there differences in post-achievement scores between the experimental and control groups?
2. Are there differences in pre-post achievement scores in the experimental group?

Literature Review

FKN LPLA based on the 7E Learning Cycle Approach

During the early 1960s, Karplus and Their (Deborah & Michele, 2008) applied a three-stage learning cycle to the elementary U.S. science curriculum. These stages were 1. Exploration Phase 2. Concept Introduction Phase and 3. Conception Application Phase.

During the 1980s, the BSCS (Biological Science Curriculum Study) divided the learning cycle model into 5 phases comprising: 1. Engagement phase, 2. Exploration phase, 3. Explanation phase, 4. Expansion, and 5. Evaluation phase (Soomro et al., 2010; Duran et al., 2011; Ergin, 2012).

Eisenkraft expanded the 5E model to a 7E model (Eisenkraft, 2003). The 7E model adds the Elicitation and Extension phases. The 7E learning cycle model phases are thus:

1. Elicitation Phase

During the Elicitation phase, student prior knowledge is investigated. Students with a broad range of experiences are better able to create new knowledge than less experienced ones (Duran et al., 2011). In this phase, the researcher asks questions to elicit student's prior knowledge. The researcher is then able to focus lesson plans on particular areas according to student needs. For example, the 7E learning cycle LPLA might emphasize Unit 2 Nanoscale and Structure of Materials, including 2.1 nanoscale and dimensional systems 2.2 properties and structure of materials, and 2.3 nanomaterials in nature. Students were asked to respond to various questions, as follows:

1.1 To investigate their imagination and sense of scale, students were asked to describe the size of real objects on various scales. Students were provided many examples of distance or material dimensions on 1 nm, 1 μm, 1 mm, 1 cm, 1 m, 10 m, 100 m, 1 km, 10 km, 100 km, and 1000 km scales.

1.2 To investigate student knowledge and awareness of different dimension systems, students were asked to answer the question, "How many dimensional systems are there in a rectangular box, in a square paper sheet, and in a dot?"

1.3 To investigate student knowledge about the properties and structures of materials, students were asked to answer the questions, "In your considered opinion, does gold in a gold nugget and gold powder have same properties?" and "Why does a water droplet not adhere to the surface of the lotus leaf?"

2. Engagement Phase

The aim of the Engagement phase is to introduce students to the subject matter by capturing their attention and form links to prior learning. This approach motivates students to think about the learning material and form questions by themselves. In this way, students are able to identify which topics to study. In the event that the topics that students are interested in do not coincide with lesson objectives, the teacher helps the students by providing appropriate examples and thus stimulates student thinking. The teacher may also show instructional media to facilitate student construction of new knowledge. During this stage, the researcher motivates student thinking towards the construction of topics for discussion related to the lesson objectives, e.g., materials covered by the LPLA (7E) for Unit 2.

2.1 To motivate students to think about nanoscale materials, students were asked to measure objects using scales that are orders of magnitude bank of the objectives' size, such as measuring a hair using a meter rule.

2.2 Students observed the dissolution of the salt samples and noted the difference in dissolution rates by placing two grams of salt and two salt tablets weighing two grams into separate 50 cm^3 beakers and added 50 cm^3 water and stirred for 30 s.

2.3 To motivate students to learn about the property and structure of materials: Students watched a video on nanomaterials to see that a nanofiber is the strongest solid (1.55 min) and a nano-boat is lightest (2.42 min).

2.4 To inform students about nanoscale in nature: Students watched a video: Properties of the lotus leaf (2.41 min).

3. Exploration Phase

During the exploration phase, students collect general information about materials by searching for documents and information from the Internet, and perform experiments to collect additional data. The researcher applies the following procedure:

3.1 Students were divided into mixed-ability groups, with five participants per group.

3.2 Participants listened to a statement on learning outcomes and learning matters.

3.3 Each group chose a topic of interest, created a plan of study, and began collecting data.

4. Explanation Phase

During the explanation phase, experimental data, interpretation, analysis, and conclusion are presented in various ways such as by verbal description or by construction of tables, drawings or physical models.

Students then present their finished work to other groups in class. The researcher applies the following procedure:

4.1 Students carried out exploratory research during the exploration phase to plan and prepare presentations.

4.2 Students made presentations to their peers by employing many means such as mind maps, tables, drawings, and so on.

5. Elaboration Phase

The Elaboration Phase involves applying and manipulating prior knowledge acquired during the Exploration phase to the Explanation phase to draw conclusions and describe situations or phenomena, thus creating new knowledge. The researcher uses the following procedure to provide examples based on the Unit 2 (7E) LPLA.

5.1 Students examined the picture of an object and identified the object's size by comparing with scales that ranged from 0.1 nm to 100 µm.

5.2 Students watched a video entitled “How small is nano?” (2.52 min)

5.3 Students were provided with examples of materials or length scales for comparison while multiplying with increasing orders of magnitude, such as ten times, one hundred times, one thousand times, ten thousand times, one hundred thousand times, one million times, ten million times, one hundred million times and one billion times.

5.4 Students created more knowledge by studying additional learning materials.

6. Evaluation Phase

This phase focuses on the assessment of student learning achievement and to what extent learning outcomes are met. The researcher assesses students by the following procedure:

6.1 Behavior assessment of working groups by looking for evidence of planning, participation, leadership, group roles, and presentation activities.

6.2 Students were assessed using worksheets and, by the end of the course, tests.

6.3 Students were questioned verbally.

7. Extension Phase

During this stage, the teacher creates opportunities for students to apply their new skills and knowledge. During this these activities students undergo "transfer of knowledge": students are better able to apply their new learning to new areas and to apply their newly gained understanding to their daily lives.

Constructivism under the 7E Learning Model

An important aspect of learning management is to provide an environment conducive to student learning. Teachers must identify clear learning outcomes and organize appropriate learning activities to guide students through the learning process. These aspects of learning management have a significant impact on student achievement (Schlenker, Blake & Mecca, 2007; Siribunnam & Tayraukham, 2009).

The learning cycle is a model of an inquiry method (Bell & Odom, 2012; Piyayodilokchai et al., 2013; SEVER & GÜVEN, 2015) that requires scientific process skills, to discover knowledge or experience in a self-directed manner (Piyayodilokchai et al., 2011; Pearce et al., 2013). Piaget believed that the child would develop ideas into a hierarchy by interaction with the environment and experience of applying logical thinking strategies (Kowasupat et al., 2012; McCloughlin, 2014) by learning through doing and active exploration (Demirbaş, 2014).

Under the 7E learning cycle, teachers determine student prior knowledge to understand the extent of their fundamental knowledge and thereby plan appropriate learning activities. With these activities in place, students are able to gain the necessary experiences and be able to transfer and construct new knowledge, thereby extending the range of their fundamental knowledge (Duran et al., 2011). This is consistent with the theory of constructivism, which assumes that learners need to possess relevant knowledge before they can gain new learning (Selahattin & Serhat, 2010; Demirbaş & Pektaş, 2015). Learning in self-directed activities students build upon prior knowledge: by constructing new knowledge and are able to transfer information to other areas of their lives (Lamanauskas, 2012). Omission of this stage will result in difficulties in developing new concepts, and so learning outcomes will not meet the learning objectives. Selahattin GÖNEN et al. concluded that constructivist learning renovates cognition and improves conceptualization skills (GÖNEN, KOCAKAYA & İNAN, 2006). Moreover, the learning cycle is a child-centered learning strategy (Uzuntiryaki et al., 2010) that facilitates construction of new knowledge and allows students to evaluate their own learning.

Methodology

1. Instrumentation

The instruments applied to this research comprised:

1.1 Five FKN lesson plans based on the 7E learning cycle and five regular lesson plans.

1.2 An achievement test comprising 20 multiple-choice questions constructed by the researcher. Each of the five FKN lesson plans was represented by four test questions (see assessments).

1.3 A student satisfaction test based on the 7E learning cycle activities comprising 20 items. (see assessments)

The unit lesson plan comprises five units: Unit 1 The Role and Importance of Nanotechnology encompassing: 1.1 a definition of nanotechnology; 1.2 a history of nanotechnology; 1.3 the importance of nanotechnology. Unit 2 Nanoscale and Structure of Materials encompassing: 2.1 nanoscale and dimensional systems; 2.2 properties and structures of materials; 2.3 nanomaterials in nature. Unit 3 Scanning Tunneling Microscopy (STM) encompassing: 3.1 the invention of STM; 3.2 the principle of scanning probe operation; 3.3 atom manipulation. Unit 4 Atomic Force Microscopy (AFM) encompassing: 4.1 the principles of AFM; 4.2 operating modes of AFM; 4.3 applying Hooke's law to AFM. Unit 5 Nanofabrication encompassing: 5.1 nanofabrication process; 5.2 production of nanoproducts; 5.3 influence of nanotechnology on current technologies.

Each learning activity lesson plan (5 lesson plans) and each regular lesson plan (5 lesson plans) comprises: 1. lesson plan title, 2. learning standards, 3. key concepts, 4. learning outcomes, 5. learning materials, 6. learning process, 7. media and learning resources, 8. measurement and evaluation, and 9. post-learning comments or recordings. The details of items 1-5 and 7 are the same, but the details of items 6 and 8-9 differ. Three nanoeducation research experts and two experts in the educational field examined the five regular lesson plans. The revised lesson plans were applied to a class of 30 Grade 11 students at the secondary school in the East Region. Students sat for an achievement test one week after instruction. Scores were analyzed by applying a difficulty index (p), discriminant index (r), and a reliability test (Cronbach alpha coefficient). (see assessments)

The five 7E lesson plans were examined by three research experts in nanoeducation and two experts in the education field. The revised lesson plans were applied to three students, and then the five revised lesson plans were applied to a class of 30 grade 11 students at school E. Thirty students (6 groups) participated in the satisfaction test after completing the teaching program (see assessments). Selected worksheet scores, behavior scores, and achievement scores for 2 groups (10 students) selected from the 6 group cohort were analyzed for effectiveness of the lesson plan (see assessments).

2. The Instructional Program

2.1 There were 216 students, at Grade 11 students at a secondary school in the Central Region were participated in an achievement test two weeks before beginning learning activities.

2.2 Achievement scores were ranked in a descending order.

2.3 Of the 216 students, 60 were divided into two groups (a control group and an experimental group) by random matching.

2.4 The control group and the experimental group attained similar scores in a pre-achievement test, and were selected by comparing student achievements between the experimental and control groups.

2.5 Nine students (3 high performing, 3 moderately performing and 3 poorly performing) were selected from the experimental group for interview on nanotechnology before commencing the teaching program.

2.6 The experimental group was divided into 6 sub-groups and these learners participated in the 7E learning cycle learning activities detailed in the five FKN lesson plans over 10 class periods.

2.7 Six sub-groups were formed from the control group of thirty students. These groups participated in the five regular FKN learning activities based on regular lesson plans over ten class periods.

2.8 After the experimental group completed their learning activities, they took a satisfaction test based on the learning activities provided by the 7E learning cycle approach.

2.9 Students from the pre-interview group underwent a semi-structured interview on their prior knowledge on nanotechnology. Each interview lasted approximately 15 minutes.

2.10 The experimental and control groups completed learning activities over one week, and achievement tests were taken by both student groups.

3. Participants

A student cohort was drawn from Grade 11 of the secondary school, a total of 216 students, from school M. Our study groups comprised 60 students, and were divided equally into a control group and an experimental group by Random Matching. The control and experimental group members attained similar scores in a pre-achievement test, and were paired by comparison between the experimental group (studying under the 7E learning cycle with LPLA provision) and the control group studying with the regular lesson plan.

4. Assessments

The pre-achievement tests for both the control and experimental groups were applied two weeks before teaching commenced, and the post-teaching tests (with the same but reshuffled options and questions) were applied one week after the teaching-learning process was completed. The satisfaction test was carried out after the experimental group had completed learning activities under the 7E learning cycle. Nine students from the experimental group were interviewed separately two weeks before and 1-2 weeks after instruction.

The achievement and satisfaction tests were both constructed by the principal researcher, and then examined by three research experts in nanoeducation and two experts in the education field. The questions in the achievement test and satisfaction test were validated by applying the Index of Item Objective Congruence (IOC) technique. The average scores of all items ranged from 0.5 to 1.00.

The achievement test consisted of 20 multiple choice questions (each having 4 options) with four questions for each of the five lesson plans, and was taken by 30 students (studying under the regular lesson plans) at school E. The scores were analyzed by difficulty index (p), discriminant index (r) and reliability (Cronbach alpha coefficient). The average scores of all difficulty indexes ranged from 0.43 to 0.77, the discriminant index started at a value of 0.2, and the Cronbach reliability was .828.

The satisfaction test consisted of 30 items with each item scored on a 5-point Likert Scale. Positively worded items were scored on a response scale: strongly agree 5, agree 4, undecided 3, disagree 2, and strongly disagree 1, while negatively worded items were scored in the reverse order. The satisfaction test was carried out on 30 students (studying under the 7E learning cycle with LPLA provision), at school E. Items were analyzed by determining the Simple Correlation Coefficient between item scores with the total score for all items. A selection of 20 items with the discrimination item (r_{xy}) ranging from 0.337 to 0.617 was analyzed by the Cronbach reliability test (.877).

The 7E learning cycle LPLA consisted of five lesson plans resulting in knowledge worksheets constructed by researcher and examined by the same three research experts. The five lesson plans, and the knowledge worksheets were presented to 3 students (room 5/2) at school E, reviewed and subsequently improved upon. The improved lesson plans were given to 30 students (room 5/1), and 10 of these students were selected for analysis of the effectiveness of LPLA. The effectiveness of lesson plan (E_1/ E_2) was determined to be 83.00 / 82.00.

An evaluation form for group-behavior was constructed by researchers and examined by the same three researcher experts. The group-behavior evaluation form was used to analyze the behavioral characteristics of 30 students (six student groups) during their study under the 7E learning cycle LPLA at school E and school M.

The participants in each of the six experimental sub-groups were selected (9 students) by purposive sampling. Students were subjected to semi-structured interviews to investigate prior knowledge before and after studying. Each pre-post interview (10 items) lasted an average of 15 minutes. Interview items concerned fundamental knowledge of nanotechnology. Examples of the questions are: "What do you think of nanotechnology?" "How does nanotechnology provide advantages or disadvantages in daily life? "How does Atomic Force Microscopy benefit scientific progress?"

5. Data Analysis

The research employed an experimental design based on randomized pretest-posttest methods. The experimental group and control group were selected by randomized matching. Analyses of achievement scores compared experimental and control group achievements both before and after the experiment. Pretest-posttest scores of the experimental and control groups were analyzed to determine an effectiveness index of the learning activity lesson plans. Experimental group satisfaction scores for learning activities were used to determine mean scores and standard deviation. Student responses were based on a 5-point Likert Scale for each item on the satisfaction strength/direction to indicate the degree of highest satisfaction to lowest satisfaction for each statement. Moreover, the 7E learning cycle LPLA was evaluated for effectiveness (E_1/ E_2) for 30 students at school M.

Results

The effectiveness (E_1/ E_2) of the 7E learning cycle LPLA for the experimental group (30 persons) is shown in Table 1**.** The table shows the efficiency (E_1) of 83.17 and the efficiency (E_2) is 80.00.

Table 1 *The effectiveness of LPLA provision via 7E learning cycle*

E_1		E_2	
Total worksheet scores	*2,468*	*Total achievement scores*	*480*
Total group behavior scores	*1,524*		
83.17		*80.00*	

The evaluation scores obtained from the satisfaction evaluation of student learning activities are shown in Table 2**.**

***Table 2** Mean, standard deviation, and satisfaction of 7E learning cycle of student responses to the learning activities*

Items of learning activities via 7E learning cycle	$\bar{X}$	*S*	*Satisfaction score*
Learning activities helping understanding of the material	*4.57*	*.63*	*strongly agree*
Learning activities promoting learning of the students	*4.53*	*.63*	*strongly agree*
Activities enabling learning the skills to follow the scientific process	*4.20*	*.55*	*Agree*
Activities in the curriculum being conducive to boredom [a]	*4.23*	*.50*	*Agree*
Learning activities stimulating students to cooperate learning	*4.10*	*.80*	*Agree*
Learning activities stimulating students to explore during learning	*4.20*	*.66*	*Agree*
Learning activities being not suitable for the students [a]	*4.23*	*.67*	*Agree*
Learning activities being congruent with learning outcomes	*4.20*	*.48*	*Agree*
Learning activities being appropriate to the subject matter	*4.13*	*.68*	*Agree*
Learning activities being a time wasting components for learning [a]	*4.00*	*.91*	*Agree*
Elicitation phase stimulating students to have confidence in ability to learn	*4.67*	*.547*	*strongly agree*
Activities in the learning activities being arranged in good sequence	*4.07*	*.58*	*Agree*
Instructor refraining from giving more knowledge to students [a]	*4.13*	*.90*	*Agree*
Students actively participating in the exploration and finding information	*4.13*	*.68*	*Agree*
Students active by involving in planning the presentation	*4.53*	*.68*	*strongly agree*

Note: [a] *Items are reverse-scored.*

***Table 2** Mean, standard deviation, and satisfaction of 7E learning cycle of student responses to the learning activities*

Items of learning activities via 7E learning cycle	$\bar{X}$	*S*	*Satisfaction score*
Exchanges of experiences with different groups making better understanding of contents	*4.57*	*.68*	*strongly agree*
Students actively involving in the use of media and learning resources	*4.13*	*.78*	*Agree*
Students being satisfied with a variety of evaluations methods	*4.20*	*.66*	*Agree*
Time in learning activities being appropriate	*4.16*	*.59*	*Agree*
Students being unable to apply knowledge [a]	*4.23*	*.86*	*Agree*

Note: [a] *Items are reverse-scored.*

Table 2 reveals that students were satisfied with the 7E learning cycle learning activities, strongly agreeing with 5 items and agreeing with15 items. The elicitation phase enhanced student confidence in the learning, and students attained the highest average score of 4.67 points. Learning activities helping understanding of the material and exchanges of experiences with different groups to create better understanding of contents had the second highest average score of 4.57 points. Learning activities to promote learning of the students and student involvement in planning presentations gained the third highest average score of 4.53 points. The learning activities reducing a time taken to learn showed the maximal score distribution, with a standard deviation of .91.

The analyses of achievement scores for before and after the experiment for both experimental and control group effectiveness index of lesson plan of learning activities scores are set out in Table 3**.**

Table 3 *Comparison of LPLA effectiveness index between the experimental and control groups*					
Group of student	*Students*	*Scores*	*Total scores*		*Effectiveness index*
			before	*after*	
Experimental	*30*	*20*	*229*	*480*	*0.6765*
Control	*30*	*20*	*229*	*359*	*0.3504*

Table 3 shows that the experimental group had an effectiveness index 0.6765, demonstrating that 67.35 percent of students progressed during the study. The control group had an effectiveness index of 0.3504, suggesting that only 35.04 per percent of control group students progressed during the study.

Post-achievement scores of the experimental and control groups were analyzed by t-test: Independent Samples assume that $\sigma_1^2 \neq \sigma_2^2$ (Equal variances not assumed) and results are set out in Table 4**.**

Table 4 *Post-achievement scores in the experimental and control groups*					
Group of student	*n*	$\overline{X}$	*S*	*t*	*Sig.(2-tail)*
experimental[a]	*30*	*16.00*	*1.819*	*4.481**	*.000*
control[b]	*30*	*11.97*	*4.582*		

** Statistically significant level. 01.*

Calculations based on statistical methods reveal that t was equal to 4.481 and Sig. (2-tail) was equal to .000. When we divided a Sig. (2-tail) result by 2 (the hypothesis is one-tailed test), we found that the Sig. (2-tail) is equal to .000, which was less than .01 ($\alpha = .01$). Thus, t had a calculated statistical significance of .01. We concluded that the experimental group students exhibited greater achievement than students in the control group, with a statistical significance at the level of .01.

Table 5 *Pre-post achievement scores in the experimental group*				
experimental group	*N*	$\overline{X}$	*S*	*t*
Pre-achievement test	*30*	*7.20*	*2.124*	*-14.537*
Post-achievement test	*30*	*16.00*	*1.819*	

$t_{(.01,\ df29)} = 2.462$ ** statistical significance level = . 01*

Calculation with statistical methods showed that t was equal to 14.537 (considering only positive values), greater than the table value of t at $t_{(.01,\ df29)}$ which was equal to 2.462. Thus, the experimental group post-achievement showed a greater score compared with the pre-achievement test, with a statistical significance of .01. The mean scores of post-test were greater than those of the pretest.

Discussion and Conclusion

Our experimental group gained a great deal as shown by the effectiveness of learning activities designed according to the 7E cycle. Students studying under this plan exhibit better academic performance than the control group do, with a greater average post-test scores (Table 4), and achieve a greater effectiveness index. The first step in the 7E learning cycle is to examine student prior knowledge to allow teacher to rectify students' conceptual errors early in the learning process, and to enable them to create new knowledge from combining existing knowledge with new experiences. Omission of this stage would make it difficult for students to develop new concepts. This first step also gives students the opportunity to prepare themselves for material in the new lesson. This approach is validated by the performance results shown in table 2. Satisfaction assessments reveal that a high average score in the elicitation phase stimulates student confidence in learning. In later stages, teachers stimulate student engagement by employing several activities, such as answering questions, watching videos, interpreting pictures, and using devices that promote student curiosity. To meet the learning needs of students, teacher must provide activities for students in the exploration phase. Students participate in learning and planning during group activities to exchange ideas with the aim of verifying the accuracy and completeness of information and knowledge gained in each group member then conclude an activity by using mind mapping. During the explanation phase, student groups share their experiences with other groups by presenting the mind-map to the class, in order to enhance understanding. During the elaboration phase, students associate knowledge acquired during group-work with knowledge gained in the exploration phase or with knowledge gained from searching by themselves. Students practice the development of ideas and solutions. During the evaluation phase, teacher can assess students' knowledge using work sheet instruments and by observing group behavior. In the extension phase, students apply their new knowledge to transfer to other situations. This is consistent with the research of GÜRBÜZ, Fatih; TURGUT, Ümit; SALAR, Rıza (2013) that shows the 7E learning model can increase student engagement and provide meaningful learning.

The experimental group post-study scores showed improvements over their pre-study scores because the learning activities via 7E cycle support student learning and students have to practice their science process skills in their quest for knowledge discovery, experience, and self-learning. As a result, students learned effective active-learning methods process and achieve greater academic scores. This is consistent with the results of student interviews (3 high-performing students, 3 moderately-performing students and 3 poorly-performing students) comprising 10 questions on nanotechnology before and after participation in the study. Students in the experimental group demonstrated their ability to transfer and apply knowledge gained to create new knowledge.

Recommendation

The nanotechnology is a widely recognized subject for 21 st century science and technology. The subject has not been included in the core curriculum of the basic education; therefore, the content of the Fundamental Nanotechnology Knowledge, developed by the researcher while studied the Doctor of Philosophy in the field, is essentially recommended. The content is suitably adapted for teaching in the level of the secondary school. For schools without nanotechnology courses, teachers may provide the subject as a free elective for students who want to explore the new technology. A normal learning plan is initially suggested for teaching methods. As teachers feel more confident in teaching the subject, they can rearrange the learning and teaching of the subject in the school curriculum by using a lesson plan for 7E learning cycle.

In addition, teachers should study and conduct the research on an appropriate learning management model for their students.

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