

ENHANCING CREATIVE PRODUCTIVITY BY USING 4E-C LEARNING MODEL
FOR SCIENTIFICALLY GIFTED AND TALENTED STUDENTS

A DISSERTATION
BY
SUMALEE WAIYAROD

Presented in Partial Fulfillment of the Requirements for the
Doctor of Education Degree in Science Education
at Srinakharinwirot University
October 2007
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SUMALEE WAIYAROD. (2005). *Enhancing Creative Productivity by Using 4E-C Learning Model for Scientifically Gifted and Talented Students*. Dissertation, Ed.D (Science Education). Bangkok : Graduate School, Srinakharinwirot University. Advisor Committee: Assoc.Prof.Dr. Sunee Haemaprasith, Assoc.Prof.Dr.Nason Phonpoke, Assoc.Prof. Chusri Wongrattana.

This study was aimed at enhancing creative productivity for scientifically gifted and talented (G/T) students by using 4E-C learning model developed by the researcher. This new learning model was based on the three-ring conception of giftedness, enrichment triad model, the 5-E instructional model, and modeling method. It consists of 4 phases: encouraging issues, experiments for modeling, creation of new model, and exhibition. Its activities focus on creating new physics models out of the students' own interest and reading of contemporary physics journals. Students also have opportunities to present their creative products in order to improve their communication skills. In this study, the 4E-C learning model was used to teach 22 scientifically G/T students who took an elective physics course, Energy in Daily Life, for 40 periods in the first semester of 2007 at Mahidol Wittayanusorn School (Public Organization).

The results of this study indicated that after scientifically G/T students had learned through, the 4E-C learning model, their creative productivity and attitudes toward physics were significantly higher at the .01 level. The students could creatively reflect their learning. The students had positive opinions on the 4E-C learning model. The students thought that learning activities were very interesting. It allowed them to create their own products. Moreover, the teachers participating in this study had positive opinions on this learning model. They thought that it was student-centered approach. The students could fulfill their high potential, especially their creative productivity, by using this model.

การส่งเสริมการสร้างผลงานอย่างสร้างสรรค์โดยใช้รูปแบบการเรียนรู้แบบ 4E-C
สำหรับนักเรียนที่มีความสามารถพิเศษด้านวิทยาศาสตร์

บทคัดย่อ
ของ
สุมาลี ไวยโรจน์

เสนอต่อบัณฑิตวิทยาลัย มหาวิทยาลัยศรีนครินทรวิโรฒ เพื่อเป็นส่วนหนึ่งของการศึกษา
ตามหลักสูตรปริญญาการศึกษาคุณวุฒิปบัณฑิต สาขาวิชาวิทยาศาสตร์ศึกษา
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การวิจัยนี้มีจุดมุ่งหมายเพื่อส่งเสริมการสร้างผลงานอย่างสร้างสรรค์สำหรับนักเรียนที่มีความสามารถพิเศษด้านวิทยาศาสตร์โดยใช้รูปแบบการเรียนรู้แบบ 4E-C ที่ผู้วิจัยได้พัฒนาขึ้น ซึ่งรูปแบบการเรียนนี้มีพื้นฐานมาจากทฤษฎีสามห่วงของเรนชูลี รูปแบบการจัดการเรียนรู้แบบเพิ่มพูนประสบการณ์ รูปแบบการเรียนรู้แบบ 5E และวิธีการสอนแบบการสร้างแบบจำลอง โดยรูปแบบการเรียนรู้แบบ 4E-C ประกอบด้วยการเรียนรู้ 4 ขั้นตอน ได้แก่ ขั้นส่งเสริมด้วยประเด็นปัญหา ขั้นทำการทดลองเพื่อสร้างแบบจำลอง ขั้นการสร้างแบบจำลองใหม่ และขั้นการแสดงผลงาน กิจกรรมที่อยู่ในรูปแบบการเรียนรู้แบบ 4E-C จะเน้นไปที่การสร้างแบบจำลองทางฟิสิกส์ขึ้นมาใหม่ในเรื่องที่นักเรียนมีความสนใจที่เกี่ยวข้องกับพลังงานในชีวิตประจำวัน ที่มาจากการอ่านวารสารทางฟิสิกส์ที่เป็นประเด็นปัญหาในปัจจุบัน นอกจากนี้นักเรียนจะได้นำเสนอผลงานที่สร้างสรรค์ของตนเอง เพื่อพัฒนาทักษะการสื่อสาร โดยในการวิจัยได้ใช้รูปแบบการเรียนรู้แบบ 4E-C ในการจัดการเรียนการสอน สำหรับรายวิชาฟิสิกส์เพิ่มเติม พลังงานกับชีวิตประจำวัน จำนวน 40 คาบเรียน ในภาคเรียนที่ 1 ปีการศึกษา 2550 สำหรับนักเรียน ระดับชั้นมัธยมศึกษาปีที่ 4 ที่มีความสามารถพิเศษด้านวิทยาศาสตร์จำนวน 22 คน ที่โรงเรียนมหิดลวิทยานุสรณ์ โรงเรียนวิทยาศาสตร์ของรัฐ

ผลการวิจัยพบว่า นักเรียนมีคะแนนการสร้างผลงานอย่างสร้างสรรค์และเจตคติต่อฟิสิกส์สูงขึ้นอย่างมีนัยสำคัญที่ระดับ .01 นักเรียนสามารถสะท้อนการเรียนรู้ได้อย่างสร้างสรรค์ และมีความคิดเห็นเชิงบวกต่อรูปแบบการเรียนรู้แบบ 4E-C นักเรียนแสดงความคิดเห็นว่ากิจกรรมการเรียนการสอนของรูปแบบการเรียนรู้แบบ 4E-C มีความน่าสนใจมาก เปิดโอกาสให้นักเรียนได้สร้างผลงานของตัวเอง สำหรับครูที่สอนโดยใช้รูปแบบการเรียนรู้แบบ 4E-C แสดงความคิดเห็นเชิงบวกโดยมีความคิดเห็นว่ารูปแบบการเรียนรู้แบบ 4E-C นี้เป็นการจัดการเรียนรู้ที่เน้นผู้เรียนเป็นสำคัญ และช่วยเติมเต็มศักยภาพของนักเรียน โดยเฉพาะอย่างยิ่งศักยภาพในการสร้างผลงานอย่างสร้างสรรค์

The dissertation titled
“Enhancing Creative Productivity by Using 4E-C Learning Model
for Scientifically Gifted and Talented Students”

by
Sumalee Waiyarod

has been approved by the Graduate School as partial fulfillment of the requirement for the
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CHAPTER 1

INTRODUCTION

Background

Thailand's National Education Act of 1999 recognizes the rights of high ability students and firmly declares to develop these students to their fullest potential. Schools are required to provide an equal educational opportunity for all gifted and talented (G/T) students to develop them to their potential. This means it allows G/T students the right to educational experiences appropriate to their level of development. For truly equal opportunity, a variety of learning experiences must be made available, at all levels, so that all children can develop their special skills and abilities to the utmost. All students have individual learning styles, interests, motivations, career goals, development levels, and socio-cultural conditions. So a school needs to several programs that respond to the students' needs. In Thailand most of the research work on G/T students was carried out on primary school teaching, but significantly less at the secondary school level. There were even fewer research studies on the teaching of science to G/T students. However, the important problem is that teachers do not have a good understanding about the design of teaching and learning strategies for nurturing G/T students.

G/T students have many high level abilities, so that it is difficult to provide a suitable education for them. The theory that is most important when talking about creative gifted person is Renzulli's the three-ring conception of giftedness (Sternberg; & Davidson. 2005: 53-92; citing Renzulli. 1986). This theory attempts to portray the main dimensions of human potential for creative productivity that is above average ability, task commitment, and creativity. This theory believes that those who are creative gifted persons have to have those three traits. Moreover, Howard Gardner (Gary; & Sylvia. 1998: 21) introduced a seven-part conception of intelligence which has become known as the theory of multiple intelligences. Many educators see Gardner's seven intelligences as seven types of intellectual giftedness. Any one person may be gifted in one or several areas. The seven areas of intelligence are linguistic, logical-mathematical, spatial, musical, bodily-kinesthetic, interpersonal, and intrapersonal intelligence. The areas that should be developed are logical-mathematical and spatial intelligence because they are involved in learning of science and technology which have a very important role for the present

and future world. Especially in the developing countries such as Thailand, we need scientists or specialists in technology to help our society. One of the interesting issues in science education that was presented at the annual meeting of National Association for Research in Science Teaching (NARST) Philadelphia, PA (NARST. 2003: Abstract), mentioned that physics was the least enrolled course in United states high school science. Also, in Thailand physics enrollment is still a problem. Therefore, this is an important field that is still troubled with many issues. Physics teachers still teach physics through rote-memory and lecturing. Laboratory and students' products that enhance thinking skills of students are the least emphasized.

Today there are programs and strategies for nurturing giftedness and talents in science. Patricia and Miller (Patricia; & Miller. 2000: Abstract) surveyed the practices of teachers of G/T students and found that there are many teaching models for their students. The survey showed that Bloom's Taxonomy of Educational Objectives was used by most teachers, the second most used was Renzulli's Enrichment Triad, the third was Parnes' Creative Problem Solving, and the fourth was Taylor's Multiple Talents. For innovative programs, Nina Buchanan and Bill Woerner (Buchanan; & Woerner. 2002: Abstract) indicated that in the past the comprehensive high school model worked well for many G/T and other students. They examined 5 high schools that successfully met the needs of G/T students through innovative curricular programs, which featured small learning communities and supportive structures such as small advisory groups, real world connections, authentic assessment, and teachers who facilitate learning. Schools and teachers should understand about what feature programs are available and develop program models or strategies that depend on the context of their school and students. The Center for Gifted Education at the College of William and Mary (Van-Tassel-Baska. 1998:6) has, in the past six years, spent considerable time addressing issues of appropriate science curriculum and instruction for high ability students. They found that one of the important components is the emphasis on inquiry. The more students can construct their understanding about science for themselves, the better able they will be to encounter new situations and apply the appropriate scientific processes to them. There are instructional models that are based on inquiry method or learning cycle. One of those important instructional models that are useful for physics instruction is modeling method or modeling cycle. Malcolm Wells and David Hestenes (Wells; & Hestenes. 1995: Abstract) showed that this model helped students to construct and use scientific models to describe, explain, predict, and control physical phenomena. Also, the modeling method can produce much larger gains in student understanding than alternative methods of instruction.

Recently, Carolyn R.Cooper, Susan M.Baum; & Terry W.Neu (Cooper; Baum; & Neu. 2004: Abstract) presented a model of talent development titled Project High Hopes. It is highly successful in identifying and developing scientific talent in G/T students. The factor that contributed to the success of the model was that the emphasis was on helping students become creative producers. The model also featured a strong mentoring component that included role-modeling and problem solving within specific scientific domains and provided students with authentic, discovery-based, experiential, and advanced level subject matter of the domain. Finally, the alternative means of assessing student achievement focused on a student's performance and the product he or she created rather than on test scores. These performances resulted in the students' shifting their identity from loser to winner.

Moreover, Newman, Jane L. (Newman. 2004: Abstract) examined a set of lessons in integration of the Talent Unlimited Model with 10 steps for completing a Type III activity, small group investigation of real problem. This study is to determine the effects of these lessons on the quality of students' creative products and on the number of students who completed their products. The result of this study indicates that following this model helps students complete their products. For the Type III activity, students are set in small groups to do project and work in areas of study and problems that are personally relevant.

These programs work well for G/T students in elementary school. However, for secondary school, the programs should be adapted, especially for scientifically G/T students.

Therefore, the purpose of this research is to develop the new learning model to enhance creative productivity in scientifically G/T students by using content of physics of energy and life. Because this content can obviously show students how physics can be involved in their real life and nowadays it is a concerned problem. Moreover, students can understand and help our country searching renewable energy in the future.

This new learning model is based on the three-ring conception of giftedness, enrichment triad model, modeling method, and the 5-E instructional model. This model is called, for convenience, the 4E-C learning model. 4E-C stands for names of 4 phases that are Encouraging issues, Experiment to model, Creation of new models, and Exhibition. And there is "Evaluation" for every phase in the model. All phases motivate G/T students, enhance them how to create new models, especially in context of energy, and give G/T students an opportunity to present their product in a real exhibition. This learning model also guides the teachers as well as the schools or organizations that are involved in gifted education to help

G/T students to improve not only their creative productivity, but also to prepare them to become a scientist or a specialist in the future.

Research objectives

This study was designed to enhance creative productivity in scientifically G/T students by using the 4E-C learning model that was developed by the researcher. The objectives of this study are:

1. To develop and implement a learning model, the 4E-C learning model, for enhancing creative productivity of scientifically G/T students
2. To study the results of implementing the 4E-C learning model on students' creative productivity.
3. To study the results of implementing the 4E-C learning model on students' attitude toward physics.
4. To determine students' learning reflection from learning activity of the 4E-C learning model.
5. To determine students' opinions on the 4E-C learning model.
6. To determine teachers' opinions on the 4E-C learning model.

Significance of the Study

The researcher developed the new learning model that enhanced creative productivity for scientifically G/T students in order to apply creative productivity and knowledge to real life. Moreover, they were able to conduct original product that was basic to creating innovation in the future and become a creative producer. All of these are very useful for science and technology as a whole.

In addition, their learning model was designed to guide physics teachers in developing learning model for scientifically G/T students.

Delimitation of the study

Population and samples

Subjects

1. Scientifically G/T students who were in grade 10 at Mahidol Wittayanusorn School, Nakhon Pathom, Thailand.
2. All teachers who teach physics at Mahidol Wittayanusorn School, Nakhon Pathom, Thailand.

Sample

1. 22 scientifically G/T students in grade 10 at Mahidol Wittayanusorn School who voluntarily took an elective physics course in the first semester, 2007.
2. Two teachers who had teaching experience with scientifically G/T at least 5 years at Mahidol Wittayanuson School at Nakhon Pathom, Thailand.

Variables

1. Independent variable
 - 1.1 The 4E-C learning model that enhances creative productivity in scientifically G/T students
2. Dependent variables
 - 2.1 students' creative productivity
 - 2.2 students' attitude toward physics
 - 2.3 students' learning reflections
 - 2.4 students' opinions of the 4E-C learning model
 - 2.5 teachers' opinions of the 4E-C learning model

Definitions of terms

1. **'4E-C learning model'** means the new learning model that enhances creative productivity of scientifically G/T students developed by the researcher. This model is based on the three-ring conception of giftedness, the Enrichment Triad Model, modeling method, and the 5-E instructional model. The name was derived from the names of phases and evaluation that is used

for every phase in the model. All the phases are Encouraging Issues, Experiments for Modeling, Creation of New Model, and Exhibition phases.

Phase 1: Encouraging Issues, it is the beginning phase of this model. The teacher allows students to study and search any issues or information on the topic by themselves. Then, each group presents their issues and discusses about that topic in a classroom. In the final part of this phase the teacher and students conclude with summary every topic presented by students together. In this phase the teacher is a coordinator of discussion.

Phase 2: Experiments for modeling, this is the second phase of the model. It is guided inquiry phase. Teacher is a facilitator. This phase consists of creative experiments that enhance modeling. Students can practice to design the experiments and to model both of physical model and mathematical model by themselves. After that they present their experimental designs and models in the classroom. The teacher gives students suggestion to improve those experiments. In this phase the teacher assesses students' product and presentation by using Student Product Assessment Form based on the Student Product Assessment Form of Reis and Renzulli (1991: 128-134) and Performance Assessment Form of the Institute for the Promoting of Teaching Science and Technology (IPST) (IPST. B.E. 2543: 306-310).

Note: these two phases can be alternately switched back and forth until the teacher considers that students are ready to create their own real physics models by checking students' creative productivity scores. These scores can be assessed by Student Product Assessment Form. If students' scores in the last activity are higher than the first activity, then students can do project in phase 3. Also, the teacher considers from students' learning reflection that shows students' ability whether or not they are ready to do project in phase 3. Then, students are allowed to go to the next phase. These two phases should consume 1/3 time of all phases. Before going to the third phase students should come up with questions involving problems in phase 1 and 2. Teacher should help student asking questions that can guide students to thinking about variables in their projects in phase 3.

Phase 3: Creation of new model, this is the third phase of the model. It is an independent inquiry phase. Teacher divides students into small groups. Each group finds out what topic they want to create a new model for. Students do science projects. They design experiment to create new model or adapt old experiments to create model in the new situation. Teacher should give them advice on doing experiment and creating physics model. This phase should allow students to have enough time to do their products. Teacher should find many

resources for students to study and search for any information on their products. Teacher assesses their products by using Student Products Assessment Form

Phase 4: Exhibition, this is the last phase. Teacher should arrange the exhibition for presentation of students' products. This phase gives students an opportunity to present and share their own products to their friends in the classroom and other students who attend this presentation. This phase makes students feel more confident with their ability and give them practice in communication skill. Teacher assesses this phase by using presentation item in Student Product Assessment Form.

2. 'Scientifically gifted and talented students' means students who have good attitude toward science, characteristics of a scientist, and who are top 240 of the highest score student group that are identified by following process:

1. Students' GPA: Students must have GPA of science and mathematics not less than 3.00, and GPAX of every subject not less than 3.00.
2. Paper-pencil tests: 480 students who pass paper-pencil mathematics and science tests are accepted to the academic camp.
3. Academic camp: 480 students join academic camp for 4 days and 3 nights. While in the camp students do many science activities and also take three tests. There are unseen mathematics, creative science, and problem solving tests. Moreover, students take Scholastic Aptitude Test (SAT), Intelligent Quotient (IQ), The Strength and Difficulty Questionnaire (SDQ) and Youth Self Report (YSR) test.

The criteria for identification as gifted students

1. T-score from SAT is not less than 60.
2. IQ score is not less than 110.
3. SDQ and YSR are not negative.
4. Top 240 students are selected by experts.

3. 'Students' creative productivity' means the ability of students to develop original products that are purposefully designed to have an impact on one or more targets by putting creative ability to work in areas of study and problem. Students' creative productivity is measured by the Student Product Assessment Form and student's learning reflection form.

4. 'Student attitude toward physics' means the attitude stated by students toward physics. It is measured by scientifically G/T students' attitudes toward physics questionnaire

based on program evaluation of science enrichment programs for gifted students (Stake; & Mares. 2001: 1065-1088).

5. 'Student's learning reflection' means the learning experiences that are reflected by students after they learn through the 4E-C learning model. It is measured by students' learning reflection form developed by the researcher.

6. 'Student opinions' means the opinions expressed by students toward the 4E-C learning model by using student interview protocol developed by the researcher.

7. 'Teacher opinions' means the opinions expressed by teachers toward the 4E-C learning model by teacher interview protocol developed by the researcher.

Theoretical framework

1. The three-ring conception of giftedness: developmental model for promoting creative productivity (Sternberg; & Davidson. 2005: 53-92; citing Renzulli. 1986.)

The three-ring conception of giftedness is a theory that attempts to portray the main dimensions of human potential for creative productivity. The name derives from the conceptual framework of the theory, namely, three interacting clusters of traits (above average ability, task commitment, and creativity) and their relationship with general and specific areas of human performance. Moreover, these three traits will be embedded on white-black background that represents environmental and personal factors to support the three rings. Gifted behavior consists of behaviors that reflect an interaction among three basic clusters of human traits--these clusters being above average general and/or specific abilities, high levels of task commitment, and high levels of creativity. G/T children are those possessing or capable of developing this composite set of traits and applying them to any potentially valuable area of human performance. Children who manifest or are capable of developing an interaction among the three clusters require a wide variety of educational opportunities and services that are not ordinarily provided through regular instructional programs. The three-ring conception of giftedness is shown in Figure 1.

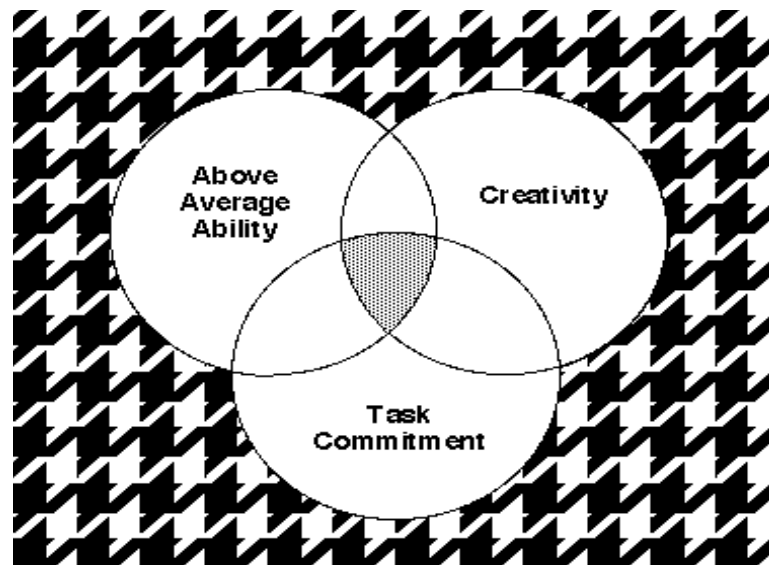


Figure 1 Three-ring conception of giftedness

Renzulli, J.S. (2006). "Three-ring conception of giftedness." (Online).

This theory believes that if we want to develop G/T students to be creative producer, we have to combine the three rings together. This theory also believes that G/T students can have high potential abilities, so we need to develop them to high level.

2. Enrichment Triad Model (Renzulli. 1994: 147–151)

The enrichment triad model is the best known and most widely used model for guiding what to do for gifted students. There are three steps and the model consists of three interrelated types of enrichment:

Type I enrichment offers students a wide range of experiences and activities in order to introduce a variety of topics. These may be facilitated through any number of outlets, including: printed materials, electronic media, field trips, etc.

Type I moves students beyond the regular curriculum to potentially exciting areas of interest such as physics, chemistry, astronomy, music, etc.

Type II enrichment is designed to give students the skills necessary to carry out investigations and develop a range of thinking and feeling processes which include:

- research skills
- higher-order thinking
- communication skills

Type III enrichment, however, is perhaps the most suitable for gifted and talented students. Within this aspect of the model, students investigate real problems individually or in small groups. This type emphasizes that students should emulate professional investigators and select appropriate audiences for final products.

However, these three types of enrichment in nature are always unnecessary to be sequential, but they can flow freely from one to the other. As illustrated in the following model portrayed in Figure 2, students may move from a type I activity to type III, and from there back to type II.

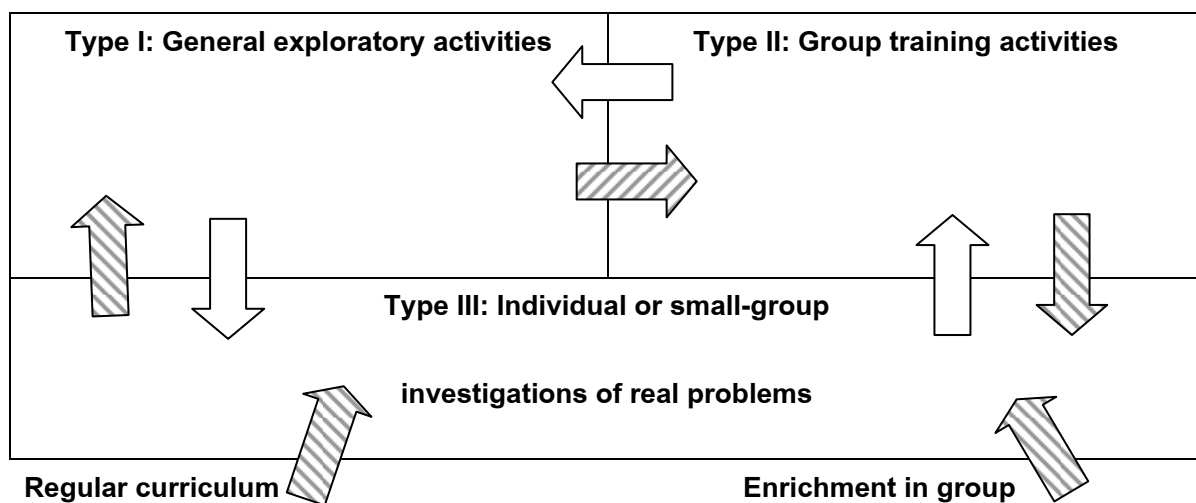


Figure 2 Enrichment Triad Model

Davis, G.A.; & Rimm, S.B. (1994). *Education of The Gifted and Talented*. p. 148.

3. Modeling cycle or modeling method (Wells, M.; Hestenes, D.; & Swackhamer, G. 1995: 606-619)

The modeling method has two stages: Model development and model deployment.

Stage I is designed to lead students systematically through the four main phases of model development: *description, formulation, ramification, and validation*. Modeling begins with description. Throughout the descriptive phase the teacher functions as a moderator. At the conclusion of the descriptive stage, the students are directed, collectively, to identify quantitatively measurable parameters expected to exhibit some cause-effect relationship. In the

ramification stage, the special properties and implications of the model are worked out. The validation stage is concerned with empirical evaluation of the ramified model.

Stage II is devoted to deployment of the model developed in stage I to a variety of new physical situations in a variety of different ways. This helps free the students' understanding of the model from the specific context in which it was developed. The general model development is shown in Figure 3.

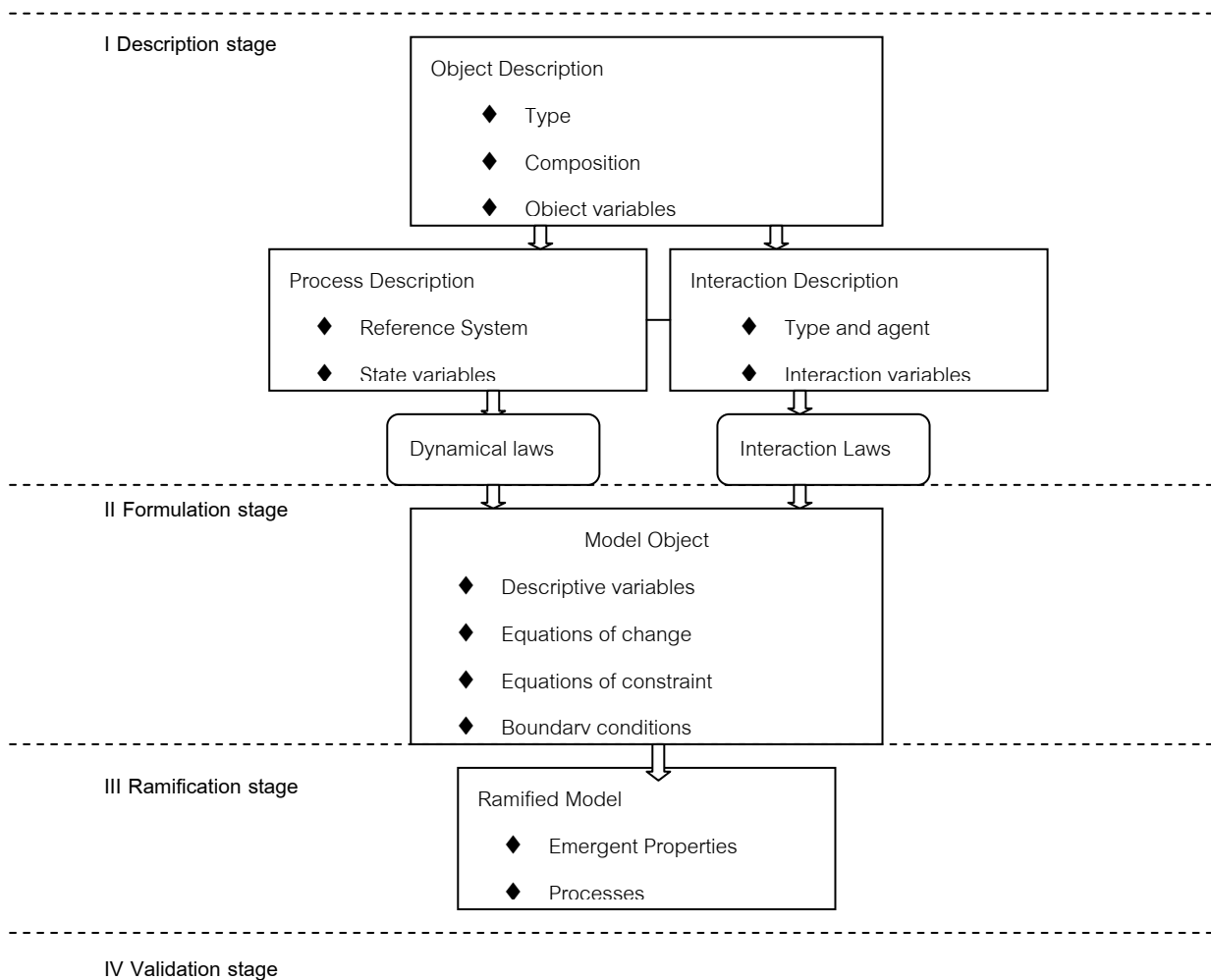


Figure 3 General model developments

Hestenes, D. (1987). "Toward a Modeling Theory of Physics Instruction." *American Association of Physics Teachers*. 55(5): 443.

4. The 5-E instructional model (Lorsbach. 1998: online)

The learning cycle or the 5-E instructional model is one of constructivist approach to education. This model consists of five stages:

Engage: In this stage teachers want to create interest and generate curiosity in the topic of study. This is also a good opportunity for teachers to identify misconceptions in student's understanding.

Explore: During the Explore stage students should be given opportunities to work together without direct instruction from the teacher. Teachers should act as a facilitator helping students to frame questions by asking questions and observing. Students should be puzzled. This is the opportunity for students to test predictions and hypotheses and discuss them with peers, record observations and ideas and suspend judgment.

Explain: During Explain, teachers should encourage students to explain concepts in their own words, ask for evidence and clarification of their explanation, listen critically to one another's explanation and those of the teacher. Students should use observations and recordings in their explanations.

Extend: During Extend, students should apply concepts and skills in new situations and use formal labels and definitions to remind students of alternative explanations and to consider existing data and evidence as they explore new situations.

Evaluate: Evaluation should take place throughout the learning experience. Teachers should observe students' knowledge and/or skills, application of new concepts and a change in thinking. Students should assess their own learning.

5. The new model "4E-C learning model"

This model was developed by the researcher and based on four of the theories that were the three-ring conception of giftedness, Enrichment triad model, modeling method, and the 5-E instructional model. The name was derived from the names of phases and evaluation that is used for every phase in the model. All the phases are Encouraging Issues, Experiments for Modeling, Creation of New Model, and Exhibition phases. This learning model is based on the same belief as the three-ring conception of giftedness. The design of learning model is based on the Enrichment Triad Model and the learning cycle. For phase 2-3 students conduct experiments and projects by following modeling method. The 4E-C learning model is shown in Figure 4.

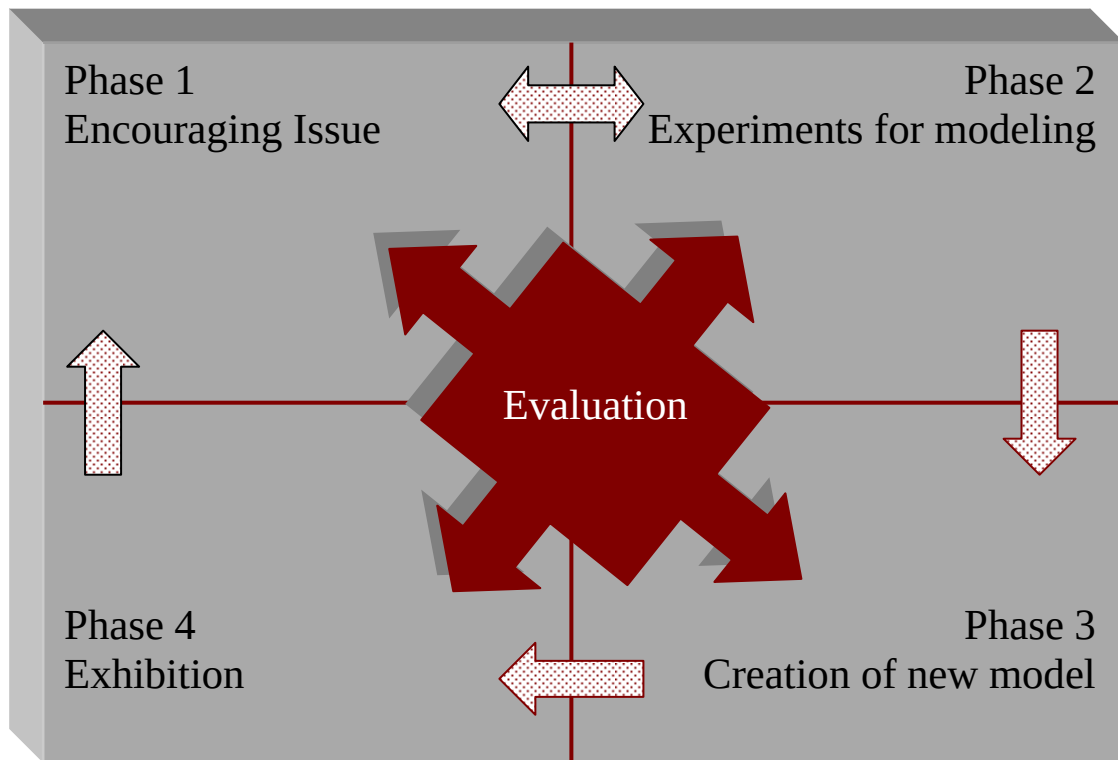


Figure 4 The 4E-C learning model

Phase 1: Encouraging Issues, it is the beginning phase of this model. First of all, a teacher divides students into small groups and, after that, gives them an interesting topic that they are going to study. The teacher allows students to study and search any issues or information of that topic by themselves. Then, each group presents their issues and discusses about that topic in the classroom. In the final part of this phase the teacher and students together conclude topics presented by student with summaries. In this phase the teacher is a coordinator of discussion. Teacher also observes students' presentations and discussion in the classroom.

Phase 2: Experiments for modeling, this is the second phase of the model. It is a guided inquiry phase. There are two teachers in this phase. First teacher is physics teacher. Second teacher is physics laboratory assistant teacher. Teachers are facilitator. First, the teacher divides students into small groups and explains how to create model in physics by following modeling method. This phase consists of creative experiments that enhance modeling. Students can practice to design the experiments and to model both physical model and mathematical model by themselves. After that they present their experimental designs and

models in the classroom. The teachers give them suggestion to improve their experimental design. In this phase the teachers assessed students' product and presentation by using Student Product Assessment Form.

Note: these two phases can be alternately switched back and forth until the teacher considers that students are ready to create their own real physics models by checking student's creative productivity scores. These scores are assessed by Student Product Assessment Form. If students' scores in the last activity are higher than the first activity, then students can proceed to do project in phase 3. Also, the teachers consider from students' learning reflection form that shows students' learning reflection whether or not they are ready to do project in phase 3. Then, students are allowed to go to the next phase. These two phases should consume 1/3 time of all phases. Before going to the third phase students should come up with questions involving problems in phase 1 and 2. Teacher should help student asking questions that can guide students to thinking about variables in their projects in phase 3.

Phase 3: Creation of new model, this is the third phase of the model. It is an independent inquiry phase. Teacher divides students into small groups. Each group finds out what topic they want to create a new model for. Students do science projects. They design experiment to create new model or adapt experiments in phase 3 to create model in the new situation. Teacher should give them advice on doing experiment and creating physics model. This phase should allow students to have enough time to do their products. Teacher should find many resources for students to study and search for any information on their products. Teachers assess their products by using Student Products Assessment Form.

Note: there should be at least three teachers for assessing students' creative productivity by using Student Product Assessment Form.

Phase 4: Exhibition, this is the last phase. Teacher should arrange the exhibition for presentation of students' products. This phase gives students an opportunity to present and share their own products to their friends in the classroom and other students who attend to presentation. This phase makes students feel more confident with their ability and gives them practice in communication skill. Teachers assess this phase by using presentation item in Student Product Assessment Form.

Research hypotheses

1. Scientifically G/T students, who learn through the 4E-C learning model, have higher creative productivity post-test scores than pre-test scores.
2. Scientifically G/T students, who learn through the 4E-C learning model, have higher attitudes toward physics post-test scores than pre-test scores.
3. Scientifically G/T students, who learn through the 4E-C learning model, have correct and reasonable learning reflection of using the 4E-C learning model.
4. Scientifically G/T students, who learn through the 4E-C learning model, have positive opinions toward the 4E-C learning model.
5. Teachers, who implemented the 4E-C learning model, have positive opinions toward the 4E-C learning model.

CHAPTER 2

REVIEW OF RELATED LITERATURE

This chapter reviews related literature that is relevant to the research objectives and the circumstances in which they are explored. The literature review aimed to identify the various exemplary perspectives of science education and gifted education that can be used to explain:

1. Definitions of giftedness
2. The three ring conception of giftedness
3. The research related to the three ring conception of giftedness
4. Characteristics of scientifically gifted and talented students
5. Identification of scientifically gifted and talented students
6. Science programs for gifted and talented students
7. Enrichment triad model
8. The research related to enrichment triad model and creative productivity
9. Developing model in physics
10. The modeling cycle or modeling method of instructional model
11. Research related to modeling method
12. The learning cycle or the 5-E instructional model
13. Research related to learning cycle

1. Definitions of giftedness

Defining gifted and talented is both an important and complicated matter. There is no one definition of gifted, talented, or giftedness that is universally accepted. A central feature of any definition of gifted is the concept of intelligence. One definition of gifted children now in use is based on superior performance rather than on measures of potential or aptitude. Nowadays there are some widely used definitions of giftedness. They are Howard Gardner's seven intelligences, Sternberg's triarchic theory, Sternberg's implicit theory of giftedness, Guilford's model of intelligence, and Renzulli's the three-ring conception of giftedness.

In Howard Gardner's seven intelligences theory of multiple intelligences (Gardner; & Sylvia. 1998: 21-22), children can be on several different dimensions and can be said to be gifted in one or more of them. Gardner believed that it would be useful to consider seven distinctive types of intellectual behavior:

1. Linguistic (verbal) intelligence, the ability to use language in written and oral expression to aid in remembering, solving problems, and seeking new answers to old problems.
2. Logical-mathematical intelligence, the ability to use notation and calculation to aid deductive and inductive reasoning.
3. Spatial intelligence, the ability to represent and manipulate three-dimensional configurations.
4. Musical intelligence, the ability to discriminate pitch, hear themes, and produce sensitive music through performance or composition; sensitive to rhythm, texture, and timbre.
5. Bodily-kinesthetic intelligence, the ability to use all or part of one's body to perform a task or fashion a product.
6. Interpersonal intelligence, the ability to understand the actions and motivations of others and to act sensibly and productively based on that knowledge.
7. Intrapersonal intelligence that is a person understanding of self, thinking styles, feelings, emotions-and intelligences. Also, it includes the ability to use that knowledge in planning and carrying out activities.

Sternberg's triarchic theory of intellectual giftedness (Colangelo; & Davis. 1997: 43-53) focused on three major dimensions of intelligence. The three dimensions include 1) how we process information through an internal representation of the world, 2) how we use past information to deal with current situations, and 3) how we adapt to real-life environments. Also, he believes that intellectual giftedness cannot be represented by an IQ number only. Analytic giftedness is the academic talent measured by typical intelligence tests, mainly analytical reasoning and reading comprehension. Synthetic giftedness refers to creativity, insightfulness, intuition, or the ability to cope with novelty. Such persons may not have the highest IQ scores, but may create the greatest contributions to society. Practical giftedness involves applying analytic and/or synthetic abilities efficiently to everyday, realistic situations. Sternberg's

“implicit” Theory of Giftedness (Heller; Monks; & A.H. 1993: 185-207) specifies five essential and adequate conditions that gifted persons have in common:

1. Excellence. A gifted person must be enormously good at something.
2. Rarity. He or she must own a high level of a feature that is unusual relative to peers.
3. Productivity. The superior trait must lead to productivity.
4. Demonstrability. The trait also must be demonstrable through one or more valid tests.
5. Value. The superior performance must be in an area that is valued by society.

Guilford’s model of intelligence (Khatena. 1982: 48-49) is a comprehensive extension of the multifactor theory that takes the form of a three-dimensional model. It consists of five kinds of mental operations, four kinds of contents, and six kinds of informational forms or products, making a total of 120 possible intellectual abilities—each different from the rest by its unique combination of the mental operation, content, and product. The model of intelligence is shown in Figure 5.

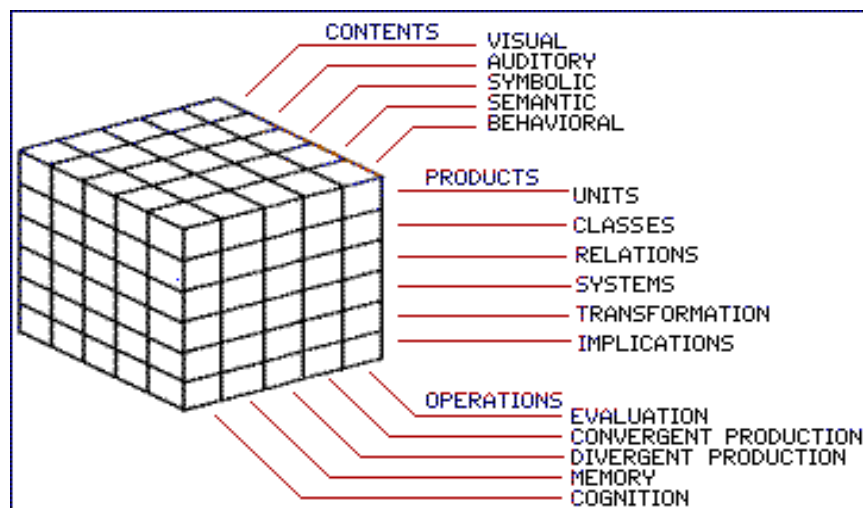


Figure 5 The structure of intellect

Joe Khatena. (1982). *Educational Psychology of The Gifted*. p.49.

Operation. In the operation intellectual activities involved are the processing of the raw materials of information by a person. In brief, the operation of cognition is knowing and a matter of constructing items of information; the operation of memory relates to the fixing in the

brain of information; the operations of divergent and convergent production are both similar-each depends on recovery of information from storage-and drastically different, in divergent production, the situation is more or less open concerning when a number of different productions are logically possible and may occur, but in convergent production, the given information is so limiting that only one response is fully acceptable; the operation of evaluation involves comparison and judgment relative to certain criteria.

Content. Broad classes of information in terms of their substantive nature - visual, auditory, and kinesthetic; content related to concrete forms of information supposed or recalled as images; symbolic content relates to information in the form of denotative signs that in themselves have no importance when the things in which they reside are not considered; semantic content related to information; and behavioral content related to essentially nonverbal information that involves the attitudes, needs, desires, moods, intentions, perceptions, thoughts, and the like, that occur in human interactions.

Product. The forms that information takes when a person briefly processes it: units are things taken as wholes and without analysis; it is through their diverse combinations that the remaining five product forms are derived; classes are three or more units of information that are grouped together by good value of their common properties; relations are associated units of information that are significantly connected; systems are organized sets of units of information that are complexes of interrelated or interacting parts; transformations are changes in information or in its operation that involves redefinition, revisions, and implications are extrapolations of information that takes the form of expectancies, predictions, or known consequences.

2. Renzulli's The three-ring conception of giftedness

Joseph S. Renzulli (Sternberg; & Davidson. 2005: 53-92; citing Renzulli. 1986.) describes three-ring conception of giftedness in a theory that attempts to give the key dimensions of human potential for creative productivity. The conceptual framework, three interacting clusters of traits, is as presented in Figure 1.1 (above average ability, task commitment, and creativity and their relationship with general and specific areas of human performance). The three-rings are embedded in a Houndstooth background that represents the interaction between personality and environmental factors that give rise to the three rings. It is

important to point out that no single cluster makes giftedness. It is also important to point out that each cluster plays an important role in contributing to the development of gifted behaviors.

2.1 The traits of giftedness

Well above average ability

Well above average ability can be defined in two ways: general ability and specific abilities. General ability consists of the capacity to process information, to integrate experiences that result in proper and adaptive responses in new situations, and the capacity to engage in abstract thinking. Specific abilities consist of the capacity to acquire knowledge, skill, or the ability to perform in one or more activities of a specialized kind and within a restricted range. These abilities are defined in a manner that represents the ways in which human beings express themselves in real-life situations. Each specific ability can be further subdivided into even more specific areas. Within this model the term above average ability will be used to describe both general and specific abilities.

Task commitment

A second cluster of traits that consistently has been found in creative-productive persons is a refined form of motivation known as task commitment. The terms that are most frequently used to describe task commitment are perseverance, endurance, hard work, dedicated practice, self-confidence, and a belief in one's ability to carry out important work.

Creativity

The third cluster of traits that characterizes gifted persons consists of factors that are usually lumped together under the general heading of creativity. The persons, eventually selected for intensive study the many research projects discussed, were recognized for their creativity through their creative accomplishment. Mackinnon's (Cognard. 2000: online; citing Mackinnon. 1964: 360) used the following dimensions of creativity:

1. Originality of thinking and freshness of approaches to architectural problems.
2. Constructive ingenuity
3. Ability to set aside established conventions and procedures when appropriate.
4. A flair for devising effective and original fulfillments of the major demands of architecture, namely, technology, visual form, planning, and human awareness and social purpose.

Moreover, this theory can be explained in more general and specific performance areas shown in Figure 6.

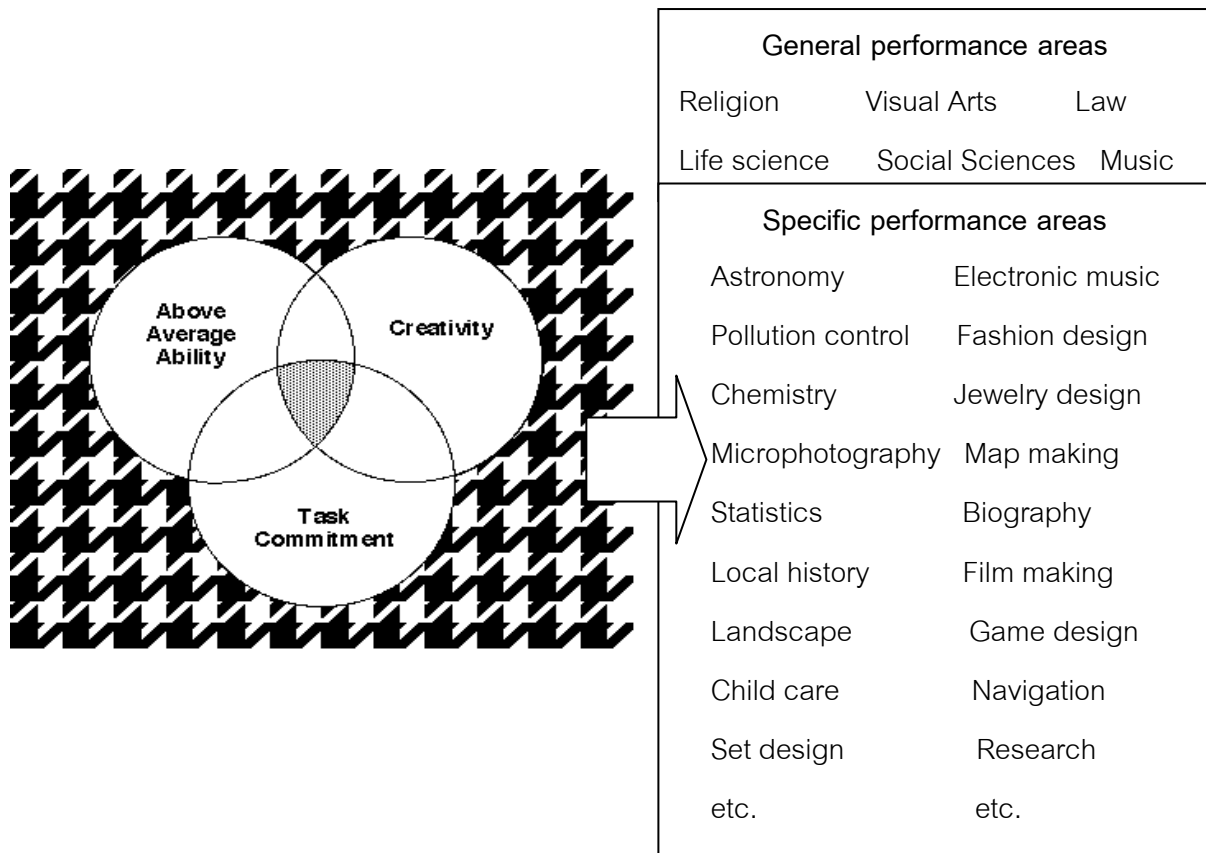


Figure 6 Graphic representation of the three-ring definition of giftedness

Sternberg; & Davidson. (2005). *The Conception of Giftedness*. p.257.

2.2 New dimensions to the three-ring conception of giftedness

Additional research and theory development has led to a new dimension of the model that calls attention to a series of six co-cognitive factors. A comprehensive review of the literature and a series of Delphi technique studies led to the development of an organizational plan for studying the 6 components and 13 subcomponents presented in Figure 7. These traits are considered as co-cognitive factors because they interact with and enhance the cognitive traits that are ordinarily associated with the development of human abilities. The two-directional arrows in this diagram are intended to point out the many interactions that take place between and among the Houndstooth components.

This new initiative was prompted by a longstanding research. It concerns with the role that gifted education should play in preparing persons with high potential for ethical and responsible leadership in all walks of life. Also a concern for the well-documented decline of social capital differs from economic and intellectual capital in that it focuses on a set of

intangible assets that address the collective needs and problems of other individuals and our communities at large. This kind of capital generally enhances community life and the network of obligations. The Operation Houndstooth is shown in Figure 7.

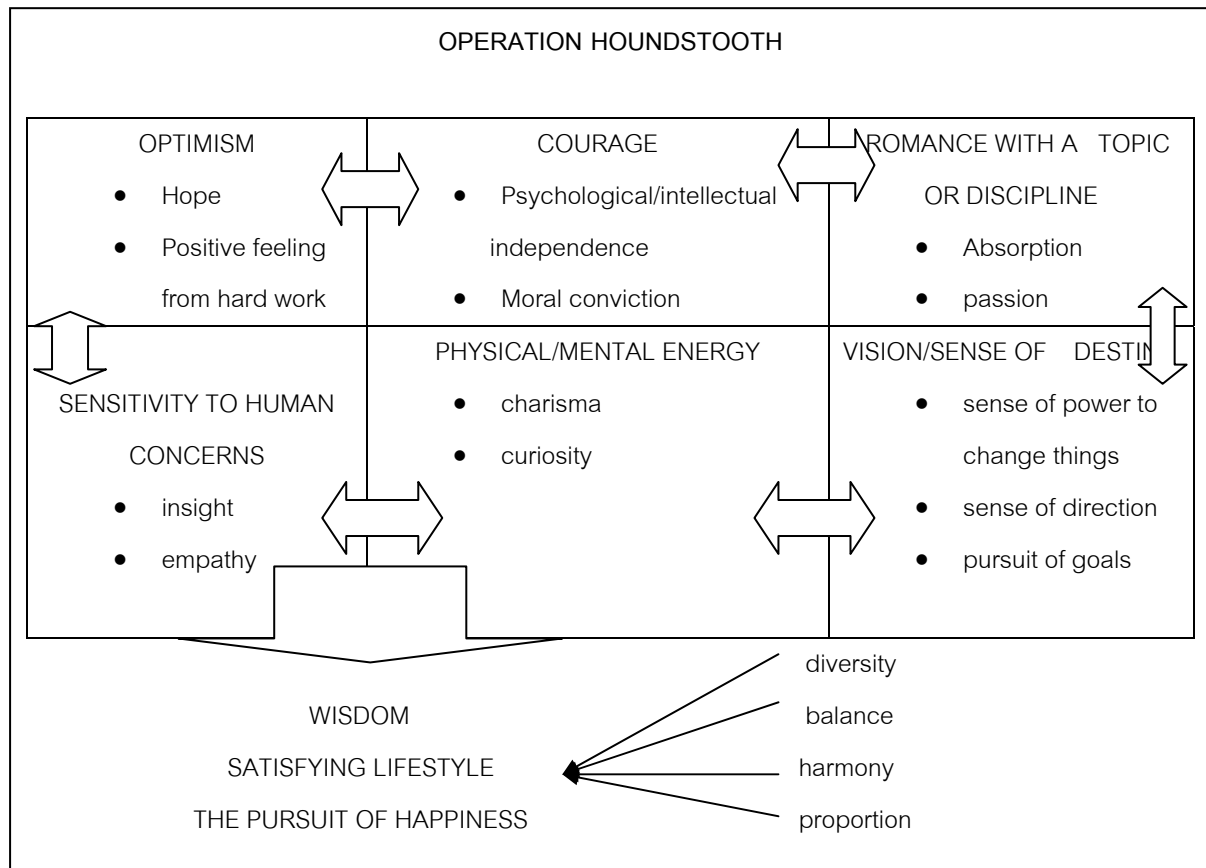


Figure 7 OPERATION HOUNDSTOOTH

Sternberg; & Davidson. (2005). *The Conception of Giftedness*. p.269.

3. Research related to the three-ring conception of giftedness

Renzulli (Renzulli. 1978: 180) presented an article that analyzed some past and current definitions of giftedness. He reviewed studies that dealt with characteristics of gifted individuals. This article supported the three-ring conception of giftedness in that no single criterion should be used to identify giftedness. Persons who have achieved recognition because of their unique accomplishments and creative contributions possess a relatively well-defined set of the three interlocking clusters of traits.

Renzulli (Renzulli. 1988: 18-25) also examined some of the commentary on criticism that had been directed toward the three-ring conception of giftedness since its original publication in 1978. This study found that the three-ring conception of giftedness can develop gifted behaviors. Major change includes shifting emphasis from being gifted to the development of gifted behaviors, labeling services rather than students, and making changes in guidelines to bringing them into line with present day research.

4. Definitions of scientifically G/T students

Walberg (Walberg. 1982: 103) reviewed childhood traits of over 200 well-known people. Walberg found traits of scientists group in those students in this group:

- Visited libraries for non school reading, had greater numbers of books at home, enjoyed professional-technical books, and found books more interesting than people.
- Had early strong interests in mechanical and scientific objects as well as the arts.
- Were more interested in work with fine details.
- Were more persistent in carrying things through; reported they had “less time to relax.”
- Studied hard and completed their work faster than classmates.
- Felt more creative, imaginative, curious, and expressive than others and believed it is important to be creative.
- Selected creativity as the “best characteristic to develop in life.”
- Indicated they were brighter and quicker to understand than their friends.
- Attached greater importance to money and expected to earn higher salaries than the average; expected to earn graduate degrees.

Qualifications and Curriculum Authority (QCA) identifies gifted pupils in science that they are likely to: (Qualificationa and Curriculum Authority. 2001: online)

- be imaginative
- read widely, particularly science
- have scientific hobbies and/or be members of scientific clubs

- be exceptionally interested in finding out more about themselves and things around them
- like researching obscure facts and applying scientific theories, ideas and models when explaining a range of phenomena
- be able to maintain their interest and go ahead of an obvious answer to underlying mechanisms and greater depth
- be questioning about how things work and why things happen
- ask many questions, suggesting that they are willing to hypothesize and speculate
- use different strategies for finding things out
- think logically, providing credible explanations for phenomena
- put forward objective arguments, using combinations of evidence and creative ideas, and question other people's conclusions
- decide rapidly how to investigate fairly and manipulate variables
- consider alternative suggestions and strategies for investigations
- analyze data or observations and spot patterns easily
- strive for maximum accuracy in measurements of all sorts, and take pleasure in them
- make connections quickly between facts and concepts they have learned, using more extensive vocabulary than their peers
- think abstractly at an earlier age than usual and understand models and use modeling to explain ideas and observations.
- understand the concepts of reliability and validity when drawing conclusions from evidence
- be easily bored by over-repetition of basic ideas
- enjoy challenges and problem solving, while often being self-critical
- enjoy talking to the teacher about new information or ideas
- be self-motivated, freely putting in extra time
- show intense interest in one particular area of science to the exclusion of other topics.

Regional educational laboratory indicated scientific giftedness and Yager (Regional educational laboratory. 2002: online; citing Yager. 1989: 223-248) indicated the same characteristics of scientific giftedness:

- Strong curiosity about objects and environments
- High interest in investigating scientific phenomena
- Tendency to make observations and ask questions
- Ability to make connections between scientific concepts and observed phenomena
- Unusual ability to generate creative and valid explanations
- Interest in collecting, sorting, and classifying objects

James J. Watters presented characteristics of students gifted in science (Watters. 2004: 41-53) as shown in Table 1.

TABLE 1: Characteristics of students gifted in science

characteristic	explanation
1. Seek meaning and explanation of phenomena	1. A passion for exploration and finding out about things. They possess a questioning nature. They tend to read scientific or factual rather than fiction. Personal drive or disposition to engage in long term explorations.
2. An awareness of the complexities of the world and sensitivity to the environment including life and death.	2. Gifted children are sensitive to their environment and seek to organize it, structure it and understand its complexity
3. Often categorize natural phenomena in abstract ways	3. The scientifically gifted child might sort on the basis of composition whereas others would sort out items on use, shape, color or surface features.
4. Often exhibit intensive interest in particular areas of science and persist in exploring these areas and understanding concepts.	4. Older students might exhibit interest well beyond the interest level of peers. In high school display a persistence and willingness to work beyond ordinary schedules often in the face of physical discomfort.
5. Will engage in collection of materials-stamps, insects, objects.	5. A passion to accumulate as much information about classes of objects as is possible.
6. Are tinkers wanting to pull objects apart and reassemble	6. Intrinsic interest in how thing works and a desire to discover for themselves. This behavior reveals a strong investigative nature. They will often build their own instruments to conduct investigations.
7. Passionate interest in the origins of things.	7. Represents the child's need to explain where they come from leading to an understanding of the past and future.
8. Builders and constructors, puzzle solvers, detailed artistic representations, well developed sense of space	8. The scientifically gifted often have strong visualization skills and in adulthood often reason through diagrams and spatial models. Evident in the search for patterns in phenomena.
9. Will gravitate toward people who are expert in fields of interest.	9. They seek like minds and mentors who are able to satisfy their insatiable appetite for knowledge.
10. Often anxious and single minded in explaining their ideas.	10. They assume that others are interested in what they are and wish to share with them their interests.

Watters. (2004, June). "In Pursuit of Excellence in Science." *Australasian journal of gifted education*. 13(2): p. 4.

In conclusion, scientifically G/T children are children identified as being well above average, high creativity, and high ability to process information in the past to new situation or to create new science product. They have high interest in investigating scientific phenomena and

high attitude toward science. They have also strong curiosity in science, task commitment to doing any science stuff, and can learn science very fast science.

5. Identification of scientifically gifted and talented students

Nebraska State Department of Education (Nebraska State Department of Education. 2000: 37-46) guides identification of high-ability learners. Nebraskas' schools have four-phase process of the identification of high-ability students. It consists of planning, nomination, screening, and selection.

Planning

- Develop an action plan of steps
- Specify many types of giftedness; underserved student populations; and different content areas.
- Write a brief philosophy statement.
- Find, or develop, objective and subjective identification measures.
- Specify resources necessary
- Institute realistic strategies for collecting, analyzing, and managing student identification data.
- Select members of implementation committee.

Nomination

Nomination, the next step in identification, casts the widest net. It utilizes a range of objective and subjective procedures: Nominations from teachers, parents, school counselors and psychologists, librarians, administrators, individuals from the community, and even students are often quite productive.

Screening

All students who are nominated must be screened. It involves assessments of particular relevance to different types of students with different interests and skills. There are three major sources of information to identify high-ability students: performance, development, and test.

Selection

The selection committee consists of teachers, principal, and gifted coordinator. It is essential that the committee:

- examine student data collected to determine inclusion for high-ability services
- protect student identities and identification data
- be impartial
- be aware of the student's need for high-ability services
- notify parents of students who are identified
- establish procedures so that decisions can be appealed

Finally, evaluation is used to improve the identification process. There are eight principles of effective identification that might be considered in developing an identification plan:

Principle 1: Utilize identification procedures which acknowledge many types of high ability.

Principle 2: Employ separate strategies to identify different aspects of high ability.

Principle 3: Use reliable and valid tests (not only I.Q. tests).

Principle 4: Find appropriate tests for underserved student populations.

Principle 5: View each child as unique.

Principle 6: Depend on multiple measures, not simply tests.

Principle 7: Recognize the disadvantages of “weighted” matrices for identification.

Principle 8: Select students on ability and need, not to satisfy institutional quotas.

Renzulli (Renzulli. 2006: online) presented a practical system for identifying gifted and talented students. There are six steps of identification:

Step 1: Test Score Nominations

This system will divide the Talent Pool for students in half and will place all students who score at or above the 92nd percentile in the talent pool. This approach guarantees that all traditionally bright youngsters will automatically be selected, and they will account for approximately 50 percent of the talent pool. Any regularly administered standardized test can be used for this purpose, however, this system recommends that admission to the talent pool be granted on the basis of any single test or subtest score. The identification system is shown in figure 8.

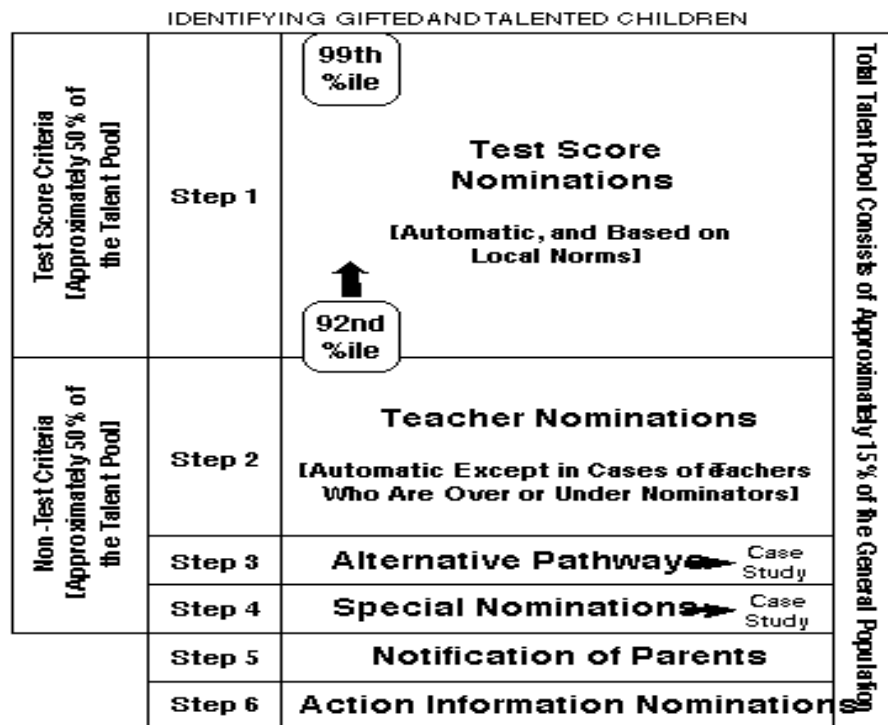


Figure 8 The Renzulli identification system

Renzulli, J.S. (2006). The Renzulli identification system. (Online).

Step 2: Teacher Nominations

Step two allows teachers to nominate students who display characteristics that are not easily determined by tests. A teacher nomination form and rating scales are used for this procedure. The rating scales are not used to eliminate students with lower ratings. Instead, the scales are used to provide a composite profile of the nominated students. For the cases of teachers who are over nominators, a request is made that they rank their nominations by order for review by a school wide committee. Procedures for dealing with under-nominators will be described in Step 4.

Step 3: Alternate Pathways

Alternate pathways are considered to be local options, and are pursued in varying degrees by individual school districts. Decisions about which alternative pathways might be used should be made by a local planning committee, and some consideration should be given to variations in grade level.

This step generally consists of parent nominations, peer nominations, tests of creativity, self-nominations, product evaluations and virtually any other procedure that may lead to initial consideration by a screening committee.

Step 4: Special nominations

This procedure involves circulating a list of all students who have been nominated through one of the procedures in Step 1 through 3 to all teachers within the school, and in previous schools if students have matriculated from other school. This procedure allows previous year teachers to nominate students who have not been recommended by their current teacher, and it also allows resource teachers to make recommendations based on their own previous experience with students who have already been in the talent pool. This step allows for a final review of the total school population, and is designed to circumvent the opinions of present year teachers. This step also helps to overcome the general biases of an under nominator or a non-nominator.

Step 5: Notification and orientation of parents

In step 5, parents are informed about how admission to the talent pool is determined, that it is carried out on an annual basis, and that additions to talent pool membership might take place during the year as a result of evaluations of student participation and progress. Parents are also invited to make individual appointments whenever they feel that additional information about the program in general is required.

Step 6: Action information nominations

This step will occasionally miss students who are not selected for talent pool membership. To help overcome this problem orientation related to spotting unusually favorable “turn-on” in the regular curriculum is provided for all teachers. This process is facilitated through the use of a teacher training activity and an instrument called an Action Information Message that provides a wide variety of in-class enrichment experience that might result in recommendations for special services. Action information can best be defined as the dynamic interactions that occur when a student becomes extremely interested in or excited about a particular topic, area of study, issue, idea or event that takes place in school or the non-school environment.

Chan (Chan, 2000: 88-93) presented the article stating that current procedures in Hong Kong generally emphasize the use of standardized instruments for identifying the intellectually gifted (using the Hong Kong Wechsler Intelligence Scale for Children or Raven’s Standard Progressive Matrices), the academically gifted (using the Hong Kong Attainment Tests), and the creatively gifted (using the Chinese versions of the Torrance Tests of Creative Thinking (TTCT) or the Wallach-Kogan Tests). Advocating the use of multiple criteria, educators in Hong Kong also employ informal measures such as nominations and rating scales

for identifying the intellectually gifted. The assessment of intelligence using individual tests is usually based on the administration of the Hong Kong Wechsler Intelligence Scale for Children, normed and standardized with Hong Kong children 5 to 15 years of age. Students with high general intellectual ability can also reliably be identified as those scoring 130 or above. Another intelligence test, Raven's standard Progressive Matrices (SPM), suitable for group assessment, also has been normed and standardized for Hong Kong children. In identifying the academically or high-achieving gifted, academic achievement test scores frequently have been used in addition to IQ scores in the identification of gifted and talented students in Hong Kong. Taking group achievement test is common in schools in the Hong Kong educational system. For identifying the creatively gifted, the TTCT were chosen on the basis of the experience of the usage of these tests in other Chinese societies such as Taiwan. With the verbal and figural subtests of the TTCT, the creative thinking or creative potential of a student can be scored in terms of fluency, flexibility, originality, and elaboration. Another set of alternative test is the Wallach-Kogan divergent thinking tests that consist of three verbal subtests and two nonverbal subtests. For identification by informal measures, teacher and parent nominations are relatively common, and they frequently form the basis for follow-up intellectual assessment in the psychological services of the special education. In the studies on norming the Torrance tests for Hong Kong students, the research team adapted and translated the Scales for Rating Behavioral Characteristics of Superior Students, which includes ratings on the learning, motivational, creative, and leadership characteristics of students.

Coleman and Ruth (Coleman; & Ruth. 2003:1-7) presented appropriate identification practice that is the best identification practice. It relies on multiple criteria to look for G/T students. Multiple criteria involve:

- Multiple types of information such as indicators of student's cognitive abilities, academic achievement, performance in a variety of settings, interests, creativity, motivation, and learning characteristics.
- Multiple time periods to ensure that students are not missed by "one shot" identification procedures that often take place at the end of second or third grade.

Step in the identification process

The identification process must be dynamic with both formal identification checkpoints and ongoing opportunities for students to be identified as their needs are recognized. The three phases in this process are:

- General screening or student search: to establish a pool of students who might qualify for services, ensuring that no student is overlooked. Screening methods can rely on student data that are readily available for all students and may involve specific cognitive and academic assessments given as part of the screening process. Comprehensive screening also includes invitations to teachers, parents, and students to suggest names of individuals who might need services.
- Review of students for eligibility: to review the students, determining which students would benefit from formal identification and services. In this phase all the data are reviewed to look for indicators that show a need for services.
- Services-options match: a school or school system needs to survey the possibilities it can offer students, both in regular classrooms and special classrooms, so that it can set the stage for planning optimal matches of students and options. This process is straightforward when the needs of the students and the options for meeting these needs are clear-cut.

In Thailand, the first science high school which is Mahidol Wittaynusorn at Nakhonprathom province has the identification of high ability students in science. This process consists are as follow:

1. Students' GPA: Students must have GPA of science and mathematics not less than 3.00, and GPAX of every subject not less than 3.00.
2. Paper-pencil tests: 480 students who pass paper-pencil mathematics and science tests are accepted to the academic camp.
3. Academic camp: 480 students join academic camp for 4 days and 3 nights. While in the camp students do many science activities and also take three tests. There are unseen mathematics, creative science, and problem solving tests. Moreover, students take SAT, IQ, SDQ, and YSR test.

The criteria for identification as gifted students

1. T-score from SAT is not less than 60.
2. IQ score is not less than 110.
3. SDQ and YSR are not negative.
4. Top 240 students are selected by experts.

In conclusion, identifying scientifically G/T students still has no single process that is the best. However, the process that is mostly accepted consists of test score nominations, teacher nominations, special nominations, notification and orientation of parent, and peer nominations. Not only identifying scientifically G/T student process is followed, but also measure of science process, scientifically creative thinking, and attitude toward science are included.

6. Science program for gifted and talented students

Michael C. Pyryt (Pyryt. 1993: 1-5) presented the article that summarizes effective strategies and programs for nurturing students who are gifted in science. The recommendation, for nurturing talents/gifts in science and technology, is that curriculum should provide the opportunity for advanced study of scientific concepts and methodology. Students should know both the content of various scientific disciplines and the processes scientists use to discover knowledge. Students should also be given the opportunity to conduct original research projects. In addition to conducting research, students need to have the opportunity to communicate the results of their research by presenting at seminars and conferences and by writing articles for publication in journals. There is also a need for the science curriculum to address the ethical dilemmas that scientists face. Teachers are important. The characteristics of quality science teacher are that he is inspired and inspiring, knows science and its techniques, understands the meanings of science and its relationship to the world, encourages individual excellence, guides the student to locate resources, adapts teaching methods to stimulate problem solving, attempts to provide flexible programming to meet the unique needs of rapid learners.

Tracy L. Cross and Laurence J. Coleman (Cross; & Coleman. 1992: 25-26) presented the article that provides useful information on teaching talented science students. They found thirty-two students who stated they wished their science class would move at a quicker pace. The second most popular theme is that teachers need to challenge students by expecting more out of them as students. Twelve of the students stated they were frustrated with the present teaching method of lecture-memorization. Several students said that teachers should stimulate their creativity in problem solving and provide more opportunities for them to apply their knowledge.

Michael C. Pyryt (Pyryt. 1993: 5) presented effective strategies and programs for nurturing students who are gifted in science. This study found that providing scientifically

talented individuals with challenging curricula, and effective teacher/mentor is the key to nurturing their gifts/talents. Educationally accelerative opportunities that are recommended are field trips, advanced placement courses, and science summer camps. Experiences that promote science achievement are simultaneous teaching of separate science subjects. Science curriculum should provide the opportunity for advanced study of scientific concepts and methodology. Students should know both the content of various scientific disciplines and the processes scientists use to discover knowledge and should be given the opportunity to conduct original research projects.

Gallagher (Gallagher. 1994: Abstract) presented wide general agreement as to the substance of new science curricula. One such list represents the general trend:

- More authentic performance assessment of students and educators, and less emphasis on standardized testing;
- More critical and creative thinking and problem solving for students, and less emphasis on rote knowledge;
- More learning for understanding and less learning for grades and scores;
- More organization of time around student learning, and less organization of time around adult or bureaucratic needs;
- More diverse types of teaching and learning opportunities in order to accomplish the above goals.

Johnson (Johnson. 1995: 36-44) reviewed the existing K-8 science curriculum materials carried out under the National Science Curriculum Project for High-Ability Learners. A curriculum for high-ability and gifted learners demands not only higher level thinking and inquiry-based materials but also materials that demonstrate adequate depth and complexity while providing for individual rates of learning.

Stepanek (Stepanek. 1999: 56) offered a diversity of strategies and resources for content and activities that will challenge all students, including gifted learners. It begins with evolving definitions of giftedness and theories of intelligence. Means of identifying gifted students and indicators of mathematical and scientific giftedness are then presented. Furthermore, they addressed teaching gifted students in inclusive classrooms and ability grouping. Recommendations about grouping students include: 1) heterogeneous groups are most appropriate when students are working on open-ended problem-solving tasks or science inquiry activities; 2) homogeneous groups are more appropriate when students are working on

skill development or reviewing material that they have already learned; 3) grouping strategies should be flexible, and students should be allowed to work independently at least occasionally according to their preferences; 4) students should have opportunities to select their own groups based on common interests; and 5) all students need to learn the skills of working together before addressing strategies for developing conducive learning environments, including support for gifted minority students and gifted girls, differentiating content, differentiating processes, and differentiating products.

Van Tassel-Baska (Van Tassel-Baska. 1998: 200) studied the effectiveness of a specialized curriculum or materials in any domain and the lack of systematic implementation data. The purpose of this study was to assess student growth on integrated science process skills after being taught a 20-36 hour science unit designed according to the new science recommendations and to curriculum features appropriate for gifted learners. This study demonstrates the importance of high-powered curricula in creating defensible programs for gifted learners in schools and illustrating an assessment approach that can be replicated in other enhancing scientific research skills. The study strongly suggests that the use of the William and Mary problem-based science units enhances learning regardless of grouping patterns employed and contributes positively to student motivation to learn. The unit of study, Acid, Acid Everywhere, which was implemented at all sites, was designed to accommodate high ability learners through an emphasis on advanced content, higher order thinking in a problem-based format, research skills in science, and the development of a challenging project demonstrating problem resolution.

Also, Van Tassel-Baska (Van Tassel-Baska. 1998: 6) presented planning science programs for high-ability learners on what should be included in science curriculum for gifted students. Three of the most important things include the following elements:

- An emphasis on higher-level thinking. Students need to analyze the relationship between real world problems and have opportunities for both critical and creative thinking within a problem-based episode.
- An emphasis on inquiry, especially problem-based learning. The more that students can construct their understanding about science for themselves the better able they will be to encounter new situations and apply appropriate scientific processes to them.

- An emphasis on learning the scientific process using experimental design procedures.

In conclusion, appropriate science curriculum that promotes high quality learning is desirable for all learners. Teachers and administrators alike need to recognize that gifted learners must be challenged in their area of greatest interest and potential expertise.

Watters (Watters. 2004: 41-53) explored how teachers and parents can help gifted students with passionate interests in science. This study found that science classes should provide opportunities for the generation of knowledge. There are significant implications for how teachers interact with students and the way they scaffold knowledge. Science classes need to address issues of environment, process, products, and content. Finally, the importance of open inquiry, in science as a strategy to enhance learning, is emphasized. Gifted students are challenged by complexity and ill-defined problems. The opportunity to experience uncertainties, ambiguities, and the social nature of scientific work and the construction of scientific knowledge provides them with the intellectual challenges that are desirable. It is important that gifted students in science consider themselves as part of communities of inquiry in which knowledge, practices, resources and discoveries are shaped; and where participants can draw on the expertise of more knowledgeable others whether they are peers, mentors or teachers.

Van Tassel-Baska and Stambaugh (Van Tassel-Baska; & Stambaugh. 2006: 161-162) stated that science education interests and gifted education needs led to the consideration of seven main components necessary to curriculum principles for gifted learners. These components consist of: 1) developing an understanding of scientific concepts, 2) developing scientific inquiry skills in collaborative settings, 3) developing a knowledge base in science areas, 4) developing interdisciplinary connections, 5) developing investigations of real-world problems, and 6) developing scientific habits of mind. Students must act as scientists and have time to immerse themselves in that role. This role includes the following objectives:

- Explore a scientific area
- Identify a meaningful problem for investigation
- State a hypothesis

- Work through a preplanned experiment or demonstration, or aid in the development of an experiment
- Make appropriate observations
- Create a simple graph or chart; label diagrams appropriately
- Record data in appropriate formats
- Analyze experiment results in light of the original problem
- Make predictions about similar problems
- Communicate using posters, oral communication, and brief lab reports

In conclusion, science program should allow G/T student to inquire or explore in scientific area. It should encourage student to have high scientific skill and higher order thinking skill. Science program should not only let student do experiment, but also let them create innovation in science. Moreover, program should encourage communication to help students being more self-confident in science.

7. Enrichment Triad Model

Joseph S. Renzulli's Enrichment Triad Model (Renzulli. 1994: 147–151) is the best known and most widely used model for guiding what to do for gifted students. There are three sequential steps: Type I enrichment, general exploratory activities designed to acquaint the student with a variety of topics and interest areas; Type II enrichment, group training activities dealing with the development of cognitive and affective processes- for example, creativity and research skills; and Type III enrichment, the investigation of real problems that are similar in nature to those pursued by authentic researchers or artists in particular fields. See in figure 2.

Type I Enrichment

The three major purposes of the Type I enrichment, general exploratory activities, are to (1) expose students to topics that are not a normal part of the school's curriculum, (2) make general enrichment activities available to all interested students, and (3) invite highly motivated students to find and pursue a later Type III independent project. Gifted students should understand that they are to explore these interest areas purposefully with a view toward identifying ideas for further study. Some students may already have longstanding interests or hobbies which are well suited for Type III projects. In these cases Type I activities serve mainly

to expose students to new areas. Resource centers should be well stocked with books, magazines, and other media dealing with a large number of topics. Another good exploratory activity is field experience in which gifted and talented students meet dynamic people involved in creative and problem-solving endeavors

Type II enrichment

The purpose of type II enrichment, group training activities, is to promote the development of a broad range of thinking and feeling processes. These skills, abilities, attitudes, and strategies should be developed in all students. Type II enrichment also includes process skills related specifically to gifted students' independent projects such as techniques for writing a play script, silk screening, or using scientific equipment.

Type III Enrichment

With Type III enrichment activities the gifted young person becomes a researcher investigating a real problem and creating an original product. Students should act as producers of knowledge not just consumers of information. For example, for a research project they should not be asked to consult encyclopedias or other already-summarized sources and then write a report. Rather they should use raw data as their main information source from which they draw their conclusion.

The students should play an active part in formulating the problem, designing the research or artistic methods, and planning the final product. The teacher, as "guide on the side," helps with clarifying the problem, designing the project, locating materials and equipment, and recommending information sources or community experts.

8. Research related to Enrichment Triad Model and creative productivity

Tsai (Tsai. 1997: 22) presented a research paper that was an enrichment model: a study of developing a pilot program for gifted students. This development of a pilot program, for highly capable primary students, was based on Renzulli's enrichment triad model. The program focused on using human resources, curriculum compacting, and enhancing creative productivity. It was found that: 1) students who received lessons using curriculum compacting in mathematics performed as well as regular mathematics class, although they spent less time in the regular mathematics class; 2) students were more attentive during regular classes because they spent less time and learning became more challenging; 3) other students not using lessons from curriculum compacting did not show negative attitudes toward the students with

curriculum compacting; 4) teachers had a positive attitude toward curriculum compacting; and 5) when students were provided with training in cognitive and affective training, learning how-to-learn skills, familiar with advanced research and reference materials, and developing written, oral, and visual communication techniques, it had a significant impact on individual and small group investigation of real problems and creativity.

Meador (Meador. 2003: 25-30) presented the article about creative thinking about science that the world needs creative scientists who produce useful, innovative solutions to our problems. First, creative scientists need to be free of rules in order to exercise flexible thinking. Second, creative scientists also seem to be more open to exercise, making them more sensitive to problems than their noncreative colleagues. In science, flexible students think of different types of variables that may impact a phenomenon. Flexible thinkers also have the ability to look at things from multiple perspectives.

Baum (Baum. 1995: 224-235) reported research with the title, "Reversing Underachievement: Creative Productivity as a Systematic Intervention". This study examined the phenomenon of underachievement and the effect of using creative productivity, Type III enrichment, as a systematic intervention in reversing the pattern. The most compelling finding of this research study was the positive gains made by the students through their involvement in the Type III intervention. Eighty-two percent of the students made positive gains during the course of the year and in the year following the intervention. Most were no longer underachieving in their school setting by the end of the intervention.

Hebert (Hebert. 1993: Abstract) presented a research that was reflections at graduation, "The Long-Term Impact of Elementary School Experiences in Creative Productivity". This research found that nine senior high school students who took enrichment triad and the revolving door identification model class exhibited the creative productivity (Type III). And they are still longitudinal creative producers.

Newman (Newman. 2005: 84-90) presented a research about a set of lessons that integrate the Talents Unlimited Model with the 10 steps of completing a Type III activity to determine the effects of these lessons on the quality of students' creative products and on the number of students who completed their products. The result showed that treatment group students showed a statistically significant difference in finishing their independent or small-group projects, as opposed to students in the control group. Moreover, treatment group students' products were of significantly higher quality as measured by the Student Product Assessment Form than the products completed by students in the control group.

Chislett L. Miller (Miller. 1994: 4-7) presented the article that compares the components of Creative Problem Solving (CPS) to the investigative procedure of Type III enrichment in the Schoolwide Enrichment Model that the was based on enrichment triad model to show that two models are complimentary. Research has shown that students who are given specific training in the methodology of a Type III investigation that was integrated with CPS have an increased likelihood of participation in the process of creating original products in response to investigations of real world problems.

In conclusion, Enrichment Triad Model is an outstanding teaching and learning model that encourages creative productivity for G/T students. This model allows students to explore in area that interests them and they can practice or be trained in that area afterward. Then, they can independently study in depth specific topic that they like. All of the three types can help student to have more creative productivity.

9. Developing model in science education

John K. Gilbert presented that a model in science (Gilbert. 2000: 11) is a representation of a phenomenon initially produced for a specific purpose. The specific purpose for which any model is originally produced in science is a simplification of the phenomenon to be used in enquiries to develop explanations of it. A model of an object can be either smaller or bigger than, or of the same size as the phenomenon which it represents. Other models are composed of abstractions, entities which are treated as if they were objects, e.g. forces, energy. A model can thus be of an idea. Model can be of a system, a series of entities in a fixed relation to each other. A model can be of an event. A model can be of a process, one or more events within a system which has a distinctive outcome.

David Malvern presented the article on mathematical models in science. In developing model, Gilbert (Gilbert. 2000: 59-90) said "The miracle of the appropriateness of the language of mathematics for the formulation of the laws of physics is a wonderful gift which we neither understand nor deserve". Many scientists mostly use mathematics to explain the nature or as representation of laws, theories, etc.

Margaret Rutherford also presented the article on models in the explanations of physics, 'the case of light' (Gilbert. 2000: 253-269). In physics, which is frequently called the fundamental science, and which explains everyday phenomena as well as unraveling 'the way

the world works', the use of models is a commonplace. Models in physics have been developed for centuries. The development of models is to help explain the phenomenon under examination, it is usually the case that this development leads to one particular model being accepted as the best available and further development expands or refines this model.

10. The modeling cycle or modeling method instructional model

David Hestenes described in the article that (Hestenes. 1987: 440-454) a model is a surrogate object, a conceptual representation of a real thing. The models in physics are mathematical models, which is to say that physical properties are represented by quantitative variables in the models. The cognitive process of applying the design principles of a theory to produce a model of some physical object or process is called model development or simply modeling. The strategy coordinates the application of scientific and mathematical knowledge to the modeling of physical objects and processes. Today the modeling method has developed to focus more on constructing and using scientific models to describe, explain, predict, and to control physical phenomena. This instruction is also based on the learning cycle. There are two stages of modeling method. They are model development and deployment as shown in Chapter 1, Figure 1.3. The two-stage modeling cycle has a generic and flexible format which can be adapted to any physics topic. In its high-school-physics implementation, the cycle is two or three weeks long, with at least a week devoted to each stage, and there are six cycles in a semester, each devoted to a major topic. Each topic is centered on the development and deployment of a well-defined mathematical model, including investigations of empirical implications and general physical principles involved. Throughout the modeling cycle the teacher has a definite agenda and specific objectives for every class activity, including concepts, introduction, conclusion, and misconceptions. Stage I of modeling method is designed to lead students systematically through the four main phases of model development: description, formulation, ramification, and validation. Stage II of modeling method is devoted to deployment of the model developed in stage I to a variety of new physical situations in a variety of the model from the specific context in which it was developed. The model may be deployed to describe, to explain, to predict, or to design a new experiment.

11. Research related to modeling method

Recently, Rutgers University (Rutgers University. 2006: 34-39) presented the article on the role of models in physics instruction. This article described meaning of model, classification of models, and engaging students in making and testing models. In general, physicists share several common ideas about models: 1) a model is a simplified version of an object or process under study 2) a model can be descriptive or explanatory 3) a model needs to have predictive power; 4) a model's predictive power has limitations. Models are classified into four types:

- 1) Models of objects
- 2) Models of interactions
- 3) Models of systems
- 4) Model of processes (qualitative, and quantitative)

This article suggested that tasks engaging students in deliberate modeling of real situation are engaged in problem solving or laboratory exercises.

Ibrahim Abou Halloun and David Hestenes (Halloun; & Hestenes. 1987: 455-462) designed a new method to teach problem solving in introductory mechanics. This method was based on modeling theory. This study was designed to test the two predictions: 1) student achievement in physics can be improved by incorporating a systematic discussion of modeling techniques into class lectures 2) student achievement can be further improved by employing the method of paradigm problems in recitation classes. There were 438 students who were students in the first semester of University Physics at Arizona State University in the fall of 1983. The students were divided into four groups, a control group of 119 students, and three treatment groups consisting of 235, 64, and 20 students. They found that the results of their pedagogical experiment could improve student performance.

David Hestenes also (Hestenes. 1987: 440-454) presented the article on an analysis the conceptual structure of physics. This study identified essential factual and procedural knowledge which was not explicitly formulated and taught in physics courses. It led to the conclusion that modeling of physical world should be the central theme of physics instruction. Such instruction focused on the construction and deployment of well-defined models of physical objects and processes. This article also presented the successful modeling development in mechanics and general model development.

Lorraine Grosslight, Christopher Unger, Eileen Jay, and Carol L. Smith (Grosslight ; et al. 1991: 799-822) studied about conceptions of models and their use in science of 33 7th-grade students of mixed-ability and 22 11th-grade honors students'. They found that students in both groups have conceptions of models that are basically consistent with a naive realist epistemology. Students' ideas became more sophisticated. However, they increasingly include the fact that models are designed for particular purposes, especially to help communication. Their finding suggested that students needed more experience using models as intellectual tools, more experience with models that provide contrasting conceptual views of phenomena, and more discussions of the roles of models in the service of scientific inquiry.

Malcolm Wells, David Hestenes, and Gregg Swackhamer (Wells; Hestenes; & Swackhamer. 1995: 606-619) presented the paper that described the design and development of a new method for high school physics instruction. Students were engaged in understanding the physical world by constructing and using scientific models to describe, explain, predict, and to control physical phenomena. Instruction is organized into modeling cycles which moved students systematically through all phases of model development, evaluation, and application in concrete situations. This study had three groups for comparison to be made between two control groups and one treatment group. The control groups were inquiry and traditional honors courses. The treatment group was modeling honors course. All three were high school physics courses in 1986-1987 with 24 students in each at Arizona, USA. The results showed that the modeling method could produce much larger gains in student understanding than alternative methods of instruction.

Ibrahim Halloun (Halloun. 1996: 1019-1041) presented schematic modeling as an epistemological framework for physics instruction. This model comprises the content core of scientific knowledge, and modeling is a major process for construction and employing knowledge in the real world. Modeling involves model selection, construction, validation, analysis, and deployment. Two groups of 87 Lebanese high school and college students participated in problem-solving tutorials that followed a schematic modeling approach. One group consisted of 59 high school students, the other was of 28 college students. Both groups improved significantly in problem-solving performance, and course achievement of students in the college group was significantly better than that of their control peers. This finding suggested that in physics instruction, the modeling process can be used in experimental activities as well as in learning textbook material and solving respective problems.

In conclusion, model and modeling is so important in science education. In physics we cannot study physics without an understanding in mathematics or even in other science areas. So since model is so important, teacher should encourage students in modeling method. There are two types of models: physical model, and mathematical model. Both of them are important. However, creating mathematical model is more complicated and needs more science skill. For this reason, if teacher can encourage students to create mathematical model, that will be useful in learning science.

12. The learning cycle or the 5-E instructional model

Anthony. W. Lersbach. (Lersbach. 1998: online) presented the learning cycle or the 5-E instructional model that it is an established procedure about how individuals learn. The learning cycle has five steps that are engagement, exploration, explanation, extension, and evaluation. This instructional model is also called the 5-E instructional model. The five steps are as follows:-

Engage: In this stage teachers want to create interest and generate curiosity in the topic of study; raise questions and elicit responses from students that will give teachers an idea of what they already know. This is also a good opportunity for teachers to identify misconceptions in students' understanding. During this stage students should be asking questions (Why did this happen? How can I find out?) Examples of engaging activities include the use of children's literature and discrepant events.

Explore: During the Explore stage students should be given opportunities to work without direct instruction from the teacher. Teachers should act as a facilitator helping students to frame questions by asking questions and observing. Using Piaget's theory, this is the time for disequilibrium. Students should be puzzled during this stage. This is the opportunity for students to test predictions and hypotheses and/or form new ones, try alternatives and discuss them with peers, record observations and ideas and suspend judgment.

Explain: During Explain, teachers should encourage students to explain concepts in their own words, ask for evidence and clarification of their explanation, and critically listen to one another's explanation and those of the teacher. Students should use observation and recording in their explanations. At this stage teachers should provide definitions and explanations using students' previous experiences as a basis for this discussion.

Extend: During Extend students should apply concepts and skills in new (but similar) situations and use formal labels and definitions. Teachers should remind students of alternative explanations and to consider existing data and evidence as they explore new situation. Explore strategies apply here as well because students should be using the previous information to ask questions, propose solutions, make decisions, experiment, and record observations.

Evaluate: Evaluation should take place throughout the learning experience. Teachers should observe students' skills, application of new concepts and a change in thinking. Students should assess their own learning. Ask open-ended questions and look for answers that use observation, evidence, and previously accepted explanations. Ask questions that would encourage future investigations.

Edmund A. Marek, Brian L. Gerber; and Ann M. Cavallo. (Marek; Gerber; & Cavallo. 2001. 1-16) presented that learning is constructing knowledge from experience. This tenet is central to the cognitive developmental model of Piaget and is the derivative for the learning cycle. The learning cycle is a teaching procedure which allows for many methods of teaching (e.g. laboratory experiments, questioning strategies, demonstrations, group work, field trips, the use of modern technologies). All of these common science teaching methodologies can be used within the three phases of learning cycle—exploring concepts, naming concepts, and expanding concepts.

13. Research related to the learning cycle

Alan Colburn (Colburn. 1997: 30-33) presented the article that learning cycle is a great strategy for middle school and high school science teaching because it works and places realistic demands on teachers and students. The learning cycle as an effective way to help students enjoy science, understands, and applies scientific processes and concepts to authentic situations. He also suggested that:

- Do the laboratory activities first
- Discuss the laboratory before verbally introducing content
- Require students to decide how laboratory findings will be communicated
- Change the test
- Begin changing teacher's role during the activity

- Have students invent the procedures to answer a laboratory question
- Continue changing teacher's role during the laboratory activity
- Be sure students apply what they learned in the content phase
- Learn the learning cycle

Lisa M. Blank (Blank. 1999: 486-506) presented the research that revised learning cycle by emphasizing formal opportunities for teachers and students to talk about their science ideas. The results showed that students in treatment classroom did not gain a greater content knowledge, but they did experience more permanent restructuring of their understandings.

Edmund A. Marek, Brian L. Gerber; and Ann M. Cavallo. (Marek; Gerber; & Cavallo. 1999: 275-278) presented four science education courses and found that the learning cycle is not a teaching method, but rather a teaching procedure. It allows for many methods of teaching. The learning cycle is an instructional model that: 1) allows science to be taught as it is structured; 2) implements the recommendations of the National Science Education Standards; and 3) reflects current constructivist learning theories.

Mary M. Bevevino, Joan Dengel, and Kenneth Adams (Bevevino; Dengel; & Adams. 1999. 275-278) presented the article that pointed out the learning cycle is an inquiry approach. Using the learning cycle format, the teachers can make learning meaningful for students and give students opportunities to use their prior knowledge and experiences to construct their own frames of thought.

Debby A. Chessin and Virginia J. Moore (Chessin; & Moore. 2004: 47-49) presented the paper that the 5-E model is a valuable tool. It allows teachers to structure science experiences. Therefore, students can use the processes of scientific inquiry to construct ideas rather than simply memorize seemingly unrelated facts. In this research, also was added a sixth "E" e-search which ties the five stages together and incorporates the use of technology into the model. The result showed that students can use basic science processes to develop conceptual understanding of a topic.

Anton E. Lawson (Lawson. 2001: 165-169) presented that the learning cycle method of teaching has proven effective at helping students construct concepts and conceptual systems as well as develop more effective reasoning patterns, primarily because it allows students to use if/then/therefore reasoning to test their own ideas and to participate in the knowledge construction process.

Lan Clark (Clark. 2003: 13-16) presented the article that he worked in a program to help classroom teachers develop their confidence in teaching science. He found that the approach for teaching science should be based on the learning cycle or the 5-E model. The five stages in this model can be implemented in an individual lesson or a series of lessons covering a topic or even as stages in the design of a unit.

In conclusion, the learning cycle or the 5-E model is a teaching procedure. The five stages are equally important and implemented in an individual lesson or series of lessons. This model is useful for teaching and learning science. It is an inquiry method. Even though sometimes it is adapted to be six "E", it is still the same as 5-E model. So science teachers should use this model to teach students.

CHAPTER 3

RESEARCH METHODOLOGY

This chapter describes both qualitative and quantitative methods that were used. It consists of framework of the study, research instrument, research procedures, data collection, and data analysis. This chapter has five major parts:

1. Framework of the study
2. Research instruments
3. Research procedures
 - 3.1 Developing the 4E-C learning model i.e., learning units and evaluation forms
 - 3.2 Examining efficiency of the model and other assessment forms
 - 3.3 Identifying scientifically G/T students
 - 3.4 Implementing the 4E-C learning model
 - 3.5 Evaluating the 4E-C learning model
4. Data collection
5. Data analysis

1. Framework of the Study

This research was to enhance creative productivity, in scientifically G/T students, by using the 4E-C learning model developed by the researcher. This learning model was administered to grade 10 scientifically G/T students as an elective physics course - Energy in Daily Life - at Mahidol Wittayanusorn School at Nakhon Pathom, Thailand, for 40 periods in the first semester of 2007.

2. Research Instruments

The research instruments used in the study are as follows:-

1. Student Product Assessment Form: this form was used to assess students' creative productivity pre-test scores from phase 2 and post-test scores from phase 3-4 of the 4E-C learning model.

2. Scientifically G/T students' attitude toward physics questionnaire: this form was used to assess scientifically G/T students' attitude toward physics both before and after they learned through the 4E-C learning model.

3. Students' learning reflection form: this form was used to determine students' learning reflection after they had learned through the activities of the 4E-C learning model.

4. Peer assessment form: this form was used to assess students' projects by students in the classroom, not in the project group assessed.

5. Team assessment form: this form was used to assess students' team working by students within the same group.

6. Student interview protocol: this form was used to interview 5 students' opinion of the 4E-C learning model after they had learned through the 4E-C learning model.

7. Teacher interview protocol: this form was used to interview 2 teachers' opinion of the 4E-C learning model after they used this learning model to teach scientifically G/T students.

8. Classroom observation form: this form was used to write down what the researcher observed in the classroom during teaching and learning all phases of the 4E-C learning model.

3. Research Procedures

This study was to develop learning model to enhance creative productivity of scientifically G/T students. The research procedures were as follows:

- 3.1 Developing the 4E-C learning model: learning model, learning units and assessment forms
- 3.2 Examining efficiency of the model and other assessment forms
- 3.3 Identifying scientifically G/T students
- 3.4 Implementing the 4E-C learning model
- 3.5 Evaluating the 4E-C learning model

3.1 Development of the 4E-C learning model

3.1.1 Developing learning model

1. Preparing

1.1 Studying related literature: this step involved studying and considering related literature regarding learning theories of G/T students, instruction and evaluation of G/T students, science instruction and evaluation, Thai National Science Curriculum Standard, program development for scientifically G/T students, program to enhance creative productivity, definition of giftedness, definition of scientifically G/T students, identification of G/T students, the three-ring conception of giftedness, Enrichment Triad Model, developing model in science education, the modeling method in physics, the learning cycle or the 5-E instructional model, and assessment strategy.

1.2 The researcher interviewed three experts who work in gifted education about teaching and learning relevant to scientifically G/T students. The researcher also interviewed three physics teachers who taught physics to scientifically G/T students for at least three years. This step was to be a part of what should be developed in scientifically G/T students.

1.3 The researcher surveyed 10 teachers' understanding of G/T services. They filled in the G/T service questionnaire based on Sherry K. Bain (Bain; Bourgeois; & Pappas. 2003: 166-172). This step was to survey how teachers understand the theory of giftedness, especially Renzulli's theory. The result was used to support the research question.

1.4 The researcher also surveyed 144 scientifically G/T students who were in Grade 12 at Mahidol Wittayanusorn School in the second semester of 2005. They filled in the students' opinions of physics content and science journal questionnaire developed by the researcher. This step was to survey scientifically G/T students' opinions of each physics topic and their interest of science journal. The results of this survey were used to be a part of choosing physics content to teach scientifically G/T student in this study.

2. Designing learning model

From preparation step, the researcher designed the 4E-C learning model that comprised 4 phases, including evaluation in every phase. They are Encouraging Issues, Experiments for Modeling, Creation of New Model, and Exhibition shown in Figure 4. The 4E-C learning model was developed as follows:-

Phase 1: Encouraging Issues, it is the beginning phase of this model. First of all, a teacher divides students into small groups and thereafter gives them an interesting topic that they are going to study. The teacher allows students to study and search any issues or information about that topic by themselves. Then, each group presents their issues and discusses that topic in a classroom. Lastly the teacher and students together make conclusion

on every topic presented by students. In this phase the teacher acts as a coordinator of the discussion. The teachers observe students' presentations and discussion in the classroom.

Phase 2: Experiments for modeling, this is the second phase of the model. It is a guided inquiry phase. Teachers are a facilitator. First, the teachers divide students into small groups and explain how to create physics model by following modeling method. This phase consists of experiments that enhance modeling. Students are trained in designing by themselves the experiments for physics model, both physical and mathematical models by themselves. After that they present their experimental designs and models in the classroom. Teachers give them suggestion to improve those experiments. In this phase teachers assess students' product and presentation by using Student Product Assessment Form. Students within group discuss and answer questions to report their learning reflection from each activity by using students' learning reflection form at the end of every experiment designing report.

Note: these two phases can be alternately switched back and forth until the teachers are satisfied that students are ready to create their own real physics models, by checking student's creative productivity scores. These scores can be assessed by student product assessment form. If students' scores in the last activity are higher than those in the first activity, then students are ready to proceed to phase 3. Also, the teachers can conclude from students' learning reflection form on the students' ability whether or not they are ready to do project in phase 3. Then, students are allowed to go to the next phase. These two phases should consume 1/3 time of all phases. Before going to the third phase students should come up with questions involving problems in phase 1 and 2. Teacher should help students asking questions that guide them to thinking about variables in their projects in phase 3.

Phase 3: Creation of new model, this is the third phase of the learning model. It is an independent inquiry phase. Teachers divide students into small groups. Each group finds out what topic it wants to create a new physics model for. Students in each group design experiment to create new model or adapt old experiments to create physics model in the new situation. Teachers should give them advice for doing experiment and creating physics model that is either mathematical model or physical model. This phase should allow students to enough time to do their products. Teachers should provide many resources for students to study and search for any information concerning their products. After that students present their products in the classroom. Teachers assess students' products by using Student Product Assessment Form. Also all students assess other groups by using peer assessment and students within a group assess each other by using team assessment.

Note: there should be at least three teachers for assessing students' creative productivity by using Student Product Assessment Form.

Phase 4: Exhibition, this is the last phase. Teacher should arrange the exhibition for presentation of students' products. This phase gives students an opportunity to present and share their own products to their friend in the class and other students who attend the presentation. This phase will make students feel more confident with their ability and practice communication skill. Teachers assess this phase by using presentation item in Student Product Assessment Form.

3.1.2 Designing learning units by following 4 phases of the 4E-C learning model

- This design was one course for one cycle of the 4E-C learning model.
- Planning of physics units: studying National Science Curriculum Standards in the basic education curriculum B.E. 2544, the aims of formulation of science teaching and learning, and sub-strand 4 and 5.
- Determining resource and learning units: there were 6 physics units. Unit 1-5 were in phase 1-2 of the 4E-C learning model. The last unit, unit 6, was in phase 3-4 of this learning model. These units consist of basic components of unit plans that are title, concept, objectives, materials and equipment, time frame, activities, and assessment. All activities focused on creating physics model that is either mathematical model or physical model. The activities of learning units are shown in Table 2.

TABLE 2: The activities of 6 learning units following 4 phases of the 4E-C learning model

Learning Unit	Activity	Phase of the 4E-C learning model
1. Energy transfer	- Discussion of energy issues in Thailand - The creation of mathematical model to show the relation of potential and kinetic energy - Presentation of the result in the classroom	1 and 2
2. Electric energy	- Discussion of electric energy issues in Thailand - The creation of physical model to show what factor has the effect on the efficiency of motor and how - Presentation of the result in the classroom	1 and 2
3. Heat	- Discussion of the use of heat in daily life issues - The creation of a mathematical model to show the transformation of mechanical energy into heat - Presentation of the result in the classroom	1 and 2
4. Nuclear energy	- Discussion of nuclear energy issues - The creation of physical model to show chain rule reaction - Presentation of the result in the classroom	1 and 2
5. Solar energy	- Discussion of the use of solar energy - The creation of a mathematical model to show what factors affect the working of solar cell panel and how - Presentation of the result in the classroom	1 and 2
6. Independent study (physics project)	- Present project topic - Conducting project to create physics model - Presentation of projects by inviting any student In school who are interested in this presentation	3 and 4

- Planning lessons: studying writing inquiry lesson plans to enhance creative productivity.
- Determining physics lessons: these lessons consist of a list of elements that are title, objectives, concepts, materials and equipment, instructional activities, and assessment.
- Writing documents: The researcher set the drafts of goals, learning outline, and expected learning outcomes of Energy in Daily Life course. The researcher developed a Teacher's Guide Book and Student's Guide Book. Teacher's Guide Book consists of the necessary information on the teaching and learning of scientifically G/T students and lesson plans. Student's Guide Book consists of activities, learning resources, work sheet, and assessment forms. See Appendix 2.

3.1.3 Developing assessment forms

3.1.3.1 *The Student Product Assessment Form*: This form was used for assessing scientifically G/T students' creative productivity after they had learned in the first and second phase and after they had completed the third and the last phase of the 4E-C learning model. The researcher adapted assessment form based on Student Product Assessment Form of Reis and Renzulli (1991: 128-134) and also performance assessment form of IPST (IPST. B.E. 2543: 306-310). This form is an authentic assessment using rubric scoring, analytic score. The Student Product Assessment Form of Reis and Renzulli is an assessment form used for assessing G/T students' creative productivity. This form can be used to assess any product of G/T students. Performance assessment form of IPST is also authentic assessment used for assessing students' science projects.

3.1.3.2 *Scientifically G/T students' attitude toward physics*: This questionnaire was used for assessing scientifically G/T students' attitude toward physics after they had learned through 4E-C learning model. The researcher adapted questionnaire based on Jayne and Kenneth (Stake; & Mares. 2001: 1065-1088). Jayne's questionnaire is an evaluation form for evaluating G/T students' attitude toward science for summer enrichment program.

3.1.3.3 *Peer assessment form*: this form was developed by the researcher for assessment of student project scores by students in the classroom who were not in the same project group.

3.1.3.4 *Team assessment form*: this form was developed by the researcher for assessment of student's team work by students within a group.

3.1.3.5 *Students' learning reflection form*: the researcher developed students' learning reflection form that students within a group reflected their learning in each activity.

3.1.3.6 *Student interview protocol*: this form was developed by the researcher to interview students about their opinions of the 4E-C learning model.

3.1.3.7. *Teacher interview protocol*: this form was developed by the researcher to interview two teachers about their opinions of using the 4E-C learning model.

3.1.3.8 *Classroom observation form*: this form was developed by the researcher to record the results of observing students' and teachers' behavior in the classroom.

3.2 Examining efficiency of the model and other assessment forms

3.2.1 Examining learning model

The teacher's guide book and the student's guide book were examined by advisors, after that these books were considered for content validity by 5 experts two of whom were subject-matter specialists, one educational measurement and assessment specialist, and two science education specialists. The experts considered content validity by using index of congruence (IC) and suggested some modification of the documents. After that the researcher revised documents following experts' suggestions. The results of IC can be seen in Appendix 1.

3.2.2 Examining the evaluating forms

3.2.2.1 The Student Product Assessment Form was examined by advisors. After that construct validity was considered by the same 5 experts. The construct validity was considered by using IC. Then, the researcher revised this form following experts' suggestions.

3.2.2.2 Scientifically G/T students' attitude toward physics questionnaire was examined by advisors. After that construct validity was considered by the same 5 experts. The construct validity was considered by using IC. Then, the researcher revised this form following the experts' suggestions.

3.2.2.3 Students' learning reflection form was examined by advisors. After that it was considered with respect to proper use of language and form by the same 5 experts. Then, the researcher revised this form following the experts' suggestions.

3.2.2.4 Peer assessment form was examined by advisors. After that construct validity was considered by the same 5 experts. The construct validity was considered by using IC. Then, the researcher revised this form following the experts' suggestions.

3.2.2.5 Team assessment form was examined by advisors. After that construct validity was considered by the same 5 experts. The construct validity was considered by using IC. Then, the researcher revised this form following the experts' suggestions.

3.2.2.6 Student interview protocol was examined by advisors. After that it was considered with respect to the proper use of language and form by the same 5 experts. Then, the researcher revised this form following the experts' suggestions.

3.2.2.7 Teacher interview protocol was examined by advisors. After that it was considered with respect to the proper use of language and form by the same 5 experts. Then, the researcher revised this form following the experts' suggestions.

3.2.3 Conducting pilot study of the 4E-C learning model

Examining efficiency of the 4E-C learning model and assessment forms by conducting pilot study: the aim of the pilot study was to check the activity plans and familiarize the teachers with the 4E-C learning model. The processes were as follows:

3.2.3.1 Selecting and preparing teachers: Two volunteer physics teachers at Mahidol Wittayanuson School who had taught scientifically G/T students for at least 5 years were selected to participate in this study. They were prepared for good understandings of the three-ring conception of giftedness, Enrichment Triad Model, and the modeling method by participating in a one day Teacher Preparation Workshop for 8 hours.

3.2.3.2 Selecting students: there were 16 scientifically G/T students in grade 10 of the second semester of 2006 who voluntarily took Energy in Daily Life course as the elective physics course for 40 periods.

3.2.3.3 Conducting pilot study: 120 scientifically G/T students filled in students' attitude toward physics. Also, 16 scientifically G/T students who took Energy in Daily Life filled in students' attitude toward physics before they took this course. The researcher and teachers, selected to participate in this study, taught scientifically G/T students by using the 4E-C learning model for 40 periods. Moreover, the researcher and the teachers assessed the students by using the Student Product Assessment Form. During this time, the researcher also observed teaching and learning events in the classroom. After that the researcher and the two teachers discussed events in order to revise the activity plans. At the end of the pilot study, scientifically G/T students filled questionnaire of scientifically G/T students' attitude toward physics. All students in the classroom assessed other group projects by using peer assessment form and also students within a group assessed each other by using team assessment form.

3.2.4 Statistics for examining tools

3.2.4.1 *Validity*: IC technique was employed to examine content validity and construct validity of learning units. Also, IC was employed to examine construct validity of the student product assessment form, peer assessment form, team assessment form, and scientifically G/T students' attitude toward physics.

3.2.4.2 *Reliability*: Cronbach's alpha coefficient was employed to examine reliability of the student product assessment form, peer assessment, team assessment, and scientifically G/T students' attitude toward physics

3.2.4.3 *Discrimination*: The t-test independent was used to test mean scores between highest score group and lowest score group of peer assessment and team assessment forms. The 30% technique was used to divide those two groups. Significant differences of both mean scores indicate that those forms have discrimination.

3.3 Identification of scientifically G/T students

3.3.1 *Studying identifying process*: studying identification of G/T students, characteristics of scientifically G/T students, and identification of scientifically G/T students.

3.3.2 *Identifying scientifically G/T students*: The researcher used the popular identification process of Mahidol Wittayanosorn School, the first science high school for G/T students in mathematics and science in Thailand. Identifying process of this school can be accepted as on par with identification process at international level. The identification was as follows:

1. Students' GPA: Students must have GPA of science and mathematics not less than 3.00, and GPAX of every subject not less than 3.00.
2. Paper-pencil tests: 480 students who pass paper-pencil mathematics and science tests are accepted to the academic camp.
3. Academic camp: 480 students join academic camp for 4 days and 3 nights. While in the camp students do many science activities and also take three tests. They are unseen mathematics, creative science, and problem solving tests. Moreover, students take SAT, IQ, SDQ, and YSR tests.

The criteria for identification as gifted students

1. T-score from SAT is not less than 60.
2. IQ score is not less than 110.
3. SDQ and YSR are not negative.
4. Top 240 students are selected by experts.

3.4 Implementing 4E-C learning model or conducting main study

3.4.1 Population and sample

Subject

1. Scientifically G/T students, who were in grade 10 in the first semester of 2007 at Mahidol Wittayanusorn School, Nakhon Pathom, Thailand.
2. All teachers who at the time taught physics at Mahidol Wittayanusorn School, Nakhon Pathom, Thailand.

Sample

1. 22 scientifically G/T students in grade 10, who voluntarily took Energy in Daily Life as elective physics course in the first semester of 2007 at Mahidol Wittayanusorn School.
2. Two teachers who had teaching experience in scientifically G/T for at least 5 years at Mahidol Wittayanuson School, Nakhon Pathom, Thailand.

3.4.2 Content of study

Content used in this study was energy involved in daily life. This content was related to Sub-strand 4 and 5. The researcher developed 6 learning units. There were 5 learning units and in phase 1-2 of the 4E-C learning model. In phase 3-4, there was one learning unit that was unit 6, independent project or research. In this phase scientifically G/T students created new physics model, either mathematical or physical about energy in daily life and then presented their own products in phase 4. Each unit 1-5 consists of one experiment for modeling, see an example in Appendix 2.

The contents of learning units were as follows:

- Unit 1: Energy transfer
- Unit 2: Electric energy
- Unit 3: Heat
- Unit 4: Nuclear energy
- Unit 5: Solar energy
- Unit 6: Independent topic, but still involving energy in daily life

3.4.3 Implementation

This step was for using the 4E-C learning model in a real classroom in which the following sections were conducted.

1. *Selecting and preparing teachers*: two physics teachers, who were involved in the pilot study were selected to participate in the main study. They were prepared again for better understandings of the 4E-C learning model by participating in a one day Teacher Preparation Workshop for 8 hours.

2. *Selecting students*: 22 scientifically G/T students who were in grade 10 in the first semester of 2007 and took Energy in Daily Life as elective physics course for 40 periods.

3. *Implementing*:

3.1 Scientifically G/T students filled students' attitudes toward physics before they learned the course through 4E-C learning model.

3.2 The teachers and students discussed the learning tasks in this course and the 4E-C learning model. The other hours were for instructing by following phases of the 4E-C learning model.

3.3 During instruction, the researcher observed and recorded interesting classroom events. Students' learning outcomes of phase 1 and 2 learning were assessed by using student product assessment form. In phase 3, students conducted their own projects to create new physics model that involved in energy in daily life. In the last phase students presented their models in the exhibition. After students finished in the third and the last phase, they were assessed by using the student product assessment form.

3.4 After instruction, the researcher discussed about classroom events with teachers to know what should be improved for teaching and learning in the classroom.

3.5 Evaluating the 4E-C learning model

3.5.1 Evaluating activities: Scientifically G/T students were assessed with respect to their creative productivity during teaching and learning in phase 1-2 by using Student Product Assessment Form. After that they were assessed again in phase 3-4 of learning model with the same assessment form. Their creative productivity scores were then compared and analyzed.

3.5.2 Grading students' scores: The percent of students' average scores from phase 2 were combined with students' scores from phase 3 and 4 to consider students' creative productivity scores. Also, students' scores from peer assessment, team assessment, and

participation in the classroom were collected. Then, all scores were included to assign students' rating grade as follow:

80% - 100%	=	excellent
70% - 79%	=	good
60% - 69%	=	pass
Less than 60%	=	not pass

3.5.3 After the completion of teaching and learning, all the students filled in students' attitude toward physics questionnaire.

3.5.4 The researcher interviewed 5 volunteers of scientifically G/T students from each group for their opinions of the 4E-C learning model by using the student interview protocol.

3.5.5 The researcher interviewed the teachers' opinions of the 4E-C learning model by using the teacher interview protocol.

4. Data Collection

Data were collected from two major sources: scientifically G/T students and participating teachers. The sources of data from each group were as follows:-

4.1 Developing learning model

4.1.1 Students: data were gathered from students' opinions of physics content and journals by questionnaire before developing learning model.

4.1.2 Teachers: data were gathered from G/T service questionnaire before developing learning model.

4.1.3 Experts: data were gathered from expert interview protocol

4.2 Implementing learning model

4.2.1 Students: data on students were gathered during implementation phase. These data were obtained at different times.

4.2.1.1 The students' creative productivity during learning was compared between the score in the second phase and the third phase of the 4E-C learning model by using the student product assessment form.

4.2.1.2 Data were also gathered from students' attitude toward physics questionnaire before and after using the 4E-C learning model.

4.2.1.3 Qualitative data were collected from scientifically G/T students' learning reflection from each activity and from the student interview protocol.

4.2.2 Participating teachers: qualitative data were collected from the teacher interview protocol after they had participated in this study.

5. Data Analysis

5.1 Statistics for Hypotheses Testing

The t-test for dependent sample was used in this study.

5.1.1 The t-test for dependent sample was employed to compare students' creative productivity pre-test and post-tests scores to test the first hypothesis. The SPSS program for Windows was used to test significance.

5.1.2 The t-test for dependent sample was used to compare students' attitude toward physics pre-test and post-test scores to test the second hypothesis. The SPSS program for Windows was used to test significance.

In addition, the basic descriptive statistics such as median was used to analyze scores from team assessment form. Also, the simple correlation technique was used to analyze correlation between students' project scores assessed by teacher and peer.

5.2 Qualitative data analysis

Qualitative data were analyzed by using analytic induction.

5.2.1 The data before developing learning model were analyzed. The researcher used the results of students' opinions of physics content and journals, G/T service questionnaire, and expert interview to develop the 4E-C learning model.

5.2.2 The data from students' learning reflection were analyzed. The researcher reported the results of students' learning reflection to explain how students' learning reflection was after they learned through the 4E-C learning model. Then, the research analyzed these data by using analytic induction.

5.2.3 Student interview data were summarized from students' interview tape scripts. The researcher analyzed students' opinions of the 4E-C learning model to explain how students' opinions of the 4E-C learning model were after they learned through the 4E-C learning model.

5.2.4 The researcher reported teachers' opinions of the 4E-C learning model. Then the researcher analyzed these data to explain how teachers' opinions of the 4E-C learning model are after they taught by using the 4E-C learning model.

CHAPTER 4

FINDINGS

This chapter presents the findings of enhancing creative productivity by using the 4E-C learning model for scientifically G/T students. The findings are presented in the following order: 1) learning model development; 2) learning model implementation and evaluation.

Learning Model Development

There were two major phases of learning model development: preparation and design.

1. Preparation of the learning model:

1.1 The researcher studied related literature regarding learning theories of G/T students, instruction and evaluation of G/T students, science instruction and evaluation, Thai National Science Curriculum Standard. This information was used to design a draft of the learning model.

The researcher gathered data on physics content that scientifically G/T students like the most by using students' opinions of physics content and journals questionnaire developed by the researcher. Also, the researcher interviewed experts about what should be developed for scientifically G/T students. The collected data and gained information were to be used for developing learning model.

The result of students' opinions of physics content and journals indicated that students like mechanics the most and they want to conduct more experiments.

The result of expert interview indicated that the skill that should be developed in scientifically G/T students is higher-order thinking, especially problem solving and creative thinking. Also, the learning model should allow students to do independent study.

2. Designing of the learning model:

2.1 The researcher developed the 4E-C learning model based on the three ring conception of giftedness, enrichment triad model, modeling method, and the 5-E instructional model. The theory of the learning model was based on the three-ring conception of giftedness. The four phases of the 4E-C learning model were based on the enrichment triad model as follow: 1) encouraging issues, 2) experiments for modeling, 3) creation of new model, and 4) exhibition. Another, the modeling method was used with the second and third phase of the 4E-

C learning model as instructional strategy. Activity plans and assessment forms were used for each phase of the 4E-C learning model. More detail of the 4E-C learning model documents are shown in Appendix 2, and assessment forms are shown in Appendix 3.

2.2 The 4E-C learning model documents and assessment forms were examined by advisors and experts. The results of experts' consideration are shown in Appendix 1.

2.3 The researcher revised these documents following experts' advice before using them in pilot study.

2.4 Identifying scientifically G/T students: the researcher followed the identifying process of Mahidol Wittayanosorn School. Identifying process of this school is accepted as on par with identification process at international level. The identification was as follows:

1. Students' GPA: Students must have GPA of science and mathematics not less than 3.00, and GPAX of every subject not less than 3.00.
2. Paper-pencil tests: 480 students who pass paper-pencil mathematics and science tests are accepted to the academic camp.
3. Academic camp: 480 students join academic camp for 4 days and 3 nights. While in the camp students do many science activities and also take three tests. They are unseen mathematics, creative science, and problem solving tests. Moreover, students take SAT, IQ, SDQ, and YSR tests.

The criteria for identification as gifted students

1. T-score from SAT is not less than 60.
2. IQ score is not less than 110.
3. SDQ and YSR are not negative.
4. Top 240 students are selected by experts.

2.5 The researcher selected two participating teachers from Mahidol Wittayanusorn School. They participated in the pilot study and the main study by using 4E-C learning model in implementation phase.

2.6 In pilot study, the researcher used 4E-C learning model for elective physics course, Energy in Daily Life, for 40 periods in the second semester of 2006. There were 16 scientifically G/T students in grade 10 who attended this course in the pilot study. The purposes of the pilot study were to try out the activity plans of the 4E-C learning model, assessment forms, and interview protocol. Also, it was to familiarize the participating teachers with the 4E-C learning model. During pilot study, the scientifically G/T students' attitude toward physics questionnaire was used for 120 scientifically G/T students in grade 10 of the second semester

of 2006. Then, the learning units were later used by two participating teachers to teach 16 scientifically G/T students in grade 10 as an elective physics course, Energy in Daily Life, for 40 periods at Mahidol Wittayanusorn School, Nakhonpathom, from December 1st, 2006 – February 28th, 2007. The reliability of assessment forms was determined by Cronbach's alpha coefficient. The results of calculating reliability of assessment forms are shown in Table 3.

TABLE 3 : Reliability of assessment forms

Assessment form	Reliability
1. Student Product Assessment Form	.883
2. Students' attitude toward physics questionnaire	.915
3. Peer assessment form	.815
4. Team assessment form	.915

The results of calculating Cronbach's alpha coefficient by using SPSS indicate that these forms have high reliability.

Also, the discrimination of team assessment and peer assessment form was determined by t-test. It is expected that if t-test is significantly different, those assessment forms have discrimination. The results of discrimination of assessment forms are shown in Table 4.

TABLE 4: Discrimination of peer assessment and team assessment form

Assessment form	df	t	P
1. Peer assessment form	8	14.000**	.000
2. Team assessment form	8	8.636**	.000

The results of comparison between mean scores of the highest and the lowest score groups by using t-test in SPSS indicate that the mean scores are significantly different at the .01 level. The results show that these forms can discriminate students' team working assessed by peers and students within a group.

Regarding the pilot study, it was found that scientifically G/T students could search, discuss, and debate contemporary issues about energy in phase 1 of the 4E-C learning model. In phase 2, they could design and conduct experiments using instruments set up by teachers.

Also, in phase 3, they could conduct their own projects to create new physics models. In the last phase, they could give interesting presentation by using multimedia. However, scientifically G/T students wanted to spend more time to conduct their projects. Also, in some experiments, there was the limitation of instrument. They had to wait until other groups finished using it. Besides, adapting motor experiment could be used to create physical model instead of mathematical model. Another finding was that students did not like writing down their learning reflection on students' self-report because they had no time for writing those reports.

As a result of adjusting the activities, time for the first phase was reduced. Meanwhile, time for the second and the third phases were extended. Also, Adapting motor experiment was employed to change from the creation of a mathematical model to a physical model, instead. Moreover, students' self-reports were combined as part of students' learning reflection forms that would be in each experiment report instead. Students within group had to work together to reflect their learning and write down on students' learning reflection forms in each experiment report.

Learning Model Implementation and Evaluation

The findings of the pilot study were used to revise the activities and the time of the 4E-C learning model. The 4E-C learning model was implemented with 22 scientifically G/T students in grade 10 at Mahidol Wittayanusorn School in the first semester of 2007 (May 15th – August 31st, 2007). It took 40 periods. Students were divided into five groups. There were four groups with four students each and another group with six students.

The data were collected by both quantitative and qualitative forms. They were collected by using 1) Student Product Assessment Form, 2) Peer assessment form, 3) Team assessment form, 4) Scientifically G/T students' attitude toward physics questionnaire, 5) students' learning reflection form, 6) student interview protocol, and 7) teacher interview protocol.

The data were analyzed as follow:

1. Testing of research hypotheses

While implementing the 4E-C learning model, the data were collected to test the research hypotheses as follows:

1.1 Pre-and Post-test

Hypothesis 1: students who learned through the 4E-C learning model, Energy in Daily Life course, have higher creative productivity scores than those taken before they learned through the 4E-C learning model.

According to this research hypothesis it is expected that students working in small groups to design and conduct experiments, analyze data, and create physics models from those data can improve their creative productivity to a higher level.

For pre-test, students' creative productivity scores were assessed by using Student Product Assessment Form while they were conducting experiments in the second phase that consisted of five learning units. For post-test, students' creative productivity scores were assessed by using Student Product Assessment Form to assess their product after they finished their projects and presentation in the third and the last phase that was the last learning unit. For pre-and post-test both participating teachers and the researcher assessed them.

The students' creative productivity pre-test and post-test mean score and the t-test for dependent sample were used to test the significance of the difference of gained scores, the result of which is shown in Table 5.

TABLE 5: The t-test results of students' creative productivity

Test	M	SD	df	t	P
Pre-test	35.35	3.09	21	6.144 ^{**}	.000
Post-test	39.47	0.37	21		

According to Table 5, the mean post-test students' creative productivity scores are higher than the pre-test.

The t-test results of students' creative productivity pre-test and post-test score indicate that the mean scores are significantly different at the .01 level. Therefore, the students' creative productivity after learning through the 4E-C learning model is significantly higher.

To see how different pre-test and post-test score of each student is, a graph of comparison of those scores is shown in Figure 9.

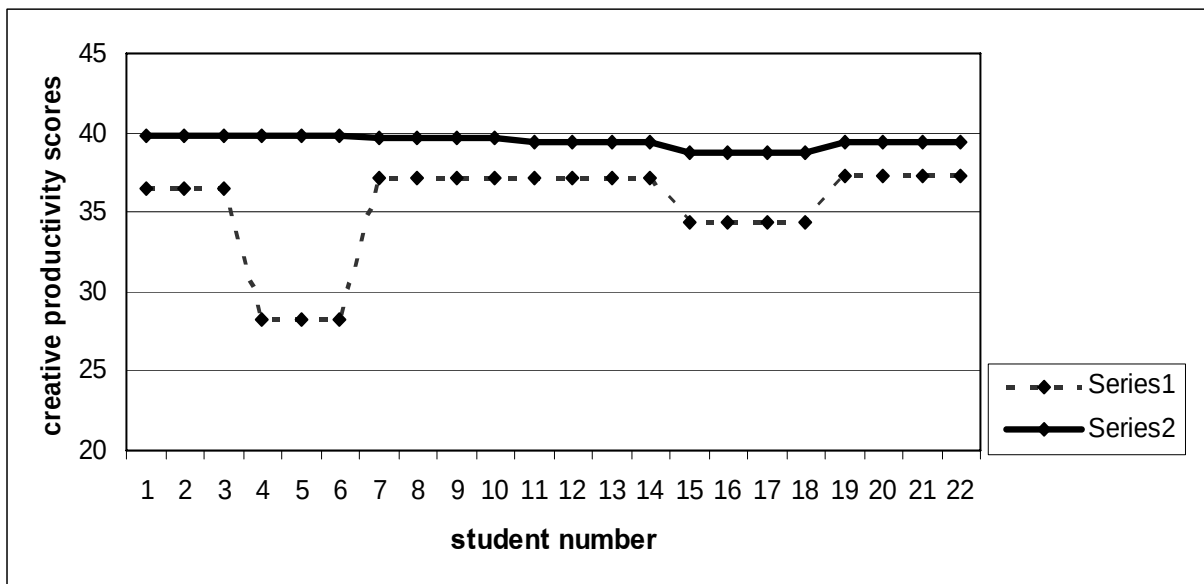


Figure 9 The comparison of students' creative productivity pre-test scores and post-test scores

For students' projects there were 5 projects as follows:

1. The electric energy consumption in Mahidol Wittayanusorn School
2. Study of the relation between light property and heat produced from light
3. Nuclear electric power plant
4. The effect of the angles on the efficiency of solar cell panel
5. The effect of electric line temperature on the rotation of motor

The examples of students' projects are shown in Appendix 4.

1.2 The students' attitudes toward physics

Hypothesis II: students who learn through the 4E-C learning model, Energy in Daily Life, have higher post-test attitudes toward physics scores than pre-test attitudes.

According to this hypothesis it is expected that students who learn through the 4E-C learning model have higher scores in attitudes toward physics. The students' attitudes toward physics scores were assessed by using scientifically G/T students' attitudes toward physics questionnaire before they learned through the 4E-C learning model. Also, again they were assessed by the same questionnaire after they had learned through this model.

The students' attitudes toward physics pre-and post-test scores and a paired-samples t-test was used to test the significance of difference of mean scores, the result of which is shown in Table 6.

TABLE 6: The t-test results of students' attitudes toward physics

Test	M	SD	df	t	p
Pre-test	2.51	0.52	21		
Post-test	3.84	0.33	21	14.052**	.000

The t-test scores of students' attitudes toward physics indicate that the mean scores are significantly different at the .01 level. Therefore, the students' attitudes toward physics are significantly higher.

Figure 10 shows the difference of attitudes toward physics of each student before and after learning through the 4E-C learning model.

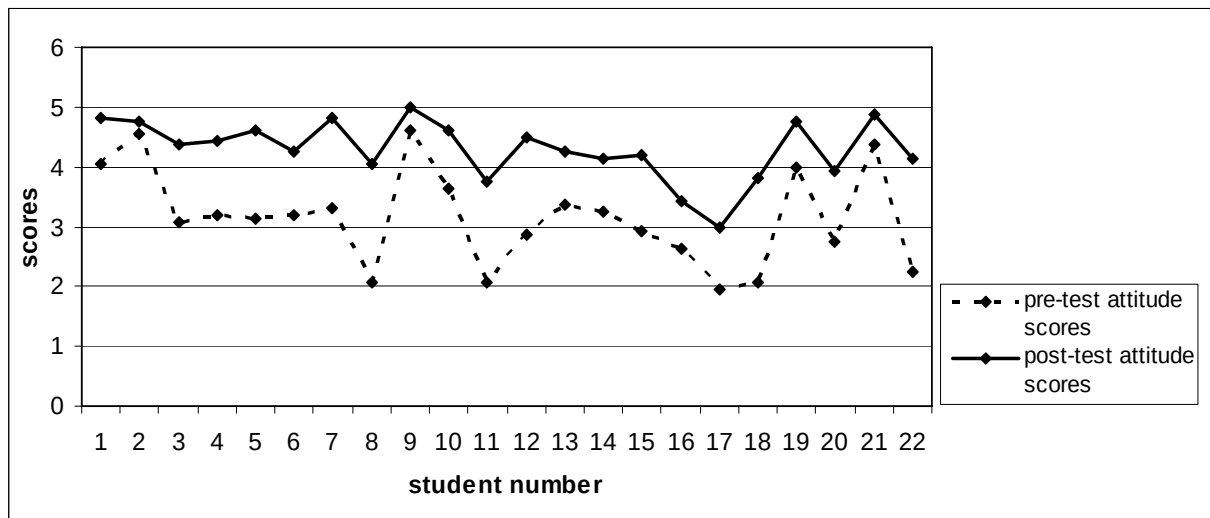


Figure 10 The comparison of pre-test and post-test students' attitudes toward physics scores

1.3 The students' team assessment score

These data show that students within each group have no different team assessment score. This result is to support the hypothesis I that if students have no different team assessment scores, students' creative productivity scores are confirmed. The students' team assessment scores are shown in Figure 11.

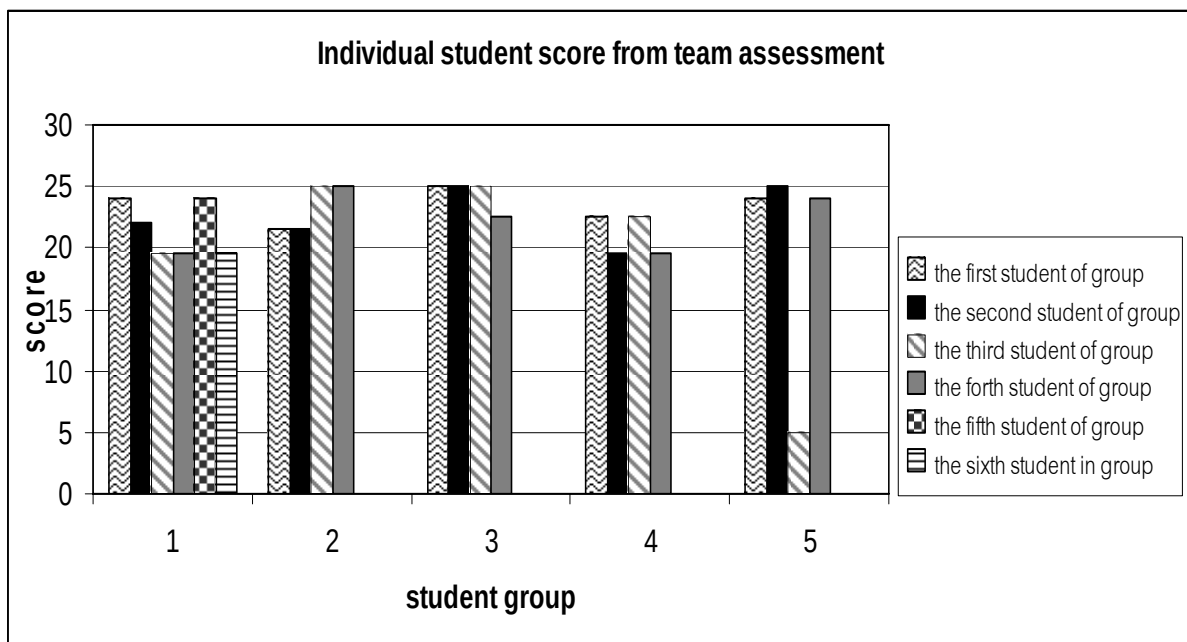


Figure 11 The comparison of students' team assessment score within group

According to Figure 11, there is an obvious indication that each student in the same group works equally. There is only one student in the fifth group getting score less than other three students. The reason probably is that student was absent one time because she had an appointment with teacher dormitory. Since there were only 5 laboratory works, she couldn't make it once that may effect on her team scores. However, in conclusion, they share and help each other to work in any activity. Therefore, the results support hypothesis I.

1.4 The students' peer assessment score

These scores are supporting hypothesis I that students' creative productivity scores from each project group assessed by teachers are reliable. The students' project scores assessed by teachers and students in the classroom were compared, the results of which is shown in Table 7.

TABLE 7: The correlation of students' project scores assessed by teachers and students

Score	df	r	t	P
From teacher and students	3	.861	2.932	.061

According to Table 7, the correlation is not significant at .01 level. This result indicates that the students' projects scores assessed by teachers and students are not correlated.

Qualitative data

The qualitative data from implementation of the 4E-C learning model were collected by students' learning reflection form, student interview protocol, classroom observation form, and teacher interview protocol.

The results of these data analyzed by using analytic induction are as follows:

1. students' learning reflection

Group 1: students could satisfactorily explain concepts of each experiment, could adapt their experimental design by using other instruments, could explain what enrichment their knowledge was, could explain what new experiences they got from conducting experiments, and could also apply their learning from those experiments in the new situations.

Note: this group could apply their model to explain new situation such as they applied chain reaction physical model to explain the binary fission of bacteria.

Group 2: students could explain concepts. They could adapt their experimental design by using other instruments. They could also explain what the enrichment to their knowledge were, and explain what new experiences they got from conducting experiments. They could apply their learning from those experiments in the new situations, but not all experiments. There was one experiment that they couldn't apply their learning in the new situation.

Group 3: students could satisfactorily explain concepts. They could adapt their experimental design by using other instruments, and could explain what the enrichment to their knowledge were, and could explain what new experiences from most of experiments were. They could apply their learning from some experiments in the new situations. However, there were two experiments that they couldn't apply their learning in the new situations.

Note: this group could interestingly adapt experimental design such as they adapted the experiment of Unit 1, energy transfer, by using light gate sensor instead of time counting because they could get more valid and reliable data.

Group 4: students could satisfactorily explain the concepts. They could adapt their experimental design by using other instruments, could explain what the enrichment to their

knowledge were, could explain what new experiences were, and could also apply their learning from those experiments in the new situations.

Group 5: students could satisfactorily explain the concepts. They could adapt their design by using other instruments, could explain what the enrichment to their knowledge from most of experiments were, could explain what some new experiences were, and could also apply their learning from some experiments in the new situations.

2. Observations of teaching and learning in the classroom, the results are shown in Table 8.

TABLE 8 : Observations of teaching and learning in the classroom

List	result
Students' behavior	1. Each group discussed topics about Thailand's energy issues and global energy issues. Each group presented their topics that students could discuss and debate by using scientific reasoning and also could integrate background knowledge to debate those topics. However, students wanted to have more time to discuss and debate. Each group was so active and stayed focus on doing first laboratory work. Students asked many questions about activity. Each group was good at sharing work within the group. They shared and discussed many ideas all the time. They could finish this laboratory work on time and present their result. 2. In the second laboratory work, each group discussed about issues on electric energy, especially electric power plants. They could tell disadvantage and advantage of each kind of electric power plants. After that they conducted adapting motor experiment. In this activity, they had many problems with the instruments, but they didn't give up and tried very hard to solve those problems. There was only one group that could overcome the difficulty. Other groups could not, but they made appointments with laboratory teacher to continue working outside schedule. One of groups had an interesting idea to conduct experiment. They wanted to study the angle factor that effected to the rotation of motor. The teacher

List	result
Students' behavior	suggested that they could study this factor as a project. Finally, every group could solve the problem and succeed with excellent solution. Also, their presentation of laboratory work was equally good. 3. In the third laboratory work, each group discussed issues about using heat in daily life. One of the interesting issues that they discussed was using geothermal energy to generate electricity. After that they conducted a laboratory experiment to convert mechanical energy into heat energy. But due to insufficient sets of some instruments, each group had to take turn to conduct laboratory activity outside schedule by arrangement with laboratory teacher. From observing them conducting this activity, every group showed task commitment and high motivation in doing this activity. They could understand how to use instruments so easily such as thermal sensor and presented the result of laboratory work very well. 4. In the fourth laboratory activity, students discussed and debated issues about nuclear energy both its advantage and disadvantage, including nuclear energy power plants. Students played nuclear energy post-it game to learn about nuclear energy from playing game. They liked it a lot and looked so happy. After that they conducted creating physical model of nuclear fission. They could so ingeniously create these models. Every group had different types of models. They could also come up with very good presentations. 5. In the fifth laboratory activity, students discussed and debated issues about solar energy. They were very interested in studying the real solar cell. After that they conducted laboratory experiment on what factor had an effect on solar cell. This laboratory experiment to work after hours needed a lot of time, so they took instruments back to their dormitory. And they made appointments with laboratory teacher to ask or get some advices. However, in this laboratory activity they could design laboratory experiment very well. Also, they could give a very good presentation.

List	result
Teachers' behavior	1. In the first laboratory activity the teacher acted as a coordinator of discussion. He summarized students' ideas and concepts after discussion. He explained concepts of fundamental energy such as the importance of energy, how many kinds of energy there were, how to calculate kinetic and potential energy, etc. While he was teaching these concepts, he also posed many questions to students. During laboratory work, he walked around while students were conducting laboratory activity and gave some advices. He also encouraged students to solve any problem that happened during activity. Moreover, he helped students to conclude ideas after they finished their presentations. For laboratory teacher, he facilitated instrumental need of the students. He also advised students how to use those instruments. 2. In the second laboratory work, teacher was coordinator of discussion. He also concluded students' ideas and concepts after discussion. He explained concepts of electric energy such as the importance of electric energy, sources of electric energy, current, voltage, resistance, how to convert any kind of energy into electric energy, how electric power plants work and so on. During laboratory activity there were many problems, so both teachers always walked around and helped with suggestion to students how to set up instruments. Laboratory activity teacher also made appointments with students in each group to continue conducting laboratory activity after the scheduled hours. 3. In the third laboratory activity, teacher was coordinator of discussion. He explained about heat, transformation of different kinds of energy, calculation of heat, the use of heat, and so on. During laboratory activity, laboratory teacher guided students how to use instruments, especially temperature sensor that had to be connected to computer to make a graph and table of data. Students who could not complete the activity made appointments with the laboratory teacher to conduct laboratory outside schedule. Also, they made an appointment that every group would present their laboratory result outside schedule as well.

List	result
Teachers' behavior	4. In the fourth laboratory work, teacher was coordinator of discussion. He explained what nuclear energy was, what nuclear reactions were, nuclear energy power plant, what advantages and disadvantages of nuclear energy were, and so on. He taught students by using nuclear energy post-it game. During laboratory activity, he walked around to help students in case advice was needed (but none was sought). Moreover, for presentation, teacher joined with students to conclude ideas on nuclear energy together. 5. In the fifth laboratory activity, teacher was coordinator of discussion. He asked students for explanation how solar cell works. Then, after students studied about solar cell by using real solar cell at the roof of the school building, he helped students to conclude how solar energy generated electric energy by means of solar cell. He asked students a question on factors affecting solar cell working. Then, students conducted laboratory work on what factors affecting solar cell working to answer that question. Laboratory teacher arranged instruments for this experiment and suggested a little about how to use them. Then, both teachers told them of their schedules so that students could ask some advice about this experiment. Also, they made appointment with students to present their results of laboratory work.

3. Student interviews

Five representatives of each group were interviewed for 5-10 minutes individually, after they had learned through this course. They were asked to express opinions towards the 4E-C learning model. Results of the interviews were as follow:

Question 1: The opinions of students toward 4E-C learning model

Student 1: *"This learning model is interesting".*

Student 2: *"This learning model is new for me. I like it".*

Student 3: *"It is one of the interesting learning models that is good".*

Student 4: *"It's okay. It's better than other courses that usually use lecture"*

Student 5: *"This learning model is very good because it allows me to learn from conducting laboratory experiment like scientist"*

Question 2: *The opinions of students toward learning activities*

Student 1: *"The most favorite activity is adapting motor. The first time I thought it was easy, but actually it was not. And I think that it was very challenging".*

Student 2: *"I think that activities were challenging, especially adapting motor".*

Student 3: *"I like all activities. The most favorite is the discussion about energy issues because we could debate about those issues".*

Student 4: *"The most favorite activity is conducting project"*

Student 5: *"I like all activities. For the most favorite activity is the study of the relation between kinetic energy and potential energy because it was the first time I could make physics model"*

Question 3: *What students got after learned through this learning model?*

Student 1: *"I know the method of creating physics equation that I've never known before"*

Student 2: *"I know how scientist creates model and how they work"*

Student 3: *"I know how to conduct project to create physics model"*

Student 4: *"I know more about contemporary issues about energy that involved in our life and about conducting project"*

Student 5: *"I know how to create physics equation and know how scientist works and studies about the phenomena and fact"*

Question 4: *The opinions of students toward assessment*

Student 1: *"I think it was good that there was no test because we already had many tests in other subjects"*

Student 2: *"I like the fact that teachers told us what they would assess by using assessment form and I prefer this assessment than the test"*

Student 3: *"I like the fact that teachers allowed us to conduct project as the way of assessment because it was the one of comprehensive knowledge strategies".*

Student 4: *"I like to conduct project instead of the test and teachers assessed our performance"*

Student 5: *"I like this way of assessment because it could really measure our"*

performance and because sometimes the paper test cannot measure students' real knowledge that actually some students can perform to create their products better than someone who gains good score in paper test"

Question 5: Students' recommendations

Student 1: *"I want more time to conduct laboratory activities and project and I want this course to add the teaching of statistics and also the teacher to conclude more about concept after doing laboratory work"*

Student 2: *"I think that we should have more time to conduct project"*

Student 3: *"I want to conduct more laboratory experiment and I want teacher in other physics courses to allow us to conduct more laboratory work"*

Student 4: *"I know that other physics course can't have many laboratory activities because there are a lot of content. But other elective physics courses should focus on conduct in laboratory activity like this course".*

Student 5: *"I think that this kind of course should extend to other subject such as chemistry, biology, and other physics course. I want other subject to be taught through by conducting experiment."*

According to student interview, students are positive of the 4E-C learning model. They know how to conduct experiment like scientist and also to creative physics model. They thought that other subject should use this learning model to teach students.

4. Teacher interviews

3.4.1 Participating teacher in teaching physics content and laboratory activities:

"I think that the objectives of the 4E-C learning model could encourage scientifically G/T students' creative productivity because they could conduct experiment, especially new project. Students' outcomes were very good and in accord with expected learning outcomes. As for content, it was suitable because this course didn't focus on content, but focused on creating scientific model. The resources of this course were good because students could search and find information by themselves. The assessment form was very good. They could directly assess students' creative productivity. The results from assessment could identify students' creative productivity".

3.4.2 Participating teacher in physics laboratory activity:

“I think that these objectives could improve scientifically G/T students’ creative productivity. Students’ conducting experiments and projects were excellent and in agreement with expected learning outcomes. The content of this course was suitable. The learning resources were various and new. The assessment form was good and easy to assess. So I think that this learning model was very good and suitable to scientifically G/T students”.

According to teacher interview, teachers have positive opinion of the 4E-C learning model. Teachers could have more understanding about the theory of giftedness and also how to develop learning unit to enhance creative productivity.

CHAPTER 5

CONCLUSION AND DISCUSSION

This chapter presents the conclusions of the study related to the objectives, hypotheses, research instruments, procedures, conclusions, implications, and recommendations.

Objectives of the Study

Objectives of the study are:

1. to develop and implement learning model, the 4E-C learning model, for enhancing creative productivity of scientifically G/T students
2. to study the results of implementing the 4E-C learning model on students' creative productivity.
3. to study the results of implementing the 4E-C learning model on students' attitude toward physics.
4. to determine students' learning reflection from learning activity of the 4E-C learning model.
5. to determine students' opinions on the 4E-C learning model.
6. to determine teachers' opinions on the 4E-C learning model.

Research Instruments

The research instruments used in the study are as follows:-

1. Student Product Assessment Form: this form was used to assess students' creative productivity pre-test scores from phase 2 and post-test scores from phase 3-4 of the 4E-C learning model.
2. Students' attitude toward physics questionnaire: this form was used to assess students' attitude toward physics both before and after they learned through 4E-C learning model.
3. Students' learning reflection form: this form was used to determine students' learning reflection after they had learned through the activities of the 4E-C learning model.

4. Peer assessment form: this form was used to assess students' projects by students in the classroom, not by students in the project group assessed.

5. Team assessment form: this form was used to assess students' team working by students within the same group.

6. Student interview protocol: this form was used to interview 5 students' opinion of the 4E-C learning model after they had learned through the 4E-C learning model.

7. Teacher interview protocol: this form was used to interview 2 teachers' opinion of the 4E-C learning model after they used this learning model to teach scientifically G/T students.

8. Classroom observation form: this form was used to write down what the researcher observed in the classroom during teaching and learning in all phases of the 4E-C learning model.

Research Procedures

The research procedures were as follows:

Step 1: Learning model preparation:

The researcher studied related documents and gathered literature on definition of G/T students, the three-ring conception of giftedness, identification of G/T students, and science program for G/T students, model to enhance creative productivity, enrichment triad model, and modeling method.

Step 2: Learning model design:

The following procedures were used in the learning model design phase:

2.1 Design learning model: the researcher developed 4E-C learning model based on the three-ring conception of giftedness, enrichment triad model, and modeling method.

2.2 Writing learning model documents: the researcher wrote a draft of six learning units following 4E-C learning model that consisted of: 1) principles, 2) course description, 3) expected learning outcomes, 4) activity plans, 5) teacher guidelines, 6) assessment forms, 7) learning unit resources, and 8) teacher's teaching record.

2.3 Examining documents: activity plans and assessment forms were examined by experts who checked the content and construct validity.

2.4 Selecting and preparing participating teachers: participating teachers are volunteers who had at least five years experience in teaching physics to scientifically G/T students at Mahidol Wittayanusorn School.

2.5 Conducting a pilot study: the preliminary teaching study was conducted on scientifically G/T students in grade 10 at Mahidol Wittayanusorn School in the second semester of 2007 for 40 periods, during December 1st, 2006 – February 28th, 2007. The aims of this phase were to check the activity plans of the 4E-C learning model, to calculate reliability and discrimination of assessment forms, and to familiarize teachers with the learning cycle strategy.

Step 3: Main study

This step aimed at implementing the 4E-C learning model concerning energy in daily life in a real classroom. The 4E-C learning model was implemented by two participating physics teachers at Mahidol Wittayanusorn School for 40 periods in the first semester of 2007, during May 15th – August 31st 2007.

Step 4: Evaluating the learning model

This step was aimed at evaluating the 4E-C learning model. Students' creative productivity was assessed by using Student Product Assessment Form. Students within a group assessed each other by using team assessment form and each group assessed other groups by using peer assessment form. Also, students' learning reflection was analyzed by using induction analysis. Moreover, the researcher interviewed both students and teachers who participated in the 4E-C learning model about their opinions toward the model.

Conclusion

The research findings were concluded as follows:-

1. Learning model development: the researcher developed the 4E-C learning model based on the three-ring conception of giftedness, enrichment triad model, and modeling method. Also, this learning model was based on the results of scientifically G/T students' opinions of physics content and journals questionnaire and experts' suggestion from interviewing before developing learning model. So the 4E-C learning model was to enhance creative productivity of scientifically G/T students by using it in the elective physics course, Energy in Daily Life. The researcher developed learning units following the 4E-C learning model phases. They were also based on the 4th and 5th standard strands of Thai National Education Standard. The 4E-C learning model consisted of 4 phases: 1) encouraging issues, 2) experiments for modeling, 3) creation of new model, and 4) exhibition.

The experts examined the learning units and assessment forms. They were revised and implemented as Energy in Daily Life course for scientifically G/T students by two participating teachers.

The 4E-C learning model was to enhance creative productivity by creating physics model both of physical and mathematical in nature for scientifically G/T students in grade 10. The students worked in small groups to discuss contemporary issues about energy and conducted experiments related to energy. These experiments were to create either physical model or mathematical model. Both of these activities were in the first and second phase of learning model that could be switched back and forth. Then, in the third phase, students conducted projects in small groups to create new physics model. After that they presented their projects in school in the last phase. The teachers facilitated extra time outside schedule among other thing, and assessed their products in every phase of the learning model.

2. Learning model implementation

The results from the learning model implementation provided two types of data:

- 1) quantitative data for testing the research hypotheses
- 2) qualitative data for examining other effects of the learning model

2.1 Testing Research Hypotheses

In the implementation of the 4E-C learning model, data were collected to test the research hypotheses and the results are as follows:-

2.1.1 Hypothesis I: After students learn through the 4E-C learning model as Energy in Daily Life, they have higher creative productivity scores. This hypothesis aims to test students' creative productivity after they have completed the 4E-C learning model, Energy in Daily Life. The pre-test and post-test scores were used to test this hypothesis by comparing the mean scores with a paired-samples t-test. The pre-test scores were students' average laboratory scores from the second phase of the 4E-C learning model and post-test scores were students' project scores from the third and the last phases.

According to the t-test result, it was found that the pre-and post-test scores of students were significantly different at the .01 level. This indicates that students gained higher scores after they learned through 4E-C learning model.

2.1.2 Hypothesis II: students who learned through the 4E-C learning model, Energy in Daily Life course, have higher post-test attitudes scores than pre-test. This hypothesis aims to test students' attitudes toward physics after they learned through the 4E-C

learning model. The pre-and post-test scores were used to test this hypothesis by comparing the mean scores with a paired-samples t-test.

According to the t-test result, it was found that the pre- and post-test scores of students were significantly different at the .01 level. This indicates that students gained higher post-test attitudes scores than pre-test.

2.1.3 Team assessment scores: the data of team assessment scores were to support hypothesis I that students' creative productivity scores are reliable if team assessment scores of each student are not different. According to these data, it was found that students who worked in the same group had no different team assessment scores. Therefore, the results support hypothesis I.

2.1.4 Peer assessment scores: the data of peer assessment scores did not support hypothesis I because students' project scores assessed by teachers and students were not significantly correlated.

2.2 Conclusion from Qualitative Data

The qualitative data were collected through 1) interviewing students and classroom activity observations, and 2) observing classroom activities as follows:

2.2.1 Student interviews and classroom activity observations: according to the data, it was concluded that the students had positive attitudes towards 4E-C learning model. They also had learned how to create physics model and improved their creative productivity. They learned physics by conducting experiment with their own design. Also, they learned physics that is related to their daily life. It is obvious that they have gained scientific skills from their physics class, especially modeling skills and higher-order thinking skill that are so important to be developed in high ability students in science.

Moreover, the students not only improved their scientific skills, inquiry abilities in physics, and fulfilled their high potential, but also developed their searching skill, communication skill, and social skill. They learned how to work as a team and exchanged experiences with each other. They also learned to be a leader in science. In addition, they were more self-confident.

However, they want to have more time to conduct laboratory investigation and project. Also, they want to learn statistics to use for analyzing data from experiment. Students recommended that other subjects should use this learning model to teach students and not only focusing on lecture.

In conclusion, both qualitative and quantitative data indicated that the students developed their creative productivity, scientific skills, communication skill, social skill, leadership skill, searching skill, and their positive attitudes toward physics.

2.2.2 Teacher interviews: according to the data, it was concluded that the participating teachers had positive attitudes toward 4E-C learning model. They claimed that the 4E-C learning model was a good model of teaching physics for scientifically G/T students because it was the student-centered approach. In regard to the learning activities, they helped the students improve creative productivity, inquiry skill, scientific skill, leadership skill, and communication skill. In other words, students improved all the learning aspects, especially higher-order thinking. The teachers were also satisfied with teaching the students by using the 4E-C learning model because their students had learned physics from their daily life. This enables them to be aware of the importance of energy in their daily life.

However, the participating teachers found some problems while teaching Energy in Daily Life. These problems were 1) limitation of instruments, 2) limitation of time, and 3) limitation of advisors for doing projects. In conclusion, the participating teachers are confident that they are able to apply the 4E-C learning model to teach other physics courses or topics.

Discussion

The following are discussions on the study results:

1. Students' creative productivity

In regard to students' creative productivity, the pre- and post-test scores showed that the mean pre- and post-test scores of the students were significantly different at the .01 level. The result supported the first research hypothesis that students who learned through the 4E-C learning model would gain higher creative productivity. Students' creative productivity was assessed by using Student Product Assessment Form. This form has 15 items of assessment that focus on 1) creative product, 2) task commitment, 3) scientific skill, 4) modeling skill, and 5) communication skill. Also, team assessment scores supported hypothesis I that each student in each group had no different team assessment scores. However, students' project scores assessed by students in the classroom were not significantly correlated to scores assessed by teachers. That may be because the forms used to assess by teachers and students were

different. Moreover, peer assessment form was used to assess only one time. So these scores may be not reliable.

In regard to the learning activities, students were allowed to focus on discussing and debating energy issues, conducting experiments of their own design as a small group, and creating physics model as well as design and conduct their own project to test their new physics model. The students then presented their findings' experiments and projects. As a result of these procedures, the students gained higher creative productivity. The result supports the article of Rutgers University (2006: 34-39) that claimed the role of model in physics instruction as being the effective approach in physics. Wells; Hestenes; & Swackhamer (1995: 606-619) also found that students who learned physics by using modeling method gained significantly higher score and had more understanding in mechanics. The result supports the findings of Tsai (1997: online) which found that enrichment model was an effective learning model for gifted students. Tsai studied primary students who participated in enrichment model pilot program based on Renzuli's enrichment triad model. Also, the result is similar to the finding of Cooper; Baum; & Neu (2004, 162-169) which found that G/T student in science who participated in "project high hope science program" that followed three procedures - identification, curriculum, and assessment - gained higher scores in science. Moreover, the result supports Van Tassel- Baska (1998, online) that claimed how planning science programs for high ability learners should focus on inquiry, higher-order thinking, and science process skill. The result support Alan Colburn (1997: 30-33) that learning cycle is a great strategy for middle school and high school science teaching. Also, it supports Mary M. Bevevino, Joan Dengel, and Kenneth Adams (1999. 275-278) that using the learning cycle format, the teachers can make learning meaningful for students and give students opportunities to use their prior knowledge and experiences to construct their own frames of thought.

According to the learning outcomes, it is suitable to teach scientifically G/T students with the 4E-C learning model because this learning model provides them with opportunity to carry out independent study, plan and design, conduct experiments, analyze data, transform data, make graph from data, and model new physics model from their study. Therefore, the learning activities of the 4E-C learning model are good activities for use with scientifically G/T students in both experiments and projects in other physics courses.

However, the one important thing is that these G/T students already have high potential. They can learn very fast and have task commitment. So this learning model is one part that helps them to improve their creative productivity based on their high ability.

2. Attitudes towards physics

Attitudes of the students who learned through the 4E-C learning model as Energy in Daily Life course were significantly different at the .01 level. The result indicated that students have significantly higher attitudes toward physics scores. The finding supports the second research hypothesis. The result is similar to the findings of Stake; & Mares (2001, 1065-1088) which found that science enrichment programs for gifted high school girls and boys improved confidence in science and motivation of gifted students.

3. Students' opinions

The opinions of students who learned through 4E-C learning model were positive. Students thought activities of 4E-C learning model, especially adapting motor experiment were interesting and challenging. They also liked conducting project because it was the integration of knowledge that led to become a creative product. Some students really liked discussion and debating. They had opportunity to improve their communication skill and become a leader in science. However, they wanted to have more time to discuss in the first phase and to conduct project in the third phase. In regard to assessment they thought that the authentic assessment was very good and the Student Product Assessment Form could exactly assess their products. They also thought that conducting project was one of the best ways to evaluate students' accomplishment.

4. Teachers' opinions

Teachers thought the 4E-C learning model was a student-centered approach. This learning model encouraged creative productivity of students through conducting experiments and projects. Teachers understand about the three ring conception of giftedness. The content and objectives of this course were suitable to the potential of students. The assessment of this course was also very appropriate because it was real authentic assessment and focused on students' creative productivity. This result was different from the first survey that the researcher carried out before developing 4E-C learning model. Those results of the survey indicated that teachers didn't have good understanding about learning theory of G/T students. But after the two teachers used the 4E-C learning model to teach Energy in Daily Life course, they had more understanding about theory and strategy of teaching G/T students.

Recommendations

As regarding the development and implementation of the 4E-C learning model, Energy in Daily Life elective physics course, was aimed at enhancing creative productivity for scientifically G/T students, to further enhance the effectiveness of this learning model and to stimulate students to achieve in all expected learning outcomes, the researcher recommended the followings:

1. General Recommendation

1.1 Application of 4E-C learning model

The 4E-C learning model can be used for other physics courses or topics such as electricity, nuclear physics, mechanics, etc. Also, this learning model can be adapted for use in other subjects such as biology, chemistry, biophysics, etc. However, the teacher should consider content and objective to be suitable to those topics or subjects.

1.2 Application of learning activity

For application of this learning model to be the most successful, there should be at least two teachers because the 4E-C learning model focuses on conducting laboratory activity. So students should have teachers to help them most of the time. The teachers have to set up and check some instruments for laboratory experiment before the class, and also to prepare extra and unexpected instruments just in case students ask for. The teachers should have enough time for students even outside class time. Also, students should have expert advisor to help them for conducting project. However, if there is only one teacher that is still manageable, but the number of students in classroom should not be too large.

The teacher may integrate mathematical skill or mathematical program to teach students in phase 2-3 of the 4E-C learning model.

1.3 Application of assessment forms

Assessment forms of 4E-C learning model can be used for every subject in science because these forms are authentic assessment and not solely focus on physics. So any subject in science that has objectives or learning outcome, focusing on developing creative productivity or modeling skill can use the assessment forms of the 4E-C learning model.

2. Recommendation for further studies

Recommendations for further studies are as follows:

2.1 Regarding Limitations

The students' creative productivity scores were significantly higher. However, when each phase was considered there were still some problems. For example, there was the limitation of time for phase 1-3 of learning model in which students wanted to spend more time in those phases, and there was the limitation of some instruments in that there were not enough for students.

So further studies should allocate the time for each phase more suitably, especially the third phase should have at least three-fourth of the total time. Also, there should be more instruments in number. However, some of them are expensive, so the researcher should devise different activities that lead to the same outcome.

2.2 Regarding Content

Further studies should consider the content change from energy in daily life to other physics content or special topic content such as nuclear topics, renewable energy, biophysics, etc. Also, further studies should change the content from physics to be chemistry, biology, or any other science area.

2.3 Regarding Assessment

Further studies can extend the use of the assessment forms, especially the Student Product Assessment Form for any subject in science. However, some items of assessment forms can be changed to focus on other lower or higher scientific skills. Peer assessment form should be used by students more than once, to be more reliable.

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APPENDIX 1:

(In Thai)

- 1.1: Students' opinions of physics content and journal questionnaire
- 1.2: The G/T service questionnaire of teachers' understanding about
G/T services
- 1.3: The result of index of correspond from experts

แบบสอบถาม
ความคิดเห็นของนักเรียนที่มีต่อเนื้อหาฟิสิกส์และการอ่านวารสารวิชาการ
เกี่ยวกับฟิสิกส์ของนักเรียน

คำชี้แจง

1. แบบสอบถามนี้เป็นส่วนหนึ่งของงานวิจัยนิตระดับปริญญาเอก มหาวิทยาลัยศรีนครินทรวิโรฒ ที่ได้รับทุนสนับสนุนจากสถาบันส่งเสริมวิทยาศาสตร์และเทคโนโลยี (สสวท) โดยข้อมูลที่ได้นี้ จะนำไปเป็นส่วนหนึ่งในการพัฒนาการจัดการเรียนการสอนในรายวิชาฟิสิกส์เพิ่มเติม สำหรับนักเรียนที่มีความสามารถพิเศษด้านวิทยาศาสตร์ ฉะนั้นผู้วิจัยจึงขอให้นักเรียนได้ช่วยตอบแบบสอบถามนี้ให้ครบทุกข้อ และกรอกข้อมูลตามความเป็นจริง โดยผู้วิจัยขอรับรองว่าข้อมูลที่นักเรียนตอบจะไม่ส่งผลกระทบใด ๆ ทั้งสิ้นต่อนักเรียนและจะนำเสนอข้อมูลในลักษณะรวม ๆ เท่านั้น
2. แบบสอบถามนี้มี 3 ตอน (4 หน้า) ให้นักเรียนกรอกข้อมูลโดยทำเครื่องหมาย / ในช่วง ☐ และช่วงว่างในตารางที่กำหนดให้ รวมทั้งกรอกข้อความสั้น ๆ ลงในช่องว่างที่กำหนดให้

ตอนที่ 1 ข้อมูลเกี่ยวกับนักเรียน

1. เพศ

☐

ชาย

☐

หญิง

2. ขณะนี้นักเรียนอายุ.....ปี.....เดือน
3. เป็นนักเรียนระดับชั้นมัธยมศึกษาตอนปลาย

☐

ม. 4

☐

ม. 5

☐

ม. 6

ตอนที่ 2 ความคิดเห็นเกี่ยวกับเนื้อหาในวิชาฟิสิกส์

โปรดทำเครื่องหมาย / ลงในช่องว่างที่ตรงกับความชอบของนักเรียนที่มีต่อเนื้อหาฟิสิกส์ในเรื่องต่าง ๆ มากที่สุด และเขียนเหตุผลที่ทำให้นักเรียนชอบสั้น ๆ ลงในช่องเหตุผล

เนื้อหา	ชอบ มาก	ชอบปาน กลาง	ชอบ น้อย	เหตุผล
1. การเคลื่อนที่ในสองมิติ				
2. การเคลื่อนที่ในสองมิติ				
3. แรง มวล และกฎการเคลื่อนที่				
4. สมดุลกล				
5. การชนและโมเมนตัม				
6. การเคลื่อนที่และการหมุน				
7. งานและพลังงาน				
8. ปรากฏการณ์คลื่น				
9. แสงและการเห็น				
10. เสียงและการได้ยิน				
11. ไฟฟ้าสถิต				
12. ไฟฟ้ากระแส				
13. ไฟฟ้าและแม่เหล็ก				
14. ไฟฟ้ากระแสสลับ และคลื่นแม่เหล็กไฟฟ้า				
15. สมบัติเชิงกลของสาร				
16. สมบัติของก๊าซและพลังงานจลน์				
17. ฟิสิกส์อะตอม				
18. ฟิสิกส์นิวเคลียร์				

**ตอนที่ 3 ความคิดเห็นเกี่ยวกับการจัดการเรียนการสอนฟิสิกส์ และการอ่าน
วารสารวิชาการของนักเรียน**

โปรดทำเครื่องหมาย / ลงในช่องว่างที่ตรงกับความคิดเห็นของนักเรียนมากที่สุดตามข้อความ
ต่อไปนี้

**1. นักเรียนต้องการให้มีจัดการเรียนการสอนฟิสิกส์แบบใดบ้าง โดยนักเรียนสามารถ
ตอบได้มากกว่าหนึ่งข้อ**

- ☐ การบรรยาย
- ☐ การสาธิต
- ☐ การทำการทดลองฟิสิกส์
- ☐ การอภิปรายหัวข้อที่สนใจ
- ☐ การทำโครงงาน
- ☐ การทำงานวิจัย
- ☐ การใช้เทคโนโลยีช่วยในการสอน
- ☐ อื่น ๆ (ระบุ).....

**2. นักเรียนอ่านวารสารวิชาการอะไรบ้างดังต่อไปนี้ โดยนักเรียนสามารถตอบได้
มากกว่าหนึ่งข้อ**

2.1 วารสารในประเทศ

- ☐ วารสารวิทยาศาสตร์
- ☐ วารสาร สสวท.
- ☐ วารสารครูวิทยาศาสตร์

☐ อื่น ๆ (ระบุ).....

2.2 วารสารต่างประเทศ

☐ Physics teacher

☐ Physics today

☐ American journal of physics

☐ Physics education

☐ Scientific American

☐ School science and mathematics

☐ อื่น ๆ (ระบุ).....

3. ข้อเสนอแนะเพิ่มเติม

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แบบสอบถาม
ความคิดเห็นของครูต่อการเชื่อมโยงทฤษฎีทางการศึกษาของนักเรียน
ที่มีความสามารถพิเศษกับการจัดการเรียนการสอนสำหรับ
นักเรียนที่มีความสามารถพิเศษ

คำชี้แจง

1. แบบสอบถามนี้เป็นส่วนหนึ่งของงานวิจัยนิตยระดับปริญญาเอก มหาวิทยาลัยศรีนครินทรวิโรฒ ที่ได้รับทุนสนับสนุนจากสถาบันส่งเสริมวิทยาศาสตร์และเทคโนโลยี (สสวท.) โดยข้อมูลที่ได้นี้ จะนำไปเป็นส่วนหนึ่งของการพัฒนารูปแบบการจัดการเรียนการสอนของรูปแบบการเรียนรู้แบบ 4E-C เพื่อส่งเสริมความสามารถในการผลิตผลงานอย่างสร้างสรรค์สำหรับนักเรียนที่มีความสามารถพิเศษด้านวิทยาศาสตร์ ฉะนั้นผู้วิจัยจึงขอความอนุเคราะห์ให้ครูช่วยตอบแบบสอบถามนี้ให้ครบทุกข้อและกรอกข้อมูลตามความเป็นจริง ผู้วิจัยขอรับรองว่าข้อมูลที่ท่านตอบจะไม่ส่งผลกระทบต่อใคร ๆ ทั้งสิ้นต่อท่านและจะนำเสนอข้อมูลในลักษณะภาพรวมเท่านั้น
2. แบบสอบถามนี้มี 3 ตอน (3 หน้า) ให้ท่านกรอกข้อมูลโดยทำเครื่องหมายวงกลมในข้อที่ตรงกับคำตอบของท่าน รวมทั้งกรอกข้อความสั้น ๆ ลงในช่วงว่างที่กำหนดให้

ตอนที่ 1 ข้อมูลของผู้ตอบแบบสอบถาม

1. เพศ

1. หญิง

2. ชาย

2. ประสบการณ์การสอนรวม.....ปี

3. ประสบการณ์การสอนเด็กที่มีความสามารถพิเศษ.....ปี

4. การศึกษาหรือการฝึกอบรมที่เกี่ยวข้องกับเด็กที่มีความสามารถพิเศษ

1. น้อยกว่า 2 ครั้ง

2. มากกว่า 2 ครั้ง แต่ไม่เกิน 5 ครั้ง

3. มากกว่า 5 ครั้ง แต่ไม่เกิน 10 ครั้ง

4. มากกว่า 10 ครั้ง

ตอนที่ 2 ข้อมูลการจัดการเรียนการสอนของโรงเรียน

1. ระดับชั้นที่จัดการเรียนการสอนในโรงเรียน.....
2. ท่านสอนระดับชั้น.....
3. จำนวนนักเรียนที่เป็นเด็กที่มีความสามารถพิเศษในโรงเรียน..... คน
4. โปรแกรมที่จัดการเรียนการสอนสำหรับเด็กที่มีความสามารถพิเศษในโรงเรียน ได้แก่
 - 1.....
 - 2.....
 - 3.....
 - อื่นๆ.....

ตอนที่ 3 การจัดการเรียนการสอนตามทฤษฎีการศึกษาเด็กที่มีความสามารถ

พิเศษและเป้าหมายสำหรับการจัดชั้นเรียนสำหรับเด็กที่มีความสามารถพิเศษ

1. ท่านคุ้นเคยกับการจัดการเรียนการสอนตามทฤษฎีการศึกษาเด็กที่มีความสามารถพิเศษหรือไม่ (เช่น ทฤษฎีสองห่วงของเรนชัวรี เป็นต้น)
 1. ค่อนข้าง
 2. ไม่ค่อย

ถ้าท่านคุ้นเคยโปรดบอกชื่อรูปแบบการจัดการเรียนการสอนหรือโปรแกรมนั้น.....

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2. ท่านได้จัดการเรียนการสอนในชั้นเรียนตามทฤษฎีหรือโปรแกรมที่เฉพาะเจาะจงสำหรับการสอนเด็กที่มีความสามารถพิเศษหรือไม่
 1. ใช่
 2. ไม่ใช่

ถ้าท่านตอบว่า “ใช่” โปรแกรมหรือทฤษฎีอะไรที่ท่านใช้ในการจัดการเรียนการสอน.....

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3. (สำหรับท่านที่ตอบว่า “ใช่” ในข้อสองเท่านั้น) ทฤษฎีหรือโปรแกรมนี้ได้มีการปรับปรุง
(เลือกเพียงหนึ่งคำตอบ)

1. เพียงท่านคนเดียวเท่านั้น
2. เพียงในโรงเรียนของท่านเท่านั้น
3. โรงเรียนอื่น ๆ ด้วย

ถ้าท่านตอบมากกว่าหนึ่งโปรแกรมหรือทฤษฎีในการจัดการเรียนการสอน โปรดอธิบาย

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4. ท่านได้กำหนดเป้าหมายเฉพาะสำหรับการจัดการเรียนการสอนสำหรับเด็กที่มี

ความสามารถพิเศษให้สัมพันธ์กับ.....

1. การพัฒนาทักษะการคิดขั้นสูง
2. การจัดกิจกรรมแบบเพิ่มพูนประสบการณ์
3. การจัดการสอนแบบ AP program
4. การส่งเสริมความมั่นใจในตนเองของนักเรียน
5. การพัฒนาทักษะทางสังคม
6. อื่น ๆ (อธิบาย).....

5. จากเป้าหมายในข้อ 4 กรุณาจัดอันดับความสำคัญของเป้าหมายเหล่านี้ต่อการสอนเด็ก

เด็กที่มีความสามารถพิเศษ โดยใส่หมายเลขหน้าข้อความสำคัญมากที่สุดคือ 1 ไปยัง

ความสำคัญน้อยที่สุดคือ 6

.....การพัฒนาทักษะการคิดขั้นสูง

.....การจัดกิจกรรมแบบเพิ่มพูนประสบการณ์

.....การจัดการสอนแบบ AP program

.....การส่งเสริมความมั่นใจในตนเองของนักเรียน

.....การพัฒนาทักษะทางสังคม

.....อื่น ๆ (อธิบาย).....

ข้อเสนอแนะเพิ่มเติม

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The results of index of congruence for content and construct validity of learning units as evaluated by 5 experts

Learning Unit	Expected learning outcome	Content sheet	activity	Learning's reflection question	result
1	0.96	1.00	1.00	1.00	Strongly congruence
2	0.97	1.00	1.00	1.00	Strongly congruence
3	1.00	1.00	1.00	1.00	Strongly congruence
4	1.00	1.00	1.00	1.00	Strongly congruence
5	1.00	1.00	1.00	1.00	Strongly congruence

Note: 0.75 - 1.00 = strongly congruence
 0.50 - 0.75 = congruence
 Less than 0.5 = have to modify

The results of index of congruence for construct validity of assessment forms as evaluated by 5 experts

Assessment form	$\bar{X}$	result
1. Student Product Assessment Form	0.97	Strongly congruence
2. Students' attitude toward physics questionnaire	1.00	Strongly congruence
3. Peer assessment form	1.00	Strongly congruence
4. Team assessment form	1.00	Strongly congruence

Note: 0.75 - 1.00 = strongly congruence
 0.50 - 0.75 = congruence
 Less than 0.5 = have to modify

APPENDIX 2:

(In Thai)

- 2.1: Teacher's guide of the 4E-C learning model
and brief of lesson plan
- 2.2: Sample of activities and Students' tasks

**คู่มือการใช้
รูปแบบการเรียนรู้แบบ 4E-C**

ความเชื่อพื้นฐาน

เด็กที่มีความสามารถพิเศษนั้นนอกจากจะต้องมีความสามารถทางการเรียนสูงกว่าค่าเฉลี่ยของเด็กปกติแล้วยังต้องมีความคิดสร้างสรรค์ รวมทั้งมีความมุ่งมั่น ทุ่มต่อการทำงาน อย่างไรก็ตามศักยภาพเหล่านี้จะต้องได้แสดงออกมาในรูปของผลงานหรือการกระทำ จึงจะถือได้ว่าเป็นการใช้ศักยภาพอย่างสมบูรณ์ ดังนั้นถ้ามีการจัดสถานการณ์หรือกิจกรรมการเรียนการสอนที่เอื้อต่อการให้เด็กที่มีความสามารถพิเศษได้มีโอกาสแสดงศักยภาพในการได้สร้างผลงานอย่างสร้างสรรค์ออกมาแล้ว ย่อมทำให้เด็กได้พัฒนาศักยภาพอย่างเต็มที่

หลักการจัดการเรียนรู้

เพื่อให้การจัดการเรียนรู้สอดคล้องตามทฤษฎีนิยามของเด็กที่มีความสามารถพิเศษและวิธีการสอนที่ส่งเสริมให้เด็กได้ฝึกการคิดขั้นสูงและสร้างผลงานอย่างสร้างสรรค์ ซึ่งจะช่วยส่งเสริมผู้เรียนให้ได้รับความรู้ความเข้าใจ ประสบการณ์ และมีทักษะการคิดขั้นสูง ที่จะสามารถนำไปประยุกต์ใช้ในชีวิตประจำวันและการศึกษาในระดับสูงต่อไปได้อย่างเต็มศักยภาพ

นอกจากนี้เพื่อให้การจัดการศึกษาเป็นไปตามสภาพปัญหาและความจำเป็น ตลอดจนสอดคล้องกับหลักสูตรการศึกษาขั้นพื้นฐาน พ.ศ. 2544 จึงได้กำหนดหลักการของรูปแบบการเรียนรู้แบบ 4E-C ไว้ดังนี้

1. เป็นการจัดการเรียนรู้เพื่อส่งเสริมการสร้างผลงานอย่างสร้างสรรค์(creative productivity) สำหรับเด็กที่มีความสามารถพิเศษด้านวิทยาศาสตร์
2. เป็นการจัดการเรียนรู้ที่ให้นักเรียนได้ร่วมอภิปรายหัวข้อที่สำคัญในปัจจุบันในเรื่องพลังงานรูปแบบต่าง ๆ
3. เป็นการจัดการเรียนรู้ที่ส่งเสริมให้ผู้เรียนสามารถพัฒนาแบบจำลองทางกายภาพและทางคณิตศาสตร์ และสามารถนำเสนอผลงานในเรื่องพลังงานกับชีวิตประจำวัน
4. เป็นการจัดการเรียนรู้ที่ส่งเสริมให้ผู้เรียนมีทักษะในการสืบเสาะหาความรู้ และทักษะการคิดขั้นสูง
5. เป็นการจัดการเรียนรู้ที่ถือว่าผู้เรียนมีความสำคัญที่สุด ยึดหลักการตรวจสอบและประเมินผลการเรียนรู้ตามสภาพจริงเพื่อพัฒนาผู้เรียน

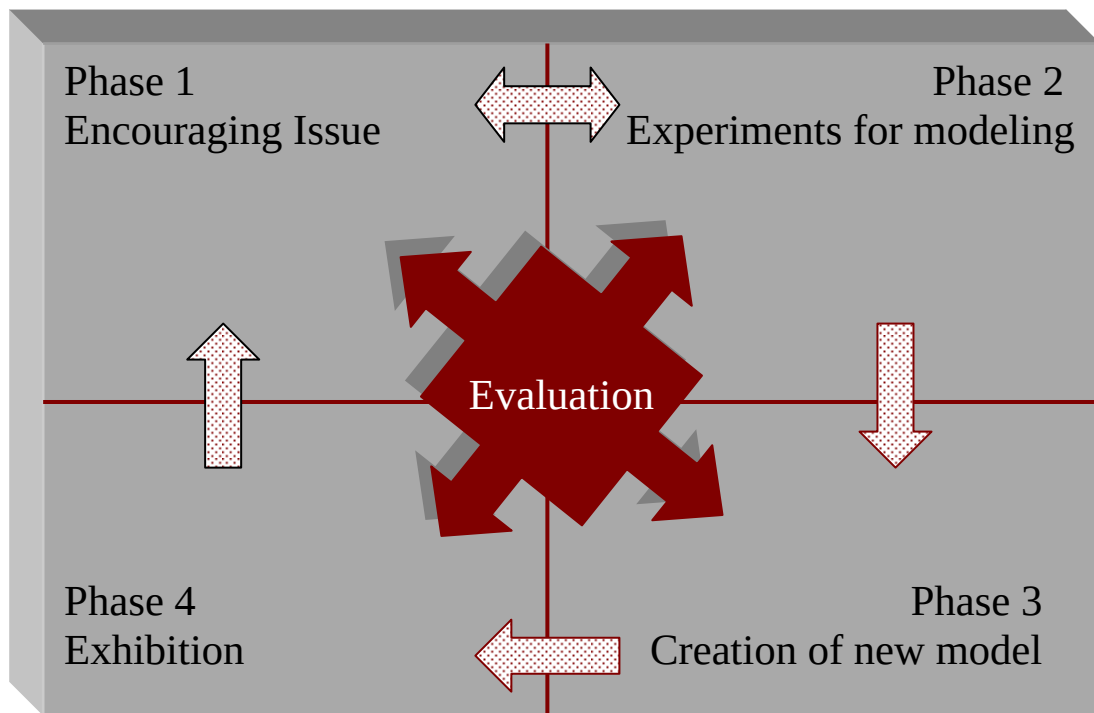
จุดมุ่งหมายของการจัดการเรียนรู้

รูปแบบการจัดการเรียนรู้แบบ 4E-C สำหรับเด็กที่มีความสามารถพิเศษด้านวิทยาศาสตร์ มีจุดมุ่งหมายหลัก ดังนี้

1. เพื่อให้ผู้เรียนที่มีความสามารถพิเศษด้านวิทยาศาสตร์ได้รับโอกาสและประสบการณ์ในการสร้างผลงานอย่างสร้างสรรค์ โดยเป็นผลงานในระดับชั้นสูง
2. เพื่อให้ผู้เรียนได้มีโอกาสในการในการอภิปรายหัวข้อทางด้านวิทยาศาสตร์ และมีความรู้กว้างขวางมากขึ้นเกี่ยวกับข่าวสารทางด้านวิทยาศาสตร์
3. เพื่อให้ผู้เรียนได้มีโอกาสได้เสนอผลงานของตนเองและมีความสามารถในการสื่อสารทางด้านวิทยาศาสตร์
4. เพื่อให้ผู้เรียนได้มีโอกาสศึกษาค้นคว้าได้ด้วยตนเอง จากแหล่งข้อมูลต่าง ๆ ทั้งแหล่งข้อมูลพื้นฐานและแหล่งข้อมูลระดับสูงกว่าระดับชั้นของผู้เรียน
5. เพื่อให้ผู้เรียนมีโอกาสได้ปฏิสัมพันธ์ทางสังคมกับเพื่อนในการทำงาน

รูปแบบการเรียนรู้แบบ 4E-C

รูปแบบการเรียนรู้แบบ 4E-C ที่ส่งเสริมการสร้างผลงานอย่างสร้างสรรค์ สำหรับเด็กที่มีความสามารถพิเศษด้านวิทยาศาสตร์ เป็นการจัดการเรียนรู้ที่แบ่งเป็น 4 ระยะ ดังภาพข้างล่าง



ระยะที่ 1 การอภิปรายประเด็นปัญหาที่สำคัญเพื่อส่งเสริมให้นักเรียนเห็นความสำคัญของวิชาชีพสโนในเนื้อหาเรื่องพลังงานที่เกี่ยวข้องกับชีวิตประจำวัน และเป็นแนวทางให้นักเรียนทราบถึงประเด็นปัญหาที่นักเรียนสามารถนำไปทำเป็นหัวข้อโครงงานเพื่อพัฒนาแบบจำลองได้ ในระยะที่ 3 โดยผู้สอนมีหน้าที่กำหนดหัวข้อให้กับนักเรียนเพื่อไปศึกษาค้นคว้าข้อมูล เกี่ยวกับประเด็นปัญหาในหัวข้อนั้น ๆ แล้วนำมาอภิปรายในชั้นเรียน จากนั้นผู้สอนและนักเรียนร่วมกันสรุปประเด็นปัญหาที่อภิปรายในชั้นเรียน ในระยะที่ 1 นี้ผู้สอนจะประเมินผู้เรียนจากการสังเกตการอภิปรายของนักเรียนภายในชั้นเรียน และบันทึกผลการสังเกตไว้ในแบบบันทึกบรรยากาศภายในชั้นเรียน

ระยะที่ 2 จัดกิจกรรมการทดลองที่ส่งเสริมให้นักเรียนได้ฝึกการสร้างแบบจำลองทั้งทางกายภาพและทางคณิตศาสตร์ โดยนักเรียนจะออกแบบการทดลองเอง เพื่อนำมาสร้างแบบจำลองทางกายภาพหรือทางคณิตศาสตร์ จากนั้นนำเสนอและอภิปรายผลการสร้างแบบจำลอง โดยผู้สอนมีหน้าที่คอยช่วยเหลือนักเรียนในขณะทำการทดลองให้สามารถปฏิบัติการทดลองได้สอดคล้องต่อกระบวนการสร้างแบบจำลอง และร่วมอภิปรายผลการสร้างแบบจำลองของนักเรียนภายหลังการทดลอง ในระยะที่ 2 นี้ผู้สอนจะประเมินผู้เรียนโดยใช้แบบประเมินการสร้างผลงานอย่างสร้างสรรค์ รวมทั้ง

สังเกตการทำกิจกรรมของผู้เรียนและบันทึกผลการสังเกตไว้ในแบบบันทึกบรรยากาศภายในชั้นเรียน

หมายเหตุ ระยะที่ 1 และ 2 นี้จะสามารถย้อนกลับไปได้จนกว่าผู้สอนจะเห็นว่าผู้เรียนมีความสามารถพร้อมที่จะนำไปออกแบบโครงงานเพื่อสร้างแบบจำลองทางกายภาพหรือทางคณิตศาสตร์ได้

ระยะที่ 3 เป็นระยะที่นักเรียนลงมือทำโครงงาน โดยออกแบบการทดลองเพื่อสร้างแบบจำลองทางกายภาพหรือทางฟิสิกส์ ซึ่งนักเรียนจะเริ่มจากเลือกหัวข้อประเด็นปัญหาที่นักเรียนสนใจที่ได้อภิปรายจากระยะที่ 1 หรือจากกิจกรรมการทดลองที่ได้ทำในระยะที่ 2 จากนั้นนักเรียนศึกษาค้นคว้าเกี่ยวกับหัวข้อที่เลือก กำหนดแนวทางการทำโครงงาน จากนั้นนำเสนอโครงร่างโครงงาน ซึ่งในขั้นนี้ผู้สอนจะเชิญผู้เชี่ยวชาญในเรื่องที่นักเรียนจะศึกษา มาช่วยให้คำแนะนำแก่นักเรียนเพิ่มเติม ในระยะที่ 3 นี้ผู้สอนมีหน้าที่ในการให้ความช่วยเหลือทั้งด้านแหล่งข้อมูล วัสดุอุปกรณ์ และการใช้เครื่องมือต่าง ๆ หลังจากนักเรียนเสร็จสิ้นการทำโครงงาน นักเรียนจะนำเสนอผลงาน โดยผู้สอนเชิญผู้เชี่ยวชาญกลุ่มเดิมมาช่วยฟังและอภิปรายผลงานของนักเรียน ซึ่งผู้สอนมีหน้าที่ร่วมอภิปรายผลงานของนักเรียนด้วย ในระยะที่ 3 นี้ผู้สอนจะประเมินผู้เรียนโดยใช้แบบประเมินการสร้างผลงานอย่างสร้างสรรค์ โดยหัวข้อที่ประเมินเกี่ยวกับการนำเสนอผลงานจะประเมินได้หลังจากระยะที่ 4

ระยะที่ 4 เป็นการจัดแสดงผลงานของนักเรียนในนิทรรศการจริง เพื่อให้เด็กได้ฝึกการนำเสนอผลงาน และตระหนักถึงศักยภาพของตนเอง ซึ่งผู้สอนมีหน้าที่คอยแนะนำการนำเสนอผลงานของนักเรียน ฝึกให้นักเรียนหัดตอบคำถามก่อนไปนำเสนอผลงานจริง และช่วยนักเรียนในการจัดแสดงผลงานในนิทรรศการ ในระยะที่ 4 นี้ผู้สอนจะประเมินผู้เรียนโดยใช้แบบประเมินการสร้างผลงานอย่างสร้างสรรค์ ที่ประเมินจากระยะที่ 3 โดยประเมินในหัวข้อการนำเสนอผลงาน

แนวปฏิบัติของการใช้รูปแบบการเรียนรู้แบบ 4E-C

การใช้รูปแบบการเรียนรู้แบบ 4E-C ที่ส่งเสริมการสร้างผลงานอย่างสร้างสรรค์สำหรับเด็กที่มีความสามารถพิเศษด้านวิทยาศาสตร์ มีแนวปฏิบัติดังนี้

1. ผู้ใช้รูปแบบฯ : ผู้สอนที่นำรูปแบบฯ ไปใช้ควรมีความเชื่อในความเชื่อพื้นฐานของรูปแบบฯ ศึกษาขั้นตอนของรูปแบบฯ ฝึกฝนเทคนิควิธีการสอน ประยุกต์และปรับใช้ให้เหมาะสมกับสถานการณ์ และสิ่งแวดล้อมในสถานศึกษา ใฝ่ใจแสวงหาความรู้ในเรื่องต่าง ๆ และพัฒนาในการสอนไปพร้อมกับการเรียนรู้ของผู้เรียน
2. กลุ่มเป้าหมาย : ผู้เรียนที่เป็นกลุ่มเป้าหมายของรูปแบบฯ นี้คือ ผู้เรียนที่มีความสามารถพิเศษด้านวิทยาศาสตร์ระดับชั้นมัธยมศึกษาปีที่4 ที่ได้เรียนกลศาสตร์ 1 มาแล้ว อย่างไรก็ตามผู้สอนสามารถนำไปประยุกต์ใช้กับผู้เรียนที่มีความสามารถพิเศษด้านวิทยาศาสตร์ในระดับชั้นอื่น ๆ ได้ตามความเหมาะสม
3. ระยะเวลาในการจัดการเรียนรู้โดยใช้รูปแบบฯนี้ คือ 40 คาบ
4. รูปแบบฯ นี้ใช้ควบคู่กับแผนการเรียนรู้ ซึ่งมีเอกสารผู้เรียน เอกสารผู้สอน และแนวทางการประเมินผลตามสภาพจริง
5. เพื่อให้การใช้รูปแบบฯ ประสบความสำเร็จสูงสุด ในการดำเนินการตามขั้นตอนที่จะช่วยให้การจัดการเรียนการสอนอย่างได้ผลตามเป้าหมาย และประสบความสำเร็จสูงสุด ผู้สอนจำเป็นต้องอย่างยิ่งที่จะต้องศึกษาระบวนการจัดการเรียนการสอนตามรูปแบบให้ละเอียดก่อนการดำเนินการ ดังนี้
 - ศึกษาคู่มือรูปแบบฯ ว่าประกอบด้วยเอกสารต่าง ๆ ได้แก่ แผนการจัดการเรียนรู้ ใบความรู้ ใบกิจกรรม แบบประเมินผลการสร้างผลงานอย่างสร้างสรรค์ แบบวัดเจตคติ และแบบสังเกตบรรยากาศการเรียนการสอน
 - ศึกษาเนื้อหาในเอกสาร ให้เข้าใจอย่างถ่องแท้ก่อนจะดำเนินการใช้
 - จัดเตรียมอุปกรณ์ และสิ่งแวดล้อมในชั้นเรียนที่เสนอแนะให้พร้อม ก่อนการใช้รูปแบบฯ
 - การจัดกิจกรรมการเรียนรู้ตามรูปแบบฯ ใช้แผนการจัดการเรียนรู้เป็นแนวทางในการจัดการเรียนการสอน ซึ่งในการจัดการเรียนการสอนจริงนั้น อาจปรับเปลี่ยนให้เกิดความเหมาะสมกับเวลา รายละเอียดของเนื้อหาสาระ ให้มีความสอดคล้องกับความต้องการของผู้เรียนได้

การเตรียมความพร้อม

กิจกรรมการเรียนการสอน ตามรูปแบบการเรียนรู้แบบ 4E-C ที่ส่งเสริมการสร้างผลงานอย่างสร้างสรรค์สำหรับเด็กที่มีความสามารถพิเศษด้านวิทยาศาสตร์ ประกอบด้วยหน่วยการเรียนรู้ที่ออกแบบสื่อและวัสดุอุปกรณ์ที่ใช้ในหน่วยการเรียนรู้ และเครื่องมือที่เกี่ยวข้องกับการวัดและประเมินผลไว้ให้ผู้สอนสามารถนำไปใช้ได้ทันที หรืออาจนำไปปรับปรุงและเพิ่มเติมได้ตามความเหมาะสม เพื่อเป็นประโยชน์ต่อกระบวนการเรียนการสอนมากที่สุด ผู้สอนควรเตรียมความพร้อมดังต่อไปนี้

การเตรียมสื่อการเรียนรู้

กิจกรรมการเรียนการสอนนี้ มุ่งเน้นให้ผู้เรียนได้เรียนรู้ โดยผู้เรียนเป็นผู้ลงมือทำกิจกรรมต่าง ๆ โดยมีแผนการเรียนรู้สำหรับผู้สอนใช้เป็นแนวทาง ผู้สอนจึงควรเตรียมสื่อและวัสดุอุปกรณ์ที่ใช้ให้อยู่ในสภาพที่ใช้การได้ดี และมีจำนวนที่เพียงพอกับผู้เรียน โดยทำความเข้าใจแผนการเรียนรู้อย่างละเอียดและชัดเจน เตรียมเอกสารผู้เรียน โดยทุกกิจกรรมจะประกอบไปด้วยใบกิจกรรมและใบความรู้ พร้อมให้ผู้สอนได้แจกให้กับผู้เรียน

การเตรียมเครื่องมือการวัดและประเมินผล

ผู้สอนต้องตระหนักว่าการเรียนการสอน และการวัดผลประเมินผลเป็นกระบวนการเดียวกัน จำต้องดำเนินการอย่างต่อเนื่อง และเพื่อให้การวัดและประเมินผลได้สะท้อนความสามารถของผู้เรียนอย่างแท้จริง ผลการประเมินควรได้มาจากแหล่งข้อมูลและวิธีการที่หลากหลาย อาทิเช่น การสังเกต การประเมินการสร้างผลงานอย่างสร้างสรรค์ซึ่งเป็นการประเมินทักษะการปฏิบัติ แบบบันทึกการสังเกตการเรียนการสอน แบบบันทึกการเรียนรู้ของผู้เรียน เป็นต้น

ดังนั้นผู้สอนควรเตรียมศึกษาวิธีการวัดและประเมินผลดังกล่าว เพื่อการเก็บข้อมูลอย่างตรงไปตรงมา และนำไปสู่การแปลผลและลงข้อสรุปที่สมเหตุสมผล

บทบาทของผู้สอน

ผู้สอนมีบทบาทในฐานะผู้เอื้ออำนวยความสะดวก ดำเนินการดังนี้

การใช้กลวิธีสอน

- ในการจัดกิจกรรมการเรียนการสอนให้ใช้วิธีการสอนที่ให้ได้กติกายเกี่ยวกับประเด็นปัญหาที่สำคัญ วิธีการสอนในการสร้างแบบจำลอง โดยการให้นักเรียนได้ลงมือปฏิบัติจริง
- ขณะผู้สอนใช้รูปแบบฯ นี้ควรสังเกตความสนใจของผู้เรียน ว่ามีความสนใจเรื่องใดเป็นพิเศษ เพื่อเตรียมจัดแหล่งข้อมูลที่มีให้เพียงพอที่จะให้เลือกใช้ตามความสนใจของนักเรียน
- ใช้คำถามช่วยกระตุ้นผู้เรียนให้เกิดการเรียนรู้ เกิดความเข้าใจในเรื่องที่กำลังเรียนรู้
- รับฟังความคิดเห็นของนักเรียน และให้ความสำคัญต่อการแสดงความคิดเห็นของผู้เรียน
- อธิบายการทำกิจกรรมให้ผู้เรียนเข้าใจอย่างชัดเจน ด้วยภาษาที่เข้าใจ นุ่มนวลและให้กำลังใจ
- คอยดูแลการทำกิจกรรมของผู้เรียนให้เป็นไปในแนวทางที่ถูกต้อง อำนวยความสะดวกเพื่อให้ผู้เรียนสามารถเรียนรู้จากการทำกิจกรรมได้
- ช่วยผู้เรียนสรุปประเด็นที่อภิปรายหลังทำกิจกรรม

การจัดบรรยากาศการเรียน

- จัดแหล่งเรียนรู้ให้เพียงพอและตรงกับความสนใจของนักเรียน
- จัดสิ่งแวดล้อมและบรรยากาศที่มีชีวิตชีวา จูงใจให้ผู้เรียนอยากค้นคว้าหาความรู้เพิ่มเติมด้วยตนเองในสิ่งที่สนใจ
- ส่งเสริมและสร้างโอกาสให้ผู้เรียนมีโอกาสดแสดงความคิดเห็นหรือนำเสนอความคิด ลดการถ่ายทอดความรู้จากผู้สอนโดยตรงให้น้อยลง
- ส่งเสริมให้ผู้เรียนมีอิสระในการสร้างผลงาน และให้คุณค่าต่อผลงานของผู้เรียน
- สร้างบรรยากาศของความเท่าเทียมกัน โดยให้ผู้เรียนได้มีส่วนร่วมในกิจกรรมอย่างเท่าเทียมกันทุกคน

บทบาทของผู้เรียน

บทบาทผู้เรียน ผู้สอนควรชี้แนะให้ผู้เรียนเข้าใจบทบาทและศักยภาพของตน ที่ควรแสดงออกอย่างสร้างสรรค์ โดยเฉพาะการฝึกฝนการสร้างผลงานอย่างสร้างสรรค์ทางด้านพิสิกส์ โดยควรให้ผู้เรียนปฏิบัติได้ในแต่ละระยะของรูปแบบฯ ดังต่อไปนี้

ระยะที่ 1

- ศึกษาค้นคว้าเป็นกลุ่มจากบทความทางวิชาการที่ผู้สอนเตรียมให้ อย่างไรก็ตามผู้เรียนสามารถค้นคว้าและเลือกบทความได้เองภายในกลุ่ม โดยเลือกค้นคว้าจากแหล่งข้อมูลระดับสูง ได้แก่ จากวารสารต่างประเทศ จากแหล่งข้อมูลทางอินเทอร์เน็ตที่เชื่อถือได้ หรือจากผู้เชี่ยวชาญ เป็นต้น
- มีบทบาทในการร่วมอภิปรายประเด็นปัญหาในชั้นเรียน

ระยะที่ 2

- ศึกษาค้นคว้า แสดงความคิดเห็น และออกแบบการทดลอง สร้างแบบจำลองทางพิสิกส์ทั้งทางกายภาพและทางคณิตศาสตร์ โดยสำหรับแบบจำลองทางคณิตศาสตร์ก็คือสมการทางพิสิกส์นั่นเอง
- มีส่วนร่วมในการนำเสนอผลงานในแต่ละกิจกรรม

ระยะที่ 3

- ศึกษาค้นคว้า แสดงความคิดเห็น ออกแบบโครงงานเพื่อสร้างแบบจำลองทางพิสิกส์ มีส่วนร่วมทั้งการทำรูปเล่มรายงาน

ระยะที่ 4

- มีส่วนร่วมในการเตรียมและการนำเสนอโครงงาน

ภาพรวมของหน่วยการเรียนรู้

โครงสร้างเนื้อหา

กลุ่มสาระการเรียนรู้วิชา วิทยาศาสตร์

รายวิชา ฟิสิกส์เพิ่มเติม

ระดับช่วงชั้น มัธยมศึกษาปีที่ 4

ขอบข่ายสาระที่เกี่ยวข้อง สาระที่ 5 พลังงาน

มาตรฐานการเรียนรู้ที่เกี่ยวข้อง มาตรฐานการเรียนรู้ที่ 3 ความรู้ ความคิด เกี่ยวกับ
กระบวนการทางกายภาพ

เวลาที่ใช้สอน 40 คาบ

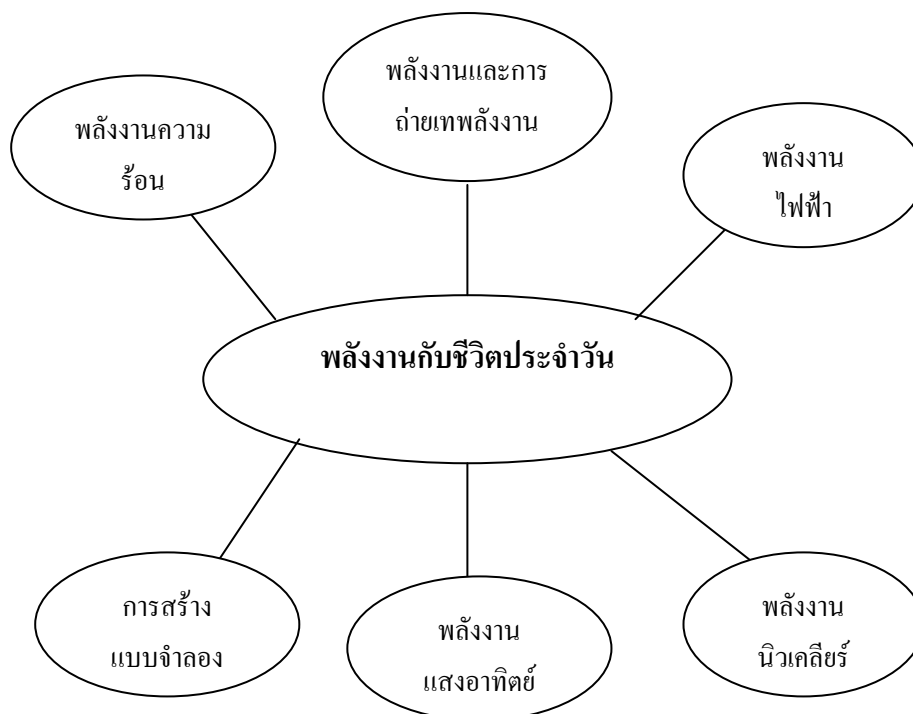
คำอธิบายรายวิชา

ศึกษาเกี่ยวกับพลังงานรูปแบบต่าง ๆ การนำพลังงานประเภทต่าง ๆ ไปใช้ประโยชน์
ได้แก่ พลังงานความร้อน พลังงานไฟฟ้า พลังงานนิวเคลียร์ และพลังงานแสงอาทิตย์

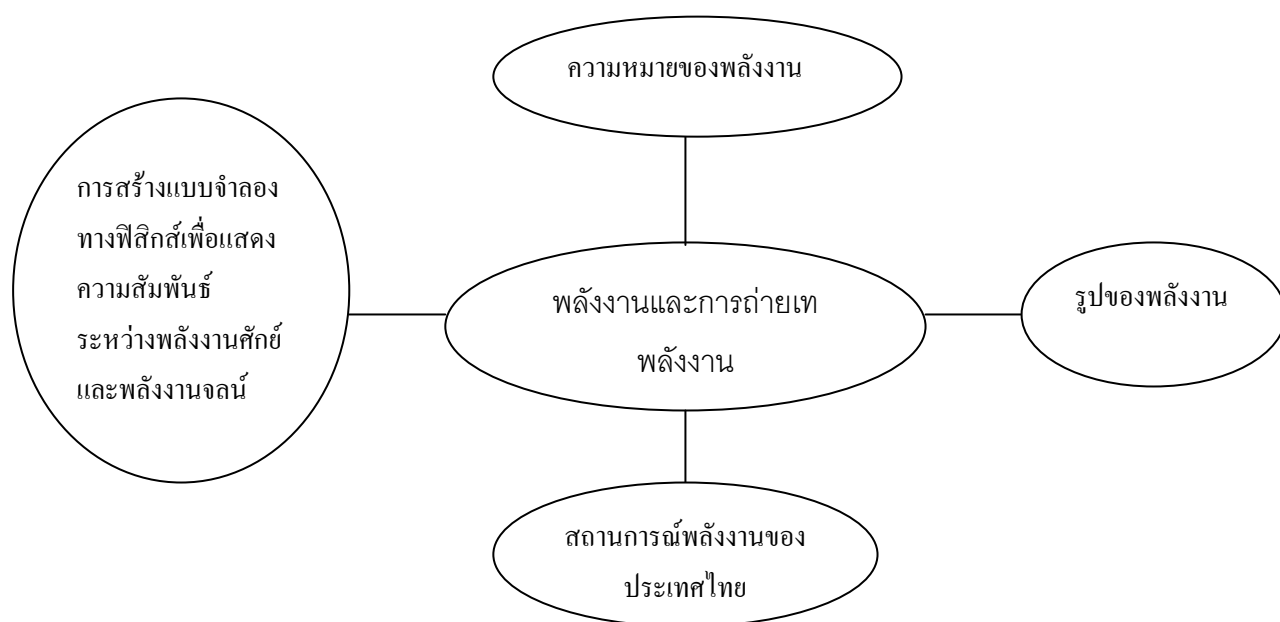
ตระหนักถึงปัญหาสถานการณ์พลังงานของประเทศไทย และแนวทางการแก้ปัญหาที่
เกี่ยวกับพลังงานในชีวิตประจำวัน

ศึกษาการสร้างแบบจำลองทางฟิสิกส์ซึ่งได้แก่แบบจำลองทางกายภาพและทาง
คณิตศาสตร์เกี่ยวกับพลังงาน โดยนำความรู้ ทักษะกระบวนการทางวิทยาศาสตร์ และทักษะ
การคิดขั้นสูงมาประยุกต์ใช้ในการทำโครงการการสร้างแบบจำลองทางฟิสิกส์ได้อย่างสร้างสรรค์

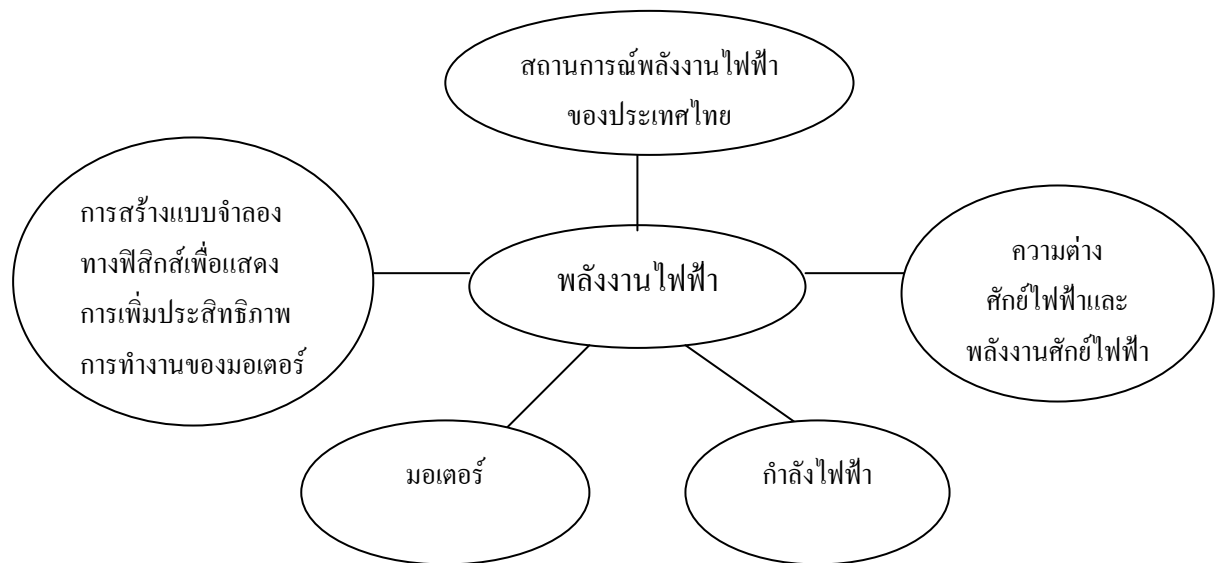
แผนผังมโนทัศน์ของแต่ละหน่วยการเรียนรู้
จำนวน 6 หน่วยการเรียนรู้ ดังนี้



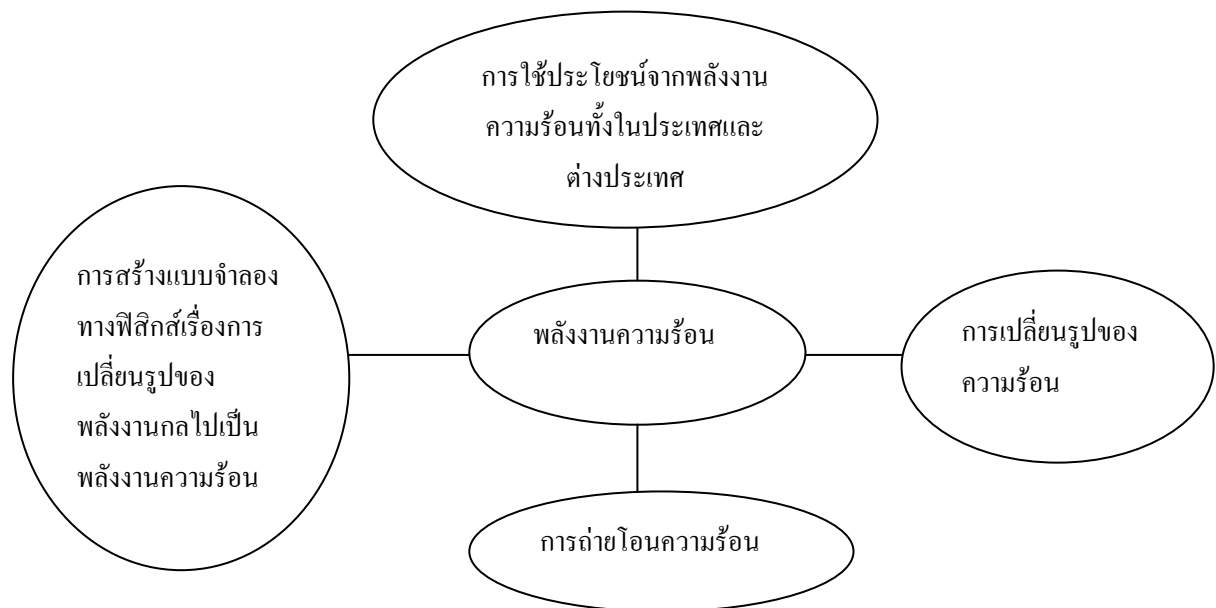
หน่วยการเรียนรู้ที่ 1: พลังงานและการถ่ายเทพลังงาน



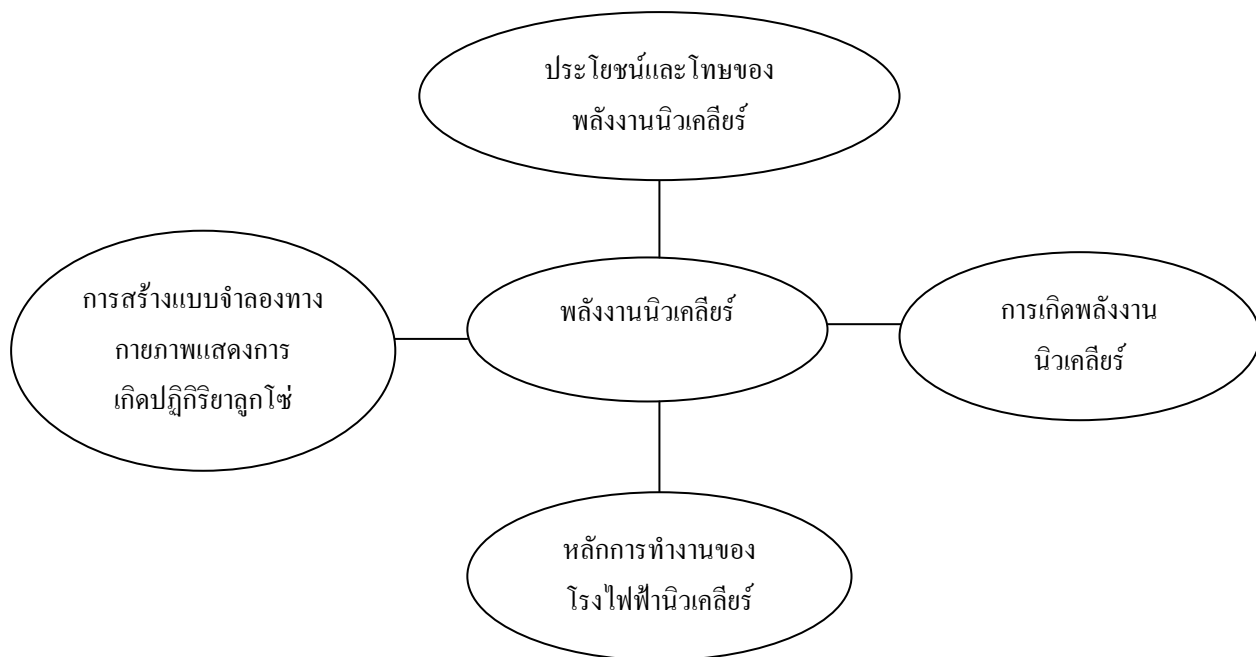
หน่วยการเรียนรู้ที่ 2: พลังงานไฟฟ้า



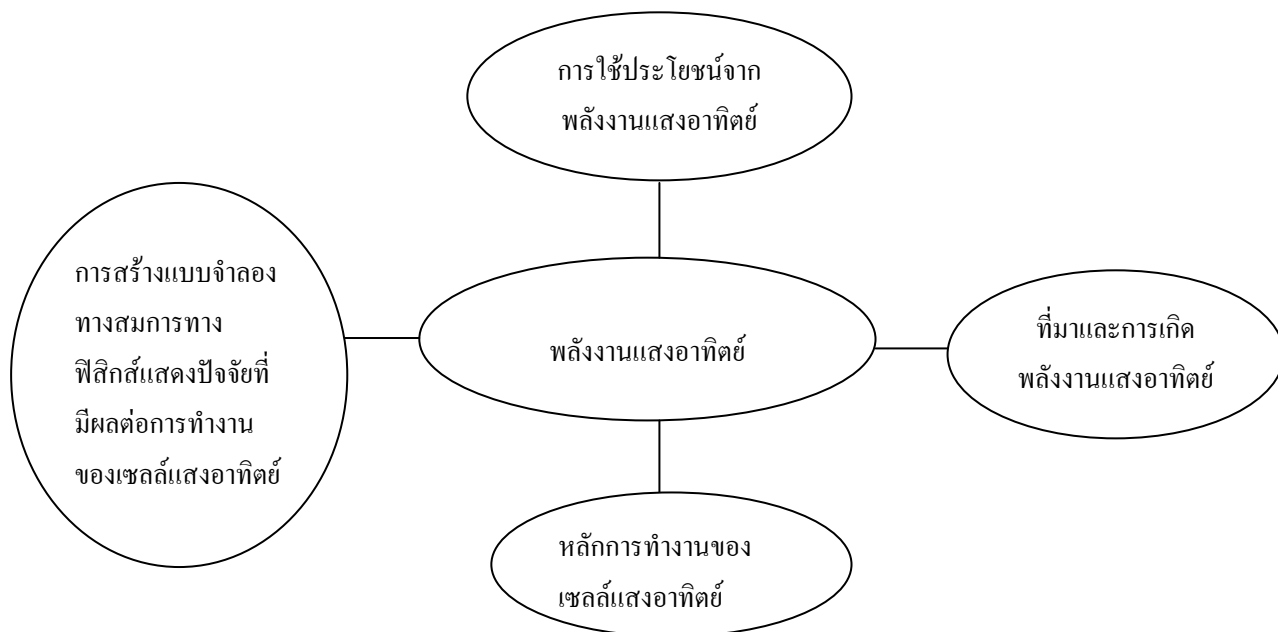
หน่วยการเรียนรู้ที่ 3: พลังงานความร้อน



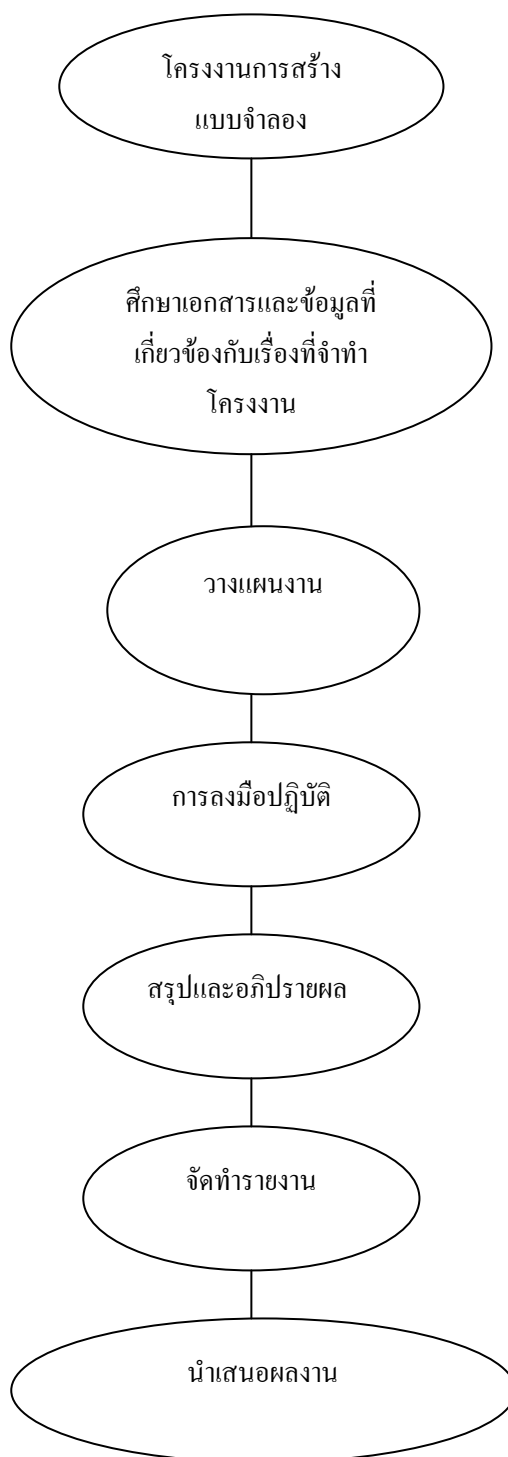
หน่วยการเรียนรู้ที่ 4: พลังงานนิวเคลียร์



หน่วยการเรียนรู้ที่ 5: พลังงานแสงอาทิตย์



หน่วยการเรียนรู้ที่ 6: โครงการการสร้างแบบจำลองทางฟิสิกส์เรื่องพลังงาน



ผลการเรียนรู้ที่คาดหวัง

1. สืบค้นและอภิปรายประเด็นปัญหาสถานการณ์พลังงานของประเทศไทยได้
2. อธิบายพร้อมยกตัวอย่างปัญหาสถานการณ์พลังงานของประเทศไทยได้
3. อธิบายความหมายของพลังงานได้
4. อธิบายรูปของพลังงานได้
5. ออกแบบการทดลองและสร้างแบบจำลองทางฟิสิกส์เพื่อแสดงความสัมพันธ์ระหว่างพลังงานศักย์และพลังงานจลน์ได้
6. สืบค้นและอภิปรายประเด็นเกี่ยวกับสถานการณ์พลังงานไฟฟ้าของประเทศไทยได้
7. อธิบายพร้อมยกตัวอย่างการนำพลังงานไฟฟ้ามาใช้ให้เกิดประโยชน์ในชีวิตประจำวันได้
8. อธิบายการเกิดพลังงานไฟฟ้าได้
9. อธิบายหลักการทำงานของมอเตอร์ได้
10. ออกแบบการทดลองและสร้างแบบจำลองทางฟิสิกส์ของการเปลี่ยนรูปพลังงานไฟฟ้าไปเป็นพลังงานกลได้
11. สืบค้นและอภิปรายประเด็นเกี่ยวกับการนำพลังงานความร้อนไปใช้ประโยชน์ได้
12. อธิบายพร้อมยกตัวอย่างการนำพลังงานความร้อนมาใช้ให้เกิดประโยชน์ในชีวิตประจำวันได้
13. อธิบายความหมายของพลังงานความร้อนได้
14. ออกแบบการทดลองและสร้างแบบจำลองทางฟิสิกส์เพื่อแสดงการเปลี่ยนรูปของพลังงานกลไปเป็นพลังงานความร้อนได้
15. สืบค้นและอภิปรายประเด็นเกี่ยวกับประโยชน์และโทษของพลังงานนิวเคลียร์ได้
16. อธิบายพร้อมยกตัวอย่างการใช้ประโยชน์และโทษของพลังงานนิวเคลียร์ได้
17. อธิบายการเกิดพลังงานนิวเคลียร์ ปฏิกิริยานิวเคลียร์ และปฏิกิริยาฟิวชันได้
18. ออกแบบการสร้างแบบจำลองทางกายภาพแสดงการเกิดปฏิกิริยาฟิวชันได้
19. สืบค้นและอภิปรายประเด็นเกี่ยวกับการนำพลังงานแสงอาทิตย์มาใช้ประโยชน์ได้
20. อธิบายพร้อมยกตัวอย่างการนำพลังงานแสงอาทิตย์มาใช้ให้เกิดประโยชน์ในชีวิตประจำวันได้
21. อธิบายหลักการนำพลังงานแสงอาทิตย์มาใช้ประโยชน์ได้
22. ออกแบบการทดลองและสร้างแบบจำลองทางฟิสิกส์แสดงปัจจัยที่ส่งผลต่อการ ทำงานของแผงเซลล์สุริยะ
23. ออกแบบและทำโครงการเพื่อสร้างแบบจำลองทางฟิสิกส์เรื่องพลังงานในชีวิตประจำวันได้
24. มีเจตคติทางวิทยาศาสตร์

ตัวอย่างแผนการจัดการเรียนรู้

แผนการจัดการเรียนรู้ เรื่อง พลังงานแสงอาทิตย์

จุดประสงค์	กิจกรรมการเรียนรู้การสอน	เวลา (นาที)	สื่อการสอน	การวัดและประเมินผล
1. สืบค้นและอภิปราย ประเด็นปัญหาเกี่ยวกับ พลังงานแสงอาทิตย์ได้	<u>Phase 1: Encouraging Issues</u> <u>ส่งเสริมการอภิปรายประเด็นปัญหาที่สำคัญ</u> <u>กิจกรรม การอภิปรายประเด็นปัญหาเรื่องพลังงานแสงอาทิตย์</u> - ครูตั้งคำถามที่ยังไม่ต้องให้นักเรียนได้คิดว่า “นักเรียนคิดว่าพลังงานแสงอาทิตย์มีประโยชน์ต่อเราอย่างไรบ้าง” ต่อไปให้นักเรียนแต่ละกลุ่มมานำเสนอประเด็นปัญหาที่นักเรียนไปศึกษามา - ผู้เรียนนำเสนอประเด็นปัญหาเกี่ยวกับเรื่องพลังงานแสงอาทิตย์และการนำไปใช้ประโยชน์ที่ไปศึกษามาเป็นกลุ่ม โดยหลังจากที่นำเสนอแล้ว นักเรียนในกลุ่มอื่น ๆ ร่วมกันอภิปรายในประเด็นนั้น ๆ - นักเรียนร่วมกันตอบคำถามจากคำถามแรกที่ครูตั้งไว้ โดยอ้างอิงจากข้อมูลที่แต่ละกลุ่มได้นำเสนอในชั้นเรียน - ครูช่วยสรุปและนำเสนอประเด็นเพิ่ม	5 25	- คอมพิวเตอร์ โปรเจกเตอร์ เครื่องฉายแผ่นใส (แล้วแต่ความต้องการใช้ในการนำเสนอของนักเรียน)	- สังเกตขณะอภิปรายและนำเสนอ - แบบสรุปหัวข้อบทความที่นักเรียนนำเสนอ

แผนการจัดการเรียนรู้ เรื่อง พลังงานแสงอาทิตย์

จุดประสงค์	กิจกรรมการเรียนรู้การสอน	เวลา (นาที)	สื่อการสอน	การวัดและประเมินผล
2. อธิบายหลักการทำงานของเซลล์สุริยะได้	<u>กิจกรรม ศึกษาหลักการทำงานของเซลล์สุริยะ</u> - ครูแจกใบกิจกรรมเรื่อง ศึกษาหลักการทำงานของเซลล์สุริยะ - ครูและนักเรียนไปศึกษาการทำงานของเซลล์สุริยะ - นักเรียนช่วยกันตั้งคำถามเกี่ยวกับการทำงานของเซลล์สุริยะ - นักเรียนร่วมกันอภิปรายหลักการทำงานของเซลล์สุริยะ - นักเรียนทุกคนสรุปสิ่งที่ศึกษาได้ลงในใบกิจกรรมเรื่อง ศึกษาหลักการทำงานของเซลล์สุริยะ - ท้ายสุดครูและนักเรียนร่วมกันสรุปหลักการทำงานของเซลล์สุริยะ - นักเรียนส่งใบกิจกรรมเรื่อง ศึกษาหลักการทำงานของเซลล์สุริยะ	70	<u>ชุดกิจกรรม ศึกษาหลักการทำงานของเซลล์สุริยะ</u> ได้แก่ แผ่นเซลล์สุริยะที่ทำงานอยู่จริง และใบกิจกรรม	- สังเกตขณะทำกิจกรรม การมีส่วนร่วมและการอภิปราย - บันทึกการเรียนรู้ของนักเรียน - จากการบันทึกผลกิจกรรม ศึกษาหลักการทำงานของเซลล์สุริยะ

แผนการจัดการเรียนรู้ เรื่อง พลังงานแสงอาทิตย์

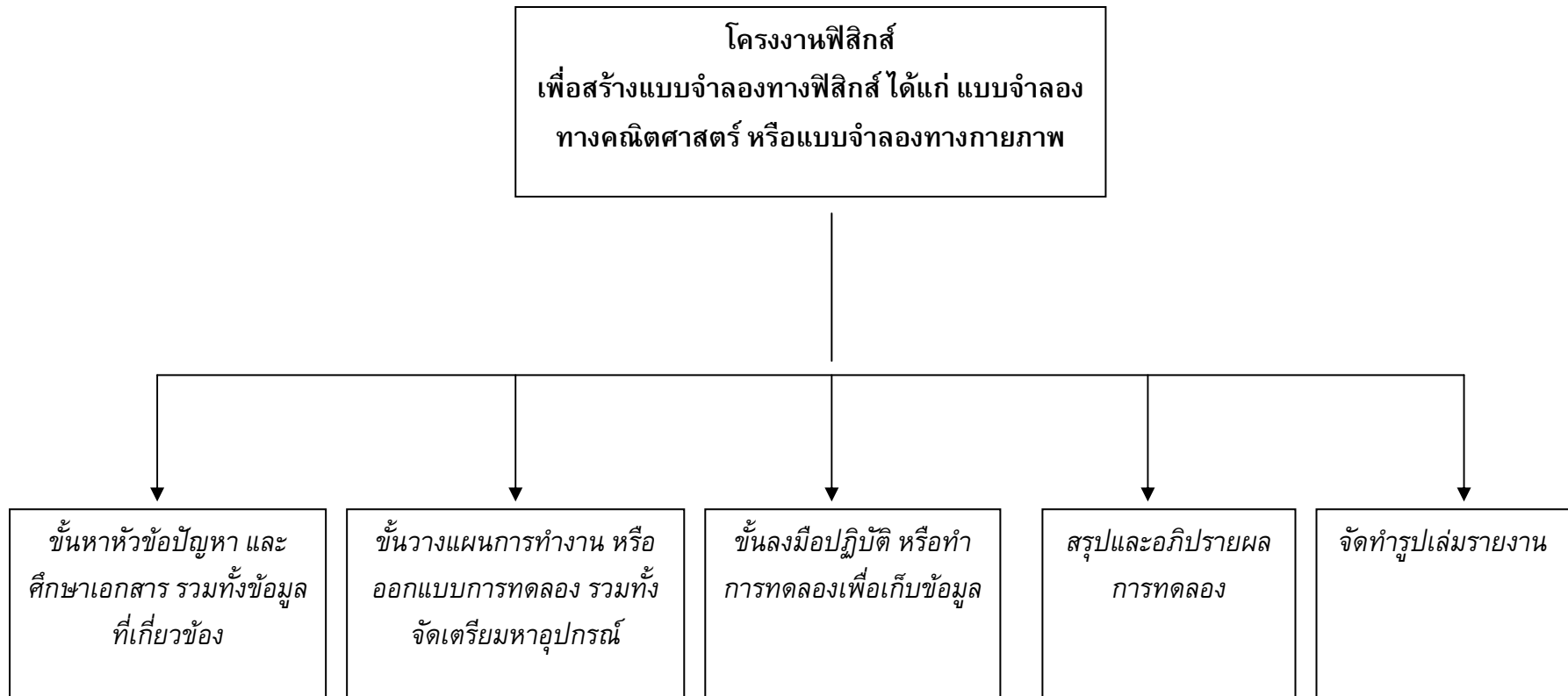
จุดประสงค์	กิจกรรมการเรียนการสอน	เวลา (นาที)	สื่อการสอน	การวัดและประเมินผล
3. ออกแบบการทดลองเพื่อสร้างแบบจำลองทางคณิตศาสตร์แสดงปัจจัยที่ส่งผลต่อการทำงานของแผงเซลล์สุริยะ	<u>Phase 2 : Experiments for modeling</u> <u>การออกแบบการทดลองเพื่อสร้างแบบจำลองทางฟิสิกส์</u> <u>กิจกรรม การออกแบบการทดลองเพื่อสร้างแบบจำลองทางคณิตศาสตร์เพื่อแสดงปัจจัยที่ส่งผลต่อการทำงานของแผงเซลล์สุริยะ</u> - ครูเตรียมอุปกรณ์การทดลองได้แก่ แผงเซลล์สุริยะ ขนาด 4 โวลต์ มัลติมิเตอร์ สายเมตร เทปขาว โคมไฟ สายไฟปากจระเข้ กล่องกระดาษขนาดปานกลาง (กล่องรองเท้าผ้าใบ) เทอร์โมมิเตอร์แบบปรอท ใบกิจกรรม - นักเรียนแบ่งกลุ่มทำการทดลอง - นักเรียนร่วมกันอภิปรายและออกแบบการทดลองภายในกลุ่ม - ครูคอยช่วยเหลือให้คำแนะนำแก่นักเรียน -	80	<u>ชุดกิจกรรม การออกแบบการทดลองเพื่อสร้างแบบจำลองทางคณิตศาสตร์เพื่อแสดงปัจจัยที่ส่งผลต่อการทำงานของแผงเซลล์สุริยะ</u> - ครูเตรียมอุปกรณ์การทดลองได้แก่ แผงโซลาร์เซลล์ 4 โวลต์ มัลติมิเตอร์ สายเมตร เทปขาว โคมไฟ สายไฟปากจระเข้ กล่องกระดาษขนาดปานกลาง (กล่องรองเท้าผ้าใบ) เทอร์โมมิเตอร์แบบปรอท ใบกิจกรรม	- แบบประเมินการสร้างผลงานอย่างสร้างสรรค์ (student product assessment form) - สังเกตขณะทำกิจกรรม การมีส่วนร่วมและการอภิปราย - บันทึกการเรียนรู้ของนักเรียน

แผนการจัดการเรียนรู้ เรื่อง พลังงานแสงอาทิตย์

จุดประสงค์	กิจกรรมการเรียนรู้	เวลา (นาที)	สื่อการสอน	การวัดและประเมินผล
3. นำเสนอผลการทดลองได้	<u>ขั้นนำเสนอผลงาน</u> - นักเรียนแต่ละกลุ่มนำเสนอผลการทดลอง - นักเรียนร่วมกันอภิปรายเกี่ยวกับการทดลอง - ครูสรุปหลักการนำพลังงานแสงอาทิตย์มาใช้ประโยชน์ และหลักการทำงานของแผงเซลล์สุริยะ	20	- คอมพิวเตอร์ โปรเจกเตอร์ (แล้วแต่ความต้องการใช้ในการนำเสนอของนักเรียน)	- แบบประเมินการสร้างผลงานอย่างสร้างสรรค์ (student product assessment form) - สังเกตขณะทำกิจกรรม การมีส่วนร่วมและการอภิปราย

Phase 3 : Creation of new model

การทำโครงการเพื่อสร้างแบบจำลองทางฟิสิกส์



แผนการจัดการเรียนรู้ การทำโครงงานเพื่อสร้างแบบจำลองทางฟิสิกส์

จุดประสงค์	กิจกรรมการเรียนการสอน	เวลา (สัปดาห์)	สื่อการสอน	การวัดและประเมินผล
1. สืบค้นข้อมูลเพื่อกำหนดหัวข้อโครงงานเพื่อสร้างแบบจำลองทางคณิตศาสตร์หรือแบบจำลองทางกายภาพได้	<u>ค้นหาหัวข้อโครงงาน</u> - ครูแนะนำแหล่งที่ใช้ในการหาข้อมูลเพื่อนำมาเป็นหัวข้อโครงงาน เช่น วารสารงานวิจัย จากผู้เชี่ยวชาญ แหล่งข้อมูลในอินเทอร์เน็ต เป็นต้น - นักเรียนศึกษาหาข้อมูล กำหนดหัวข้อโครงงาน จากนั้นศึกษาเอกสารที่เกี่ยวข้องกับหัวข้อโครงงาน - นักเรียนปรึกษาครูที่ปรึกษา และนำเสนอหัวข้อโครงงาน	3	-วารสารงานวิจัยคอมพิวเตอร์ที่เชื่อมต่ออินเทอร์เน็ต	- จากการซักถามและนำเสนอหัวข้อโครงงาน
2. ออกแบบการทดลองเพื่อสร้างแบบจำลองทางฟิสิกส์หรือแบบจำลองทางกายภาพได้	<u>ขึ้นวางแผนการทำงาน</u> - นักเรียนช่วยกันออกแบบวิธีการเก็บข้อมูล หรือออกแบบการทดลองเพื่อสร้างแบบจำลองทางฟิสิกส์ - นักเรียนวางแผนการทำงานภายในกลุ่ม โดยมีการอภิปรายร่วมกันตลอดเวลา - นำผลการออกแบบการทดลองเสนอต่อครูที่ปรึกษา - ครูแนะนำนักเรียนหากเกิดปัญหาพร้อมทั้งช่วยในเรื่องการจัดหาวัสดุและอุปกรณ์	2		- แบบประเมินการสร้างผลงานอย่างสร้างสรรค์ (student product assessment form) - สังเกตขณะทำกิจกรรม การมีส่วนร่วมและการอภิปราย

แผนการจัดการเรียนรู้ การทำโครงการเพื่อสร้างแบบจำลองทางฟิสิกส์

จุดประสงค์	กิจกรรมการเรียนรู้การสอน	เวลา (สัปดาห์)	สื่อการสอน	การวัดและประเมินผล
	- นักเรียนจัดเตรียมอุปกรณ์ที่ใช้ในการทำการทดลองหรือเก็บข้อมูล <u>ชั้นลงมือปฏิบัติ</u> - นักเรียนลงมือเก็บข้อมูลจากที่ได้ออกแบบไว้ โดยอาจเป็นการทำการทดลอง หรือวิธีการอื่น ๆ - นำผลการทดลองที่ได้เสนอต่อครูที่ปรึกษา <u>ชั้นสรุปและอภิปรายผล</u> - นักเรียนร่วมกันสรุปและอภิปรายผลการทดลองภายในกลุ่ม - นำผลการสรุปและอภิปรายผลการทดลองเสนอต่อครูที่ปรึกษา - ครูช่วยแนะนำเพิ่มเติมหากนักเรียนต้องการความช่วยเหลือ	3 1	- อุปกรณ์การทดลอง หรือ อุปกรณ์ต่าง ๆ ที่นักเรียนต้องการใช้ในการทำโครงการ	- แบบประเมินการสร้างผลงานอย่างสร้างสรรค์ (student product assessment form) - สังเกตขณะทำกิจกรรม การมีส่วนร่วมและการอภิปราย

Phase 4 : Exhibition

แผนการจัดการเรียนรู้ การนำเสนอผลงาน

จุดประสงค์	กิจกรรมการเรียนรู้การสอน	เวลา (สัปดาห์)	สื่อการสอน	การวัดและประเมินผล
นำเสนอผลงานอย่างสร้างสรรค์ และอภิปรายผลของโครงการได้	<u>การนำเสนอผลงาน</u> - ครูจัดเตรียมงานเพื่อให้นักเรียนได้นำเสนอผลงาน โดยจัดทำสื่อประกาศเชิญชวนการฟังการนำเสนอผลงานภายในโรงเรียน ทั้งครู นักเรียน และผู้ที่สนใจ - นักเรียนเตรียมการนำเสนอผลงานอย่างสร้างสรรค์และทันสมัย - ครูช่วยจัดหาอุปกรณ์ที่นักเรียนต้องใช้ในการนำเสนอ เช่น คอมพิวเตอร์ โปรเจกเตอร์ หรือโปรแกรมสำเร็จรูปต่าง ๆ เป็นต้น - ครูเป็นพิธีกรในงานนำเสนอและการอภิปรายโครงการ - นักเรียนนำเสนอผลงานต่อผู้เข้าร่วมฟัง และร่วมอภิปรายภายหลังการนำเสนอผลงาน	1	- สื่อต่าง ๆ ที่ใช้ประกาศเชิญชวนผู้สนใจเข้าร่วมฟังการนำเสนอผลงาน - คอมพิวเตอร์ โปรเจกเตอร์ หรืออุปกรณ์ต่าง ๆ ที่นักเรียนต้องการใช้ในการนำเสนอ	- แบบประเมินการสร้างผลงานอย่างสร้างสรรค์ (ข้อที่ประเมินการนำเสนอผลงาน) - สังเกตขณะทำกิจกรรม การมีส่วนร่วมและการอภิปราย

ตัวอย่างใบกิจกรรม

ใบกิจกรรม

เรื่อง การออกแบบการทดลองเพื่อสร้างแบบจำลองทางคณิตศาสตร์แสดงปัจจัยที่ส่งผล ต่อการทำงานของแผงเซลล์สุริยะ

ชื่อนักเรียน 1).....ชั้น.....
 2).....ชั้น.....
 3).....ชั้น.....
 4).....ชั้น.....

วันที่ทำการทดลอง.....

คำชี้แจง ให้นักเรียนเลือกใช้อุปกรณ์จากที่กำหนดให้นำไปออกแบบการทดลองเพื่อสร้างสมการคณิตศาสตร์ โดยนักเรียนไม่จำเป็นต้องใช้อุปกรณ์ทั้งหมด หรือหากต้องการอุปกรณ์อย่างอื่นเพิ่มเติมให้ถามจากครูผู้สอนหรือครูปฏิบัติการ

วัสดุอุปกรณ์

1. แผงโซลาร์เซลล์ 4 โวลต์
2. มัลติมิเตอร์
3. สายเมตร
4. เทปขาว
5. โคมไฟ
6. สายไฟปากจระเข้
7. temperature sensor (ถ้าไม่มีใช้เทอร์โมมิเตอร์แบบปรอท)

คำถามก่อนทำกิจกรรม

1. ตัวแปรใดบ้างที่ส่งผลต่อการทำงานของแผงโซลาร์เซลล์

2. นักเรียนคิดว่ากระแสไฟฟ้าและแรงดันไฟฟ้าจะมีการเปลี่ยนแปลงหรือไม่ อย่างไรต่อการทำงานของแผงโซลาร์เซลล์

จุดประสงค์การทดลอง

3.....

อุปกรณ์การทดลอง

วิธีการทดลอง

This image shows a full page of white paper with ten horizontal dashed lines, typical of primary school handwriting practice paper. The lines are evenly spaced and extend across the entire width of the page. There is no text or other markings on the paper.

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ตารางบันทึกผลการทดลอง

กราฟแสดงผลการทดลอง

สมการทางคณิตศาสตร์ที่ได้จากกราฟแสดงผลข้อมูล

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สรุปและอภิปรายผลการทดลอง

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คำถามท้ายกิจกรรมสะท้อนความคิดของนักเรียน

1. นักเรียนคิดว่ามีปัจจัยอื่น ๆ อีกหรือไม่นอกเหนือจากที่นักเรียนทำการทดลอง ที่ส่งผลต่อการทำงานของแผงเซลล์สุริยะ และส่งผลอย่างไร

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2. นักเรียนคิดว่าปัจจัยใดที่สำคัญที่สุดที่ส่งผลต่อการทำงานของแผงเซลล์สุริยะ เพราะเหตุใด

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3. ถ้านักเรียนสามารถออกแบบการทดลองได้เองอย่างไม่มีข้อจำกัดในเรื่องวัสดุและอุปกรณ์ นักเรียนจะปรับแก้การออกแบบการทดลองนี้อย่างไร

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4. คำถามเกี่ยวกับการนำแบบจำลองไปใช้

- สิ่งใดบ้างในการทำการทดลองนี้ที่ช่วยเพิ่มพูนความรู้ของนักเรียน

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- สิ่งใดบ้างในการทำการทดลองเพื่อสร้างสมการทางคณิตศาสตร์ที่ขัดแย้งกับความรู้เดิมของนักเรียน

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- สิ่งใดบ้างในการทดลองเพื่อสร้างสมการทางคณิตศาสตร์ที่เป็นสิ่งใหม่สำหรับนักเรียน

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- สมการทางคณิตศาสตร์ที่นักเรียนสร้างขึ้นสามารถนำไปใช้ในสถานการณ์อื่น ๆ ได้อย่างไรบ้าง

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ใบกิจกรรม

เรื่อง การสร้างแบบทางกายภาพแสดงการเกิดปฏิกิริยาลูกโซ่

ชื่อนักเรียน 1).....ชั้น.....
 2).....ชั้น.....
 3).....ชั้น.....
 4).....ชั้น.....

วันที่ทำการทดลอง.....

คำชี้แจง ให้นักเรียนเลือกใช้อุปกรณ์จากที่กำหนดให้นำไปออกแบบการทดลองเพื่อสร้างสมการ
 คณิตศาสตร์ โดยนักเรียนไม่จำเป็นต้องใช้อุปกรณ์ทั้งหมด หรือหากต้องการอุปกรณ์อย่างอื่น
 ให้ถามจากครูผู้สอนหรือครูปฏิบัติการ

วัสดุอุปกรณ์

1. โดมิโน

คำถามก่อนทำกิจกรรม

1. ปฏิกิริยาลูกโซ่เกิดขึ้นได้อย่างไร

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2. ปฏิกิริยาลูกโซ่มีลักษณะอย่างไร

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จุดประสงค์การทดลอง

3.....

อุปกรณ์การทดลอง

วิธีการทดลอง

[illegible]

แผนภาพแสดงแบบจำลองทางกายภาพ

กราฟแสดงข้อมูลที่ได้จากการใช้แบบจำลองแสดงการเกิดปฏิกิริยาลูกโซ่

สรุปและอภิปรายผลการทดลอง

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คำถามท้ายกิจกรรมการสะท้อนความคิดของนักเรียน

1. จงอธิบายพร้อมยกตัวอย่างสมการแสดงการเกิดปฏิกิริยาลูกโซ่

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2. นักเรียนสามารถใช้แบบจำลองแสดงการเกิดปฏิกิริยาลูกโซ่ได้หรือไม่อย่างไร

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3. นักเรียนค้นพบอะไรบ้างจากการออกแบบแบบจำลองนี้ที่เกี่ยวข้องกับปฏิกิริยาลูกโซ่

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3.1 สิ่งใดบ้างในแบบจำลองที่นักเรียนสร้างขึ้นนี้เป็นสิ่งใหม่สำหรับนักเรียน

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3.2 แบบจำลองที่นักเรียนสร้างขึ้นสามารถนำไปใช้ในสถานการณ์อื่น ๆ ได้อย่างไรบ้าง

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4. คำถามเกี่ยวกับการนำแบบจำลองไปใช้

4.1 สิ่งใดบ้างในแบบจำลองที่นักเรียนสร้างขึ้นที่ช่วยเพิ่มพูนความรู้ของนักเรียน

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4.2 สิ่งใดบ้างในแบบจำลองที่นักเรียนสร้างขึ้นที่ขัดแย้งกับความรู้เดิมของนักเรียน

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4.3 สิ่งใดบ้างในแบบจำลองที่นักเรียนสร้างขึ้นนี้เป็นสิ่งใหม่สำหรับนักเรียน

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4.4 แบบจำลองที่นักเรียนสร้างขึ้นสามารถนำไปใช้ในสถานการณ์อื่น ๆ ได้อย่างไรบ้าง

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ตัวอย่างผลการทำใบกิจกรรมของนักเรียน

ใบบันทึกผลการออกแบบการทดลอง
เรื่อง การออกแบบการทดลองเพื่อสร้างแบบจำลองทางคณิตศาสตร์แสดงปัจจัยที่
ส่งผลต่อการทำงานของแผงเซลล์สุริยะ

ปัญหา ระยะห่างจากแหล่งกำเนิดแสง มีผลอย่างไร ต่อความยาวศักย์ไฟฟ้าของแผง
จุดประสงค์การทดลอง โซลาร์เซลล์

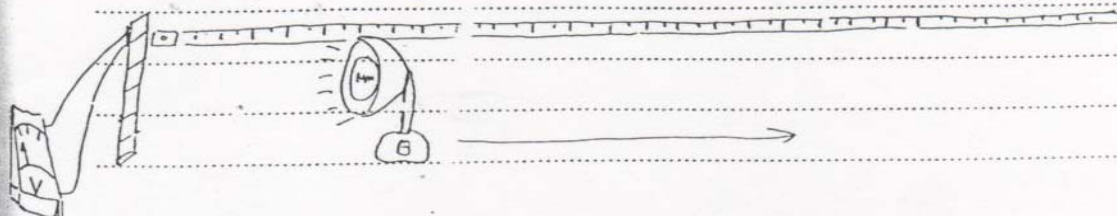
1. เปรียบเทียบความยาวศักย์ไฟฟ้าของแผงเซลล์สุริยะ ที่ระยะห่างจาก
 แหล่งกำเนิดแสงต่างๆ กัน
2. เพื่อสร้างแบบจำลองทางคณิตศาสตร์ เพื่ออธิบายความสัมพันธ์ระหว่าง

อุปกรณ์การทดลอง ระยะห่างจากแหล่งกำเนิดแสง กับความยาวศักย์ไฟฟ้าของแผงเซลล์สุริยะ

อุปกรณ์	จำนวนชิ้น
เซลล์แสงอาทิตย์ 4 V	1
โวลต์มิเตอร์	1
สายวัด	1
เทปขาว	1
โคมไฟฮาโลเจน 20 watt	1
สเกล	2

วิธีการทดลอง

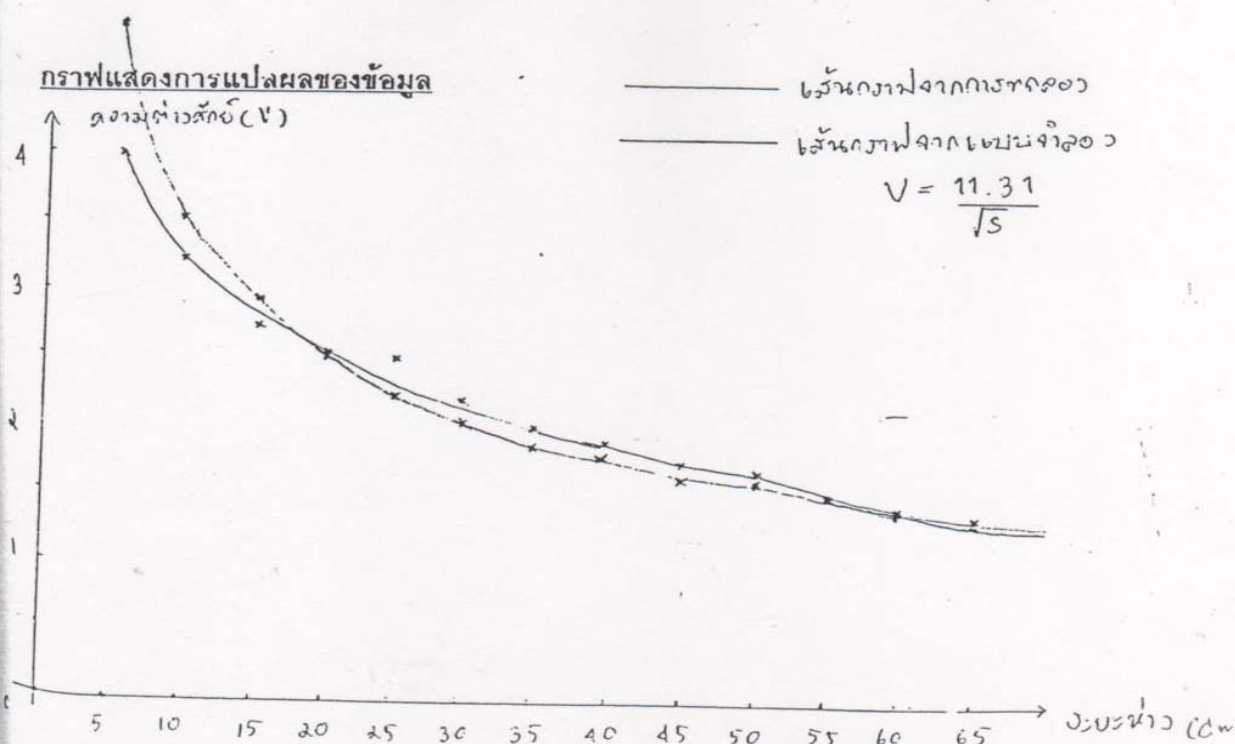
1. ติดเซลล์แสงอาทิตย์เข้ากับสเกล และติดสายวัดเพื่อกำหนดระยะห่าง
 จากแหล่งแสง
2. เปิดโคมไฟ และตั้งที่ระยะห่างจาก แหล่งแสง 5, 10, 15, ..., 65 cm
 โดยให้ระนาบผิวโคมไฟขนานกับผิวเซลล์แสงอาทิตย์
3. อ่านค่าความยาวศักย์ที่ได้จากโวลต์มิเตอร์ นำมาวิเคราะห์ผล



ตารางบันทึกผลการทดลอง

ระยะน้ำ (cm)	5	10	15	20	25	30	35	40	45	50	55	60	65	150
ความต่างศักย์ (V)	4.00	3.25	2.75	2.50	2.50	2.25	2.00	2.00	1.75	1.75	1.50	1.50	1.50	0.75

* ค่าที่อ่านได้จากมิเตอร์เป็นค่าที่ไม่ละเอียด เนื่องจากสเกลวัดอ่านค่าได้ไม่ละเอียด จึงทำให้มีลักษณะของตัวที่ซ้ำกันขึ้น เนื่องจากความแตกต่างของค่าไม่สามารถบอกได้อย่างแน่นอน



สมการทางคณิตศาสตร์ที่ได้จากกราฟ

หากลักษณะของกราฟ น่าจะวัดความสัมพันธ์ทางคณิตศาสตร์ เมื่อกำหนดให้

V เป็นค่าความต่างศักย์ (V) และ s เป็นระยะนำว (cm) ดังนั้น

$$V \propto \frac{1}{\sqrt{s}}$$

จะได้ $V = \frac{k}{\sqrt{s}}$ เมื่อ k เป็นค่าคงที่ของการแปรผัน

$$k = V\sqrt{s}$$

โดยการหาค่า k จาก V และ s แต่ละค่าพบว่า มีค่าใกล้เคียงกัน ใกล้เคียงกับ

8.9, 10.27, 10.65, 11.18, 12.5, 12.32, 11.83, 12.64, 11.73, 12.37, 11.83,
12.64, 11.73, 12.37, 11.12, 11.61, 12.09, 9.18 เฉลี่ยเท่ากับ 11.31

สรุปและอภิปรายผลการทดลอง $\therefore$ จึงสรุปความสัมพันธ์ได้เป็น $V = \frac{11.31}{\sqrt{s}}$

จากผลการทดลองสรุปได้ตามสมการทางคณิตศาสตร์ได้เป็น

$$V = \frac{k}{\sqrt{s}}$$

จากความสัมพันธ์ระหว่างความเข้มแสง I กับระยะนำว s

$$I = \frac{C}{s^2}, \quad C \text{ เป็นค่าคงที่ของการแปรผัน}$$

จะได้

$$s = \sqrt{\frac{C}{I}}$$

และ

$$V = \frac{k\sqrt{I}}{\sqrt[4]{C}}$$

นั่น $\frac{k}{\sqrt[4]{C}}$ เป็นพจน์ค่าคงที่ จะสรุปได้ว่ามีความสัมพันธ์ระหว่างความเข้มแสงกับความต่างศักย์

$$V = k\sqrt{I}$$

คำถามท้ายกิจกรรมการสะท้อนความคิดของนักเรียน

1. นักเรียนคิดว่ามีปัจจัยอื่น ๆ อีกหรือไม่นอกเหนือจากที่นักเรียนทำการทดลอง ที่ส่งผลต่อ

การทำงานของแผงเซลล์สุริยะ และส่งผลอย่างไร

- คนหนึ่งน่าจะมีส่วนที่ทำให้ การทำงานของแผงเซลล์สุริยะลดลง
เนื่องจากทำให้ความต้านทานมากขึ้น

- ความยาวคลื่นแสง แสงที่มีความยาวคลื่นสั้น มีพลังงานมาก น่า
จะทำให้พลังงานไฟฟ้าที่ได้มากตามไปด้วย

2. นักเรียนคิดว่าปัจจัยใดที่สำคัญที่สุดที่ส่งผลต่อการทำงานของแผงเซลล์สุริยะ เพราะเหตุใด

ความเข้มแสง เพราะ

1.) ความเข้มแสง เป็น ปัจจัยที่เปลี่ยนแปลงมากในแต่ละช่วงเวลา
ของวัน ในขณะที่อุณหภูมิ หรือ ความยาวคลื่นไม่มีการเปลี่ยนแปลง
มากนัก

2) ตัวเซลล์แสงอาทิตย์ จะมีการดูดกลืนคลื่นแสงในช่วงที่จำเพาะ
ช่วงหนึ่ง คลื่นแสงในช่วงความยาวคลื่นอื่นจะไม่ผ่าน จะไม่ผล

3. ถ้านักเรียนสามารถออกแบบการทดลองได้เองอย่างไม่มีข้อจำกัดในเรื่องวัสดุและอุปกรณ์
นักเรียนจะปรับแก้การออกแบบการทดลองนี้อย่างไร

- ใช้อุปกรณ์วัดค่าความต่างศักย์ ที่เที่ยงตรง และวัดค่าได้ละเอียด

- แสงสว่างในหลอดแสงก็ในหลอดความเข้มแสงที่สม่ำเสมอ

ควบคุมความเข้ม หรือ กำหนดระยะห่างที่แน่นอนได้ละเอียด
แม่นยำ

- สดวกทำการทดลองกับเซลล์แสงอาทิตย์หลายรูปแบบ
รวมทั้งเซลล์แสงอาทิตย์ที่มีขนาดแตกต่างกัน

4. คำถามเกี่ยวกับการนำแบบจำลองไปใช้

- สิ่งใดบ้างในการทำการทดลองนี้ที่ช่วยเพิ่มพูนความรู้ของนักเรียน

- ทำให้เข้าใจหลักการทํางานเบื้องต้นของเซลล์แสงอาทิตย์

- ความรู้เกี่ยวกับฟังก์ชันสามัญ (Common fe) ทางคณิตศาสตร์
ที่สามารถนำมาประยุกต์ในการสร้างแบบจำลอง

- ประสิทธิภาพเกี่ยวกับการใช้วงจรอุปกรณ์วัดทางไฟฟ้า

- สิ่งใดบ้างในการทำการทดลองเพื่อสร้างสมการคณิตศาสตร์ที่ขัดแย้งกับความรู้เดิมของ
นักเรียน

ความสัมพันธ์ของความต่างศักย์ที่แปรผันตรงกับเวลาที่ส่อง

ความเข้มแสง ซึ่งในตอนแรกเข้าใจว่า เป็นการแปรผันเชิง

เส้นตรงกับ ความเข้มแสง

- สิ่งใดบ้างในการทดลองเพื่อสร้างสมการคณิตศาสตร์ที่เป็นสิ่งใหม่สำหรับนักเรียน
 - การประยุกต์ใช้ความรู้ทางคณิตศาสตร์ในการสร้างแบบจำลอง
 - เข้าใจความสัมพันธ์ระหว่างระยะทาง ความเร็ว และค่าความต่างศักย์ที่วัดได้จากเซลล์แสงอาทิตย์
- สมการคณิตศาสตร์ที่นักเรียนสร้างขึ้นสามารถนำไปใช้ในสถานการณ์อื่นๆได้อย่างไรบ้าง
 - ใช้ในการติดตั้งเซลล์แสงอาทิตย์ให้สามารถใช้ประโยชน์ตามวัตถุประสงค์ได้อย่างมีประสิทธิภาพ

VITAE

VITAE

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2000	Bachelor of Science (Physics) from Srinakarinwirot University
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