DESIGNING AND IMPLEMENTING NANOSCIENCE AND NANOTECHNOLOGY CURRICULUM MATERIALS FOR HIGH SCHOOL AND UNDERGRADUATE STUDENTS

CHOOJIT SARAPAK

A THESIS SUBMITTED IN PARTIAL FULFILLMENT
OF THE REQUIREMENTS FORTHE DEGREE OF
DOCTOR OF PHILOSOPHY
(SCIENCE AND TECHNOLOGY EDUCATION)
FACULTY OF GRADUATE STUDIES
MAHIDOL UNIVERSITY
2013

Thesis
entitled

DESIGNING AND IMPLEMENTING NANOSCIENCE AND NANOTECHNOLOGY CURRICULUM MATERIALS FOR HIGH SCHOOL AND UNDERGRADUATE STUDENTS

……………………………………………
Miss Choojit Sarapak
Candidate

……………………………………………
Asst. Prof.Khajornsak Buaraphan, Ph.D.
Major advisor

……………………………………………
Mrs.Tussatrin Wannagatesiri, Ph.D.
Co-advisor

…………………………………………
Assoc. Prof. Bhinyo Panijpan, Ph.D.
Co-advisor

…………………………………………
Prof. Banchong Mahaisavariya,
M.D., Dip Thai Board of Orthopedics
Dean
Faculty of Graduate Studies
Mahidol University

…………………………………………
Lect. Namkang Sriwattanarothai, Ph.D.
Program Director
Doctor of Philosophy Program in
Science and Technology Education
Institute for Innovative Learning
Mahidol University

Thesis
entitled

DESIGNING AND IMPLEMENTING NANOSCIENCE AND NANOTECHNOLOGY CURRICULUM MATERIALS FOR HIGH SCHOOL AND UNDERGRADUATE STUDENTS

was submitted to the Faculty of Graduate Studies, Mahidol University
for the degree of Doctor of Philosophy (Science and Technology Education)
on
January 28, 2013

…………………………………………
MissChoojitSarapak
Candidate

…………………………………………
Assoc. Prof. NasonPhonphok , Ph.D.
Chair

…………………………………………
Assoc. Prof. BhinyoPanijpan, Ph.D.
Member

…………………………………………
Asst. Prof.KhajornsakBuaraphan, Ph.D.
Member

…………………………………………
Mr. SupanYodyingyong, Ph.D.
Member

…………………………………………
Mrs.TussatrinWannagatesiri, Ph.D.
Member

…………………………………………
Prof. BanchongMahaisavariya,
M.D., Dip Thai Board of Orthopedics
Dean
Faculty of Graduate Studies
Mahidol University

…………………………………………
Assoc.Prof. WannapongTriampo, Ph.D.
Director
Institute for Innovative Learning
Mahidol University

ACKNOWLEDGEMENTS

This thesis could not successfully completed without the kindness of advisor’s team. First and foremost to my advisor, Mrs. Tussatrin Wannagatesiri,Ph.D andAsst.Prof.Khajornsak Buaraphan, Ph.D. who gave good advice and be guidance of this thesis since start until successful and also checked and corrected the fault of this thesis. My co-advisor, Assoc. Prof. Bhinyo Panijpan, who is a good guidance for experiment. He gave appreciate suggestion.

I would like to special thank for all of staff atThe institute of innovative learning, Mahidol university and The Materials Research Science and Engineering Center at the University of Wisconsin – Madison (UW MRSEC)for their helpful in providing facilities and materials for my thesis activity. Also, I would like to special thank for Kevin Niemi from The institute of biology education at University of Wisconsin – Madison for the expert suggestion and cooperation during I spent my great time in Madison-Wisconsin, USA.

Finally, My graduation would not be achieved without best wish from my parents, Mr. Pradit and Mrs. Wan Sarapakwho help me for everything and always gives me greatest love, with power and financial support until this study completion and the last gratefully special thanks to my relation and my friends for their help and encouragement.

Choojit Sarapak

DESIGNING AND IMPLEMENTING NANOSCIENCE AND NANOTECHNOLOGY CURRICULUM MATERIALS FOR HIGH SCHOOL AND UNDERGRADUATE STUDENTS

CHOOJIT SARAPAK 5136916 ILSE/D

Ph.D.(SCIENCE AND TECHNOLOGY EDUCATION)

THESIS ADVISORY COMMITTEES:KHAJORNSAK BUARAPHAN, Ph.D. TUSSATRIN WANNAGATESIRI, Ph.D., BHINYO PANIJPAN, Ph.D.

ABSTRACT

This research reports an effort to integrate basic concepts of nanoscience and nanotechnology to the high school and undergraduate curriculum. The new curriculum entitled the Nanoscience and Nanotechnology Curriculum, is consisted of six learning modules (18 hours) aimed at promotingstudent's basic knowledge of nanoscience and nanotechnology in high school and undergraduate levels. This study is a multiple case study conducted in one high school and one university located in the Eastern region of Thailand. There were 38high school and 41 students who participated in the newly created curriculum. The data was analyzed both qualitatively and quantitatively. The main results reveal that the participating high school and undergraduate students developed more understanding about nanoscience and nanotechnology and more positive attitudes toward the curriculum. The discussion and implications from this study are also presented.

KEY WORDS: NANOSCIENCE /NANOTECHNOLOGY /NANOTECNOLOGY ACTIVITY/NANOTECHNOLOGY CURRICULUM

127 pages

การสร้างและใช้หลักสูตรความรู้พื้นฐานทางนาโนเทคโนโลยีในระดับชั้นมัธยมศึกษาตอนปลายและระดับปริญญาตรี

DESIGNING AND IMPLEMENTING NANOSCIENCE AND NANOTECHNOLOGY CURRICULUM MATERIALS FOR HIGH SCHOOL AND UNDERGRADUATE STUDENTS

ชูจิต สาระภาค 5136916 ILSE/D

ปร.ด. (วิทยาศาสตร์และเทคโนโลยีศึกษา)

คณะกรรมการที่ปรึกษาวิทยานิพนธ์: ขจรศักดิ์ บัวระพันธ์, Ph.D., ทัศตริน วรรณเกษศิริ, Ph.D., ภิญโญ ภานิชพันธ์ , Ph.D.

บทคัดย่อ

การวิจัยครั้งนี้มีจุดมุ่งหมายเพื่อสร้างและใช้หลักสูตรความรู้พื้นฐานทางวิทยาศาสตร์นาโนและนาโนเทคโนโลยีสำหรับนักเรียนระดับมัธยมศึกษาตอนปลายและนักศึกษาระดับปริญญาตรีซึ่งแบ่งออกเป็น 6 หน่วยการเรียนรู้ที่ครอบคลุมความรู้พื้นฐานเกี่ยวกับวิทยาศาสตร์นาโนและนาโนเทคโนโลยี รวมเวลาทั้งหมด 18 ชั่วโมง งานวิจัยนี้เป็นงานวิจัยแบบพหุกรณีศึกษาที่เก็บรวบรวมข้อมูลจากโรงเรียนมัธยมศึกษาจำนวน 1 แห่ง และมหาวิทยาลัย จำนวน 1 แห่ง ณ ภาคตะวันออกของประเทศไทย ผู้เข้าร่วมการวิจัยประกอบด้วยนักเรียนระดับมัธยมศึกษาตอนปลาย จำนวน 38 คน และนักศึกษาระดับปริญญาตรี จำนวน 41คน ข้อมูลเชิงปริมาณจะวิเคราะห์ทางสถิติ ส่วนข้อมูลเชิงคุณภาพจะวิเคราะห์โดยการให้รหัส จัดหมวดข้อมูล และหาประเด็นหลัก ผลการวิจัยพบว่า หลักสูตรความรู้พื้นฐานทางวิทยาศาสตร์นาโนและนาโนเทคโนโลยีสามารถพัฒนาความเข้าใจของนักเรียนระดับมัธยมศึกษาตอนปลายและนักศึกษาระดับปริญญาตรีเกี่ยวกับวิทยาศาสตร์นาโนและนาโนเทคโนโลยีได้ และส่งเสริมให้นักเรียนนักศึกษามีเจตคติที่ดีขึ้นต่อกิจกรรมทางวิทยาศาสตร์นาโนและนาโนเทคโนโลยี ในตอนท้ายผู้วิจัยได้อภิปรายผลและเสนอแนะการนำหลักสูตรความรู้พื้นฐานทางวิทยาศาสตร์นาโนและนาโนเทคโนโลยีไปใช้

127 หน้า

CONTENTS

CONTENTS (cont.)

LIST OF TABLES

LIST OF TABLES (cont.)

LIST OF FIGURES

CHAPTER I

INTRODUCTION

Nanotechnology is one branch of technology that has the potential to impact our daily lives. Nanotechnology can be applied to many kinds of materials such as ceramics, metals, and polymers to create new materials, which are the foundation of emerging technology advancement. In the coming decades, nanotechnology has enormous impact on manufacturing, electronics, information and communication technology. This new technology leads to many applications which aim to make our lives better more and more. Nowadays, in modern society, nanotechnology embeds in our lives in many formats such as clothes, umbrella, cosmetics, mobile devices, etc. Really, when we talk about nanotechnology, we should consider nanoscience also. Frequently, we call this emerging field as **nanoscience and nanotechnology (NST)**. Nanoscinece allows us to understand the world we live in as well as the universe surrounding us at a deeper level; whereas nanotechnology help us lives with more convenient ways.

Importance of NST

NST is related to the growing of countries. The application of NST transforms the world through dramatic advances in almost all fields including medicine, engineering, electronics, aeronautic and so on. NST education is considered as an important instrument in the search for sustainable development and poverty reduction of the countries. Therefore, the education system throughout the world gears toward preparing more human resource who are ready prepared with NST in order to meet this growing challenge. The educational system is being inspired to merge major nanoscience concepts to curricula at every level from kindergarten to high school and next higher level (Roco, 2003).

Teaching about NST

NST has become one portion of several curricula in many countries and regions such as Europe, USA, Japan, China, and Korea. There are a number of NST curriculum for high school and undergraduate students in developed countries aimed to provide the next generation for future nanoscience advantages (Tomasik et al, 2009; Planinsic & Kovac,2008; Tahan et al,2006; Sullivan et al,2008; Brazell et al, 2009; Winkelmann ,2009; Samet,2009; College et al,2009; Dyehouse et al,2008; Murriello et al, 2009).

To help students being NST capable, we must first prepare teachers. For example, in USA, physic teachers are developed to gain more knowledge about nanophysics (Planinsic and Kovac,2008). Many science teacher development programs are created to help middle and high schools' science teachers incorporate nanoscience into their classrooms (Tomasik et al, 2009).

The teaching of NST should be added to classrooms as knowledge-centered and learning-centered environments, which concern creative thinking, critical thinking and life-long learning. Classrooms that emphasize interactive learning and cooperative learning would give students opportunities to work and participate with each other, while research-based learning would also provide students opportunities to gain hands-on experience (Semih & Yelda, 2008; Michael et al., 2002). A research study by O'Connor and Hayden (2008) stated that the utilization of contextualizing nanotechnology in science classrooms could enhance students' interest in learning about nanotechnology and enjoy its futuristic concepts. Problem-based learning is another approach that could enhance classroom discussions. Consorting teachers' opinions on effective teaching of nanotechnology included in hands-on experiments, creating animations, holding contests, building websites and integrating nanotechnology into textbooks which need to be provided that would convey students' interests in new technology (Chih-Kuan et al., 2006). Various orientations towards teaching NST are identified, e.g. Michael et al. (2002), Tahan et al. (2006), O'Connor and Hayden (2008), and Winkelmann (2009), that interactive learning, cooperative learning, contextual learning, activity-driven, discovery, project-based science and also inquiry all could be effective approaches for teaching NST.

Teaching about NST in Thailand

Thailand, as a developing country, has taken into account that NST are modern trends and stated in the 10th National Economic and Social Development Plan (2007-2011). NST is focused on as an important area for research and development because the specific and unusual properties of matter at the nano size scale present the opportunity to produce new and sophisticated technologies in diverse fields such as medicine, energy and manufacturing (the National Science and Technology Development Agency: NSTDA, 2012). Moreover, nanomaterial goods/products are becoming a vital part of our everyday lives, e.g. clear (nanoparticulate), sunscreen, clean (nanosolar) energy, fine (nano) filters and so on. These influences of nanotechnology require education to inform Thai citizens.

In addition, Thai National Nanotechnology Strategic Plans (B.E. 2004-2013) aims to drive forward the growth of country’s economy by : 1) Drive forward nanotechnology to support strategic cluster, 2) Accelerate human resources development in nanotechnology, 3) Increase the investment in nanotechnology R&D. 4) Develop basic infrastructure and finally, 5) Create proper public awareness and understand about nanotechnology. The Act of Scientific and Technological Development (Ministry of Science and Technology) (Pornsinsirirak, 2005), it aims to promote nanotechnology knowledge to public as well as primary and secondary students by using various approaches such as seminar, conference, or workshops in order to prepare people be aware of nanotechnology and gain enough nanotechnology knowledge and study in higher levels (Kerdcharoen,2007). However, there are limited curriculum to prepare science teachers in Thailand regarding NST.

From literature search, there are universities as Mahidol University , Chulalongkorn University, Chiangmai University, Kaketsart University and Knonkaen University (Pornsinsirirak, 2005 & Tanthapanichakoon, 2005) providing nanotechnology courses for graduate students. NST is mostly taught in graduate level, particularly for specific majors (Pornsinsirirak, 2005). It is not integrated into compulsory education.

The teaching of NST for K-12 students is also in crisis. Someone asks a crucial question like “Can high school students learn NST?” However, little is known about this question due to few research studies concerning NST education in Thailand. However, teaching K-12 students about NST is appeared in many countries.

For example, Nanoscale Science and Engineering Education (NSEE) raised in a workshop report in 2005 suggested 8 basic NST concepts: 1) size-dependence of solid state properties, 2) properties that change with nano-sizing, 3) uses of nano-scaled applications and devices, 4) changes in physical properties at the nano-scale, 5) increase in surface area/volume at the nanoscale, 6) chemical properties of nanoscale materials, 7) changes in size and shape of nanocrystals, and 8) preparation and manipulation of gold nanoparticles (NSF, 2005). Next in 2007, the NanoSense project created classroom tests and disseminated NST curriculum units to help high school students understand underlying principles, applications and implications of nanoscale science (SRI, 2007). Another study by Alford et al. (2009) suggested ideas of learning NST driven by the applications of nanotechnology. Lately, the Center for Innovation in Engineering and Science Education (CIESE) and a research group at SIT and the Academies at Englewood High School developed, integrated and piloted biology and chemistry curriculum modules related to nanoscale in high school classes. The content of the modules is related to examples such as infection control and infection-controlling biomaterials, surface coating material, a surface coating and nanosized hydrogel, bacteria and biofilm and so on. CIESE modules had properly addressed National Science Education Standards (NSES) relating to life science, science as inquiry and science and technology (CIESE, 2011). All information above put on view that NST could be introduced through integration of existing science curriculum by setting NST-related concepts and their applications.

In addition, the NanoSense project (SRI,2007), scientists and partner high-school science teachers has developed four curriculum units that can be inserted whole or in part into high-school science classrooms. In Taiwan, a K-12 Nanotechnology program is provided by Nanotechnology Human Resources Development (NHRD) with a focus on providing teachers information about nanotechnology and to develop materials to inspire students to learn nanotechnology (Lu and Chia-Chi, 2011). As had been discussed above, we might briefly say that NST can be used as a context for teaching K-12 school science (Jones et al. 2007; Ryu, 2005; Stevens et al. 2007; Tretter et al. 2006).

In order to integrate NST into the current science curriculum for Thai students, various factors are needed to be considered throughout the integrated curriculum development process: 1) the planning step: assessing needs and issues and identifying key issues and trends in NST area-related to existing science curriculum, 2) the developing step: developing and sequencing of grade-level and unit objectives, identifying resource materials and identifying assessment tasks, 3) putting the curriculum integration into practice and evaluating, and 4) determining the accomplishment of the curriculum.

In this research focuses on to develop the nanoscience and nanotechnology curriculum (NSTC) for Thai K-12 and undergraduate students by using meaningful contexts linked with their everyday lives. The research questions are:

1) What are high school students and student science teachers' understanding from participating in the NSTC?

2) What are high school students and student science teachers' attitudes toward participating in the NSTC?

The research purposes are:

1) To create the NSTC for high school students and student science teachers

2) To determine the effect of the NSTC on high school students and student science teachers' understanding about NST

3) To determine the effect of the NSTC on high school students and student science teachers' attitudes toward participating in the NSTC

Operational Definition of Terms

The NSTC means the learning unit created for high school students and student science teachers for encouraging their understanding and attitudes about NST. The NSTC consists of 6 lesson plans with learning processes, learning activity, learning materials and assessments.

Lesson plan 1: Nano-surface activity
Lesson plan 2: Size and dependent properties activity
Lesson plan 3: Magic sand activity
Lesson plan 4: Nano- bubbles activity
Lesson plan 5: Nitinol activity
Lesson plan 6: Nanotechnology tools

The learning unit created for high school students consists of 6 lesson plans with learning processes, learning activity, learning materials and assessments.

Lesson plan 1: Nano-surface activity
Lesson plan 2: Size and dependent properties activity
Lesson plan 3: Magic sand activity
Lesson plan 4: Nano- bubbles activity
Lesson plan 5: Nitinol activity
Lesson plan 6: CD and DVD grating activity

Students' understanding about NST means:

- Students are able to define and to give examples about the terms of NST in their own word.
- Students are able to explain and discuss current situations concerning NST.

All we can track from their post-instruction scores and assignments.

Students' attitudes toward participating in the NSTC means:

- Students' feelings after participated in the NSTC by responding to Likert scales ranged from strongly disagree to strongly agree regarding (1) whether the NSTC helps them learn with joy and wants to learn more, (2) whether the NSTC helps them achieve their study goals,(3) whether the NSTC is essential for including in their science classes,(4) whether the NSTC helps them acquire more in-depth knowledge of the subject.
- Students' feelings after participated in the NSTC by responding to open-end questions regarding (1) knowledge gained from the NST learning unit,

(2) feelings about activities in the NSTC, (3) further questions or curiosities about nanotechnology, (4) benefits gained from the NSTC, and (5) opinions about the necessity of NST. All we can track from the responses in the attitudes toward NST questionnaires.

CHAPTER II
LITERATURE REVIEW

This section illustrates the review of related literature about nanoscience and nanotechnology (NST) and NST education. The details are as follows.

2.1 Definition of nanoscience and nanotechnology

Nanoscience and nanotechnology (NST) benefits for our daily lives through various forms such as medicine, cosmetics, appliances, clothing, transportation, communication, heating and sports equipment. Governments of many countries are currently making huge efforts to be at the forefront of nanoscale science and engineering research. For example the US government, through the National Science and Technology Council, launched in the 2001 fiscal year the National Nanotechnology Initiative (NNI) involving 25 federal agencies to coordinate federal nanotechnology development (Bénédicte Hingant and Virginie Albeb 2010).

Nanotechnology is one branch of technology that has the potential to impact our daily lives. Nanotechnology can be applied to many kinds of materials such as ceramics, metals, and polymers to create new materials, which are the foundation of emerging technology advancement. In the coming decades, nanotechnology has enormous impact on manufacturing, electronics, new materials, medicine, the chemical and pharmaceutical industry, biotechnology, agriculture, information and communication technology. This new technology leads to many applications which aim to make our lives better more and more. Nowadays, in modern society, nanotechnology embeds in our lives in many formats such as clothes, umbrella, cosmetics, mobile devices, etc.

Really, when we talk about nanotechnology, we should consider nanoscience also. Frequently, we call this emerging field as nanoscience and technology (NST). Nanoscinece allows us to understand the world we live in as well as the universe surrounding us at a deeper level; whereas nanotechnology help us lives with more convenient ways.

However, the definition of NST varies across contexts. There is currently no consensus on what can be considered as *nano* and not-nano. Generally, NST shared two characteristics. First, NST focus on the study of nanometric scale which its properties differ significantly from a macroscopic scale. Second, it is often mentioned that at the molecular level the different traditional disciplines (physics, biology, chemistry etc.) can share common objects of study (Bénédicte Hingant and Virginie Albeb 2010). NST are thus considered as intrinsically interdisciplinary.

2.2 NST education

Because of the importance of NST as mentioned earlier, many countries around the world initiated many curricula and workshops for cultivating NST education for their own students or workforce. For example, Tomasik et al. (2009) created nanoscience course consisted of 8 week-lessons: Introduction to Nanoscience, The Nanoscale, Properties of Nanomaterials, Measuring: Nanoscale Structures, Synthesis of Nanomaterials, Health and Environmental Effects, Nanotechnology, Nanomaterials and Nature and Societal Impacts. The Nanoscale Science and Engineering Education (NSEE) proposed the basic concepts of NST for a classroom: 1) Size-dependence of solid state properties, 2) Properties that change with nano-sizing, 3) Uses of nano-scaled applications and devices, 4) Changes in physical properties at the nano-scale (example–magnesium oxide), 5) Increase in surface area/volume at the nanoscale, 6) Chemical properties of nanoscale materials, 7) How changes in size and shape of nanocrystals affect chemical and consolidation properties of magnesium oxide and 8) Preparation and manipulation of gold nanoparticles (NSF 2005). The following two sections describes NST in secondary and undergraduate levels.

2.2.1 NST in secondary level

SRI International (2008) created the NanoSense project aimed to help high school students understand underlying principles, applications, and implications of nanoscale science that account for nanoscale phenomena by working closely with partner teachers and scientists. Moreover, Porter (2007) proposed four course modules in the chemical nanotechnology course including:

I: An Introduction to Nanotechnology*:* The initial course meeting introduced course policies and grading, a general overview of course objectives, and concentrated on developing working definitions of both nanoscience and nanotechnology.

II: Viewing the Nanoworld*:* Nanotechnology research results are habitually presented in an exceedingly visual manner, frequently displaying a myriad of electron or scanning probe micrographs.

III: The Science behind the Hype: The principal module of the course, consisting of six class meetings, strove to illuminate the fundamental science behind many of the key concepts and focus areas of nanotechnology.

IV: Exploring Nanodreams and Nightmares: These course meetings, toward the end of the half-semester, transitioned the course focus toward the consideration of the political, economical, environmental, and ethical issues related to a technology with such potential social impact.

Krajcik et al. (2008) raised the big idea workshop of nanoscience for grades 7-12 science education. Alford et al. (2009) created a NST elective course driven by the applications of nanotechnology at St. Helena Secondary College for year 10 students (age ranged from 15–16 years). There are seven flexible modules in this program that can be adapted to suit any middle school science course. The purpose of this course is to help students understand processes that occur at one-billionth of a meter and where the properties are different to those found in bulk quantities of the same material. The combination of both scale and properties makes nanotechnology meaningful. Wansom et al. (2006) suggested that NST education should be interdisciplinary that students need to be subjected to the interdisciplinary context of nanoscience or nanotechnology in order to be prepared to function effectively in multidisciplinary industrial environment.

Some courses and workshops of NST introduce knowledge to learners not only fundamental concepts of NST, but also knowledge to research and apply NST to develop new technologies. Some curricula may be structured for high schools which learn about basis of nanoscience and others were structured for undergraduate to graduate schools, all of these based on efficiency of schools or universities. Planinsic and Kovac (2008) suggested that NST has become part of the curriculum in several universities and high schools in Europe in which the principal challenge for the latter is re-education of high school science teacher, similar changes and activities are occurring in several universities in the USA and the institute for physics teacher has been formed to upgrade high-school teachers' knowledge and understanding of recent developments in nanophysics.

Wansom et al.(2006) unpacked the big ideas in Nanoscale Science & Engineering, some examples are showed in following table 2.1

Table 2.1 Big ideas in Nanoscale Science and Engineering curriculum

Big Idea	Description	Illustrative Examples
Size and Scale	At the nanoscale, factors relating to size and scale (e.g., size, scale, scaling, shape, proportionality, and dimensionality) help describe matter and predict its behavior. Students must be able to appreciate and compare the sizes of objects on all scales, not just those that can be seen or seen with the aid of an optical microscope. In this big idea, "size" is defined as the actual extent, bulk, or amount of something. "Scale" has several dimensions, linking the size of an object to a numerical representation in conventionally defined units (e.g., meters, grams, etc.)	The dimensions of C-60 buck balls (approximately 1 nm in diameter) or single-walled carbon nanotubes (also approximately 1 nm in diameter), are a billion times smaller than a 1-meter "Smart car," a million times smaller than the thickness of a dime, or 10,000 times smaller than the diameter of a human red blood cell

Table 2.1 Big ideas in Nanoscale Science and Engineering curriculum.(cont.)

Big Idea	Description	Illustrative Examples
Surface-to-Volume Ratio	As the size of an object is reduced to the nanoscale (1-100 nm), the fraction of atoms at the surface increases dramatically. This is quantified by the ratio of surface area-to-volume or surface-to-volume ratio. The dramatic increase in the fraction of atoms at the surface of nanoparticles is partly responsible for their unusual surface-dominated behavior.	A cube 1 centimeter on a side is sliced into 10 slices in the x, y, and z directions. The surface area of the now 1000 smaller cubes has just increased from 6 cm^2, or the area of a large postage stamp, to 60 cm^2, the area of a typical credit card. If we continue subdividing down to cubes of 1 nm on a side, the surface area becomes 60,000,000 cm^2 or 6000 m^2, about 50% larger than the size of a football field in the U.S. and only slightly smaller than an Olympic soccer field.
Societal Impact	As is true of all technological innovation, nanotechnology has great potential for impacting our lives in both positive and negative ways. Not only must practitioners (nanoscientists and nanotechnologists) be cognizant of these issues, but an educated citizenry will be called upon to make informed policy decisions regarding the future risks vs. benefits of nanotechnology to society.	Nanotechnology is poised to improve our quality of life, e.g., through advances in healthcare, improvements in water quality, and developments in sustainable energy. On the other hand, there is the potential for increased health risks. For example, nanoscale objects are small enough to pass through conventional water purification systems and are capable of

Table 2.1 Big ideas in Nanoscale Science and Engineering curriculum.(cont.)

Big Idea	Description	Illustrative Examples
Societal Impact (cont.)		penetrating the biological barriers that protect living organisms. There is increasing concern about health risks associated with the unchecked promulgation of nanoscale materials.

2.2.2 NST in undergraduate level

O'Connor and Hayden (2008) studied in contextualising nanotechnology in chemistry education and summarized the topics which covered in the introductory nanotechnology lectures presented to the undergraduate students: 1) The history of nanotechnology, 2) What is a nanomaterial? 3) Why nanotechnology? 4) Buckminsterfullerene, 5) Nanotubes and nanowires, 6) Quantum dots, 7) Where will nanotechnology make an Impact? 8) Molecular self-assembly, 9) Sol gel technology, and 10) Nanoanalytical Techniques (AFM, STM, etc. Likewise, other topics are introduced and summarized that are shown in table 2.2.

Table 2.2 Nanotechnology curriculum for undergraduate level

Nanomaterial	Properties	Current and Potential Uses in Industry and Medicine
Buckminsterfullerene, C60, 'Buckyball'	- Extremely stable, can withstand high temperatures and pressures. - May react with other species while maintaining the spherical geometry. - Ability to entrap other smaller species by doping fullerenes, they can be electrically insulating, conducting.	Lubricants. - Polymers. - Toners. - Pigments. - Drug delivery systems.

Table 2.2 Nanotechnology curriculum for undergraduate level. (cont.)

Nanomaterial	Properties	Current and Potential Uses in Industry and Medicine
Nanotubes	- Extremely light, strong and flexible. - Can act like conductors, semiconductors or insulators. - Electrons move without losing energy inside the nanotubes, which makes them ideal connectors for electrical devices.	- Microelectronics - microcircuits, cell phones, computers. - Conductive plastic auto body panels. - Polymers and coatings. - Nanotube resistors. - Artificial joint and bone replacement materials. - Drug delivery systems. - Biosensors.
Quantum Dots	- Nanoscale objects (1-10 nm) - Contain tiny amounts of free electrons. - Semiconductor crystals that absorb and emit photons of light at specific light waves, from visible colours into infrared. - Dot size determines which colour is absorbed. - light at specific light waves, from visible colours into infrared.	- Used to track DNA molecules in cells. - Efficient alternatives to conventional lighting source. - Biosensors used to detect agents of biological warfare.

Uddin and Chowdhury (2001) integrated nanotechnology into the undergraduate engineering curriculum by means of the curriculum are summarized as appeared in Table 2.3.

Table 2.3 Integrated nanotechnology into the undergraduate engineering curriculum

Educational goals	Courses /Topics	Teaching approach/skills
- Provide understanding, characterization and measurements of nanostructure properties - Provide ability for synthesis, processing and manufacturing of nanocomponents and nanosystems - Provide ability for design, analysis and simulation of nanostructures and nanodevices - Prepare students to conduct research and development of economically feasible and innovative applications of nanodevices in all spheres of our daily life.	**Nanotechnology I: Fundamentals of Nanoscience.** This is an introductory course and should be required for all engineering students. Sample topics for this course are listed below: 1) Introduction and Overview of Nanotechnology. - The macroscopic and microscopic world. - Molecular manufacturing. - Self- assembly. - Impact on the society. 2)Nanoscience/Nanotechnology of organic materials. - Building blocks of living organisms. - The cell. - DNA, RNA and genes. - Protein synthesis and protein engineering. - Biosensors. - Recombinant techniques. - Genetic engineering. 3)Nanoscience/Nanotechnology of inorganic materials - Introduction to molecular chemistry. - Introduction to solid state physics. - Introduction to quantum	- Nanotechnology should be taught by creating both knowledge-centered and learning-centered environments inside and outside the classroom. - Nano-activities should encourage students to gain creative thinking, critical thinking and life-long learning. - Interactive learning both inside and outside the classroom. - Students develop projects and laboratory experiments. - Students should be given opportunities to work directly with established nanotechnology research centers (local, regional, national, international) to gain hands-on experience. - Guest speakers from industry and research centers should be provided to seminar class.

Table 2.3 Integrated nanotechnology into the undergraduate engineering curriculum (cont.)

Educational goals	Courses /Topics	Teaching approach/skills
	- mechanics and statistical mechanics. - Chemical, electrical, mechanical, magnetic, optical and thermal properties of nanomaterials. - Structure-property-application relationship of nanomaterials. **Nanotechnology II: Synthesis, Processing and Manufacturing of Nanocomponents and Nanosystems.** This could be a junior/senior level elective course. Sample topics for this course are listed below: - Molecular manufacturing and mechanosynthesis. - Nanomechanics. - Self-assembly. - Nanosystem components. - Microelectromechanical systems (MEMS) - Synthesis and processing of nanostructures. - Molecular manufacturing. Nanofabrication.	

Koretsky et Al. (2007) developed nanotechnology curriculum at Oregon state university with title as *The Science, Engineering and Social Impact of Nanotechnology*. The course is intended to be a general engineering survey course that ensures all engineering students have access to a course offering a basic understanding of the emerging field of nanotechnology. The learning outcomes and the course outline are summarized and presented in Table 2.4.

Table 2.4 Course outline of nanotechnology curriculum

Learning outcomes	Course outline	Teaching approach
course, students become able to: 1. Define After successful completion of this nanotechnology. Identify existing and potential products based on nanostructured materials. Predict how these products might impact society. 2. Explain how the properties of nanostructured materials are different from their nonnanostructured bulk material counterparts. 3. Describe major manufacturing methods used to produce nanostructured materials. 4. Explain the difference in approach of top-down vs. bottom-up manufacturing methods. 5. Identify the common methods used for nanomaterial characterization.	**1. Introduction.** - Definition of nanotechnology and a review of the scale of things natural and man-made - Review of existing nanotechnology products and possible future applications of nanotechnology. **2. Characterization Methods.** - Micro-imaging methods (AFM, STM, SEM, TEM) - Composition and phase characterization (XRF, EDX, XRD, TEM/ED) Concentration - adjustments and measurements **3. Manufacturing Methods for Nanomaterials.** - Top-Down Processing Methods (Lithography, Micromachining, Beam machining and laser machining)	The teaching and learning approach includes several features to promote active learning such as: - Hands-on activities and demonstrations. - The integrated use of wireless laptops through an in-house developed web-based learning tool to promote metacognition and assessment of student learning A capstone ethics project where students complete a risk assessment of the impact of nanotechnology on society.

Table 2.4 Course outline of nanotechnology curriculum. (cont.)

Learning outcomes	Course outline	Teaching approach
6. Describe the principles by which each method works and the type of information obtained. 7. Explain how the unique properties of nanomaterials might impact human health and the environment. Identify the major areas of nanotoxicity research and summarize the status of each area. 8. Compare the two prevalent ethical theories, utilitarianism and absolutism. 9. Develop an ethical framework to assist in conducting a risk assessment. 10. Perform a risk assessment to determine the best direction for nanotechnology development.	- Bottom-Up Processing Methods (Self-assembly and other Selective additive processes) **4. Nanotoxicity.** Review potential health and safety concerns. **5. Nano-ethics.** - Review of ethical theories: utilitarianism and absolutism - Development of an ethical framework: value inventory, ethics assessment, risk assessment - Case study on asbestos. **7. Final Project**: **risk** assessment of nanotechnology development	

In summary, the NST courses designed for high school students focus on fundamental concepts of NST, while others designed for undergraduate students focus on development of NST research skills for creating newer technologies.

2.3 Teaching about NST

In teaching NST, several strategies are utilized and can be summarized as followed.

2.3.1 Student-centred learning

O'Connor and Hayden (2008) studied on two groups of students (second-year and fourth-year students) and found that most students in both groups felt comfortable when talking about nanotechnology in the future and shown a greater interest in carrying out research in the area of nanotechnology. Overall, a greater awareness of current research within the Institute in nanotechnology was achieved for both groups.

Ron and Merav (2011) used student-centered pedagogy for increasing high-school students’ continuing motivation. Moving from teacher-centered to student-centered pedagogy switches the control of the learning environment from the teacher to the learners. The study found that students appreciated the topic of nanotechnology and it increased their motivation to further learn about nanotechnology and chemistry. The student-centered pedagogy that was chosen also contributed to a positive effect regarding students' continuing motivation.

Uddin and Chowdhury (2001) mentioned that nanotechnology should be taught by creating both knowledge-centered and learning-centered environments inside and outside the classroom. Because the technology is advancing so fast, activities that encourage creative thinking, critical thinking and life-long learning should be given the highest priority. Technology cans play a powerful role in facilitating interactive learning both inside and outside the classroom. Students can participate in nanotechnology research development projects and laboratory experiments all over the world via the internet. Students should be given opportunities to work directly with established nanotechnology research centers (local, regional, national, international) to gain hands-on experience.

2.3.2 Inquiry based teaching

Stevens et.al (2007) designed an inquiry-focused, problem-based curriculum which topics covered amplification of bacteria and visualization through optical and scanning probe microscopes for students who had completed sixth-grade. The results revealed that the students who were engaged in problem-based learning context developed fuller conceptual understanding than students in traditional context as well as demonstrated more collaborative tendencies, thus arrangement of social communities within a problem-based learning setting can be instrumental in helping the formation of learners understanding.

Timothy et Al. (2010) studied teaching nanotechnology via a guided inquiry approach and found that the students are able to observe a visual representation of the collected data and to answer their exploratory question. When students make the realization that the scientific content they are constructing in the physics classroom has diverse applications beyond traditional schooling; they would gain an appreciation for advancements in science and technology and its relevance in society.

2.3.3 Learning Progressions

Stevens et.al.(2007) used the Learning Progressions to Inform Curriculum, Instruction and Assessment Design to identify and characterize not only the ways where students develop understanding of important concepts within individual related topics but also how students build a more sophisticated model for the particle model of matter.

Delgado et al. (2007) reported that the development of students' conceptions of size that improvement of curriculum, instruction and assessment of size and scale can be guided by a learning progression or learners' successively more sophisticated ways of thinking about a topic.

2.3.4 Problem-based teaching

Lyshevski et al. (2006) developed the nano set course problem based combined with interactive computer-aided instruction delivery utilizing virtual reality and foster active learning by giving homework assignments, laboratories and projects to students. They found that the designed course created, promoted, and supported undergraduate research activities.

Hersam et al. (2004) described an approach for the design of a nanotechnology engineering course employing the non-traditional pedagogical practices of collaborative group learning, interdisciplinary learning, problem-based learning, and peer assessment. The results effectively addressed and achieved the range of overall course goals, including practical, social, personal, and intellectual learning objectives as evidenced by improved student performance and experience.

Powers and DeWaters (2004) mentioned that problem-based and project-based approaches to student learning that is to improve the understanding of basic concepts and to encourage deep and creative learning despite academic content areas.

2.3.5 Hands-on activities

Wongchoosuk and Berger (2002) designed the demonstration apparatus of atomic force microscope (AFM) which aims to persuade students to interest and understand nanotechnology by using simple materials.

Planinsic and Kovac (2008) created a teaching model of AFM and found that it was successful in introducing nanoscience in high school students and introductory physics course.

Jones et al (.(2004) investigated the use of nano Manipulator (nM) that allow for the control of an atomic force microscope (AFM). The nM is tool which students can use to control AFM by using microcomputer program then students will feel to how AFM work through joystick device on computer screen named tactile feedback. When AFM tip scan to virus or another students will feel and understand in virus morphology, besides they can change 2-dimension image of virus from other textbooks to 3-dimension image. From the nM, The students can have hands-on experiences with objects at nanometer scale and after instruction students were more likely to have some understanding of nanoscale and many were more knowledgeable about atomic force microscopy.

2.3.6 Visualization

Xie and Lee (2012) used a visual approach to nanotechnology education and found that the students should be given opportunities to interact with simulations themselves just like in a hands-on laboratory; but, the tension between student autonomy and their need for guidance needs to be addressed. Classroom dynamics, such as teacher-student interaction and student-student collaboration, can play a positive role on amplifying the power of visual simulations. The guided inquiry is usually more effective than open inquiry. The guided inquiry uses clear goals, careful scaffolding, ongoing assessment, and teacher intervention to lead students to independent learning. In particular, the results indicated that college students gained deeper understanding of abstruse quantum ideas from our visual quantum simulations and a visual approach for teaching nanotechnology that is widely applicable in K-16 education.

O'Connor and Hayden (2008) bridged the gap from macro to nano by creating the visualization of the nanoscale structures and how they are incorporated in macro level applications, for examples, molecular models and animated DVDs (‘Nanotechnology’ and ‘Nano: the Next Dimension’). In particular in the later of the two DVDs mentioned the animation of a scanning tunneling microscope etching a pattern on a surface at the atomic level was very useful to convey the tunneling effect.

Ong et al. (2002) reviewed an interactive nano-visualization of materials over the internet, and discovered that many visuals are also available through a wide range of relevant websites. The research has shown how the internet can be a valuable tool in visualization of nanotechnology materials.

Ernst (2009) studied the visual examples and simulated real-world applications in the topic of Nanotechnology Education: Contemporary Content and Approaches and found that they enhanced students’ engagement and understanding in nanotechnology. The use of intrinsically motivating approaches, such as visual and kinesthetic learning methods, creativity strategies, problem-based learning, and learning through design are particularly effective methods for reinforcing STEM-based material.

Skonchai and et al. (2011) investigated the epistemic platform for science learning with a computer game in learning fundamental NST to enhance students’ science learning achievement, strategic problem solving ability, and attitude toward science. They found that the epistemic platform helped the students improve science learning achievement, strategic problem solving ability in science learning and attitude towards science and helped the participating teacher develop positive opinion towards the curriculum unit of epistemic platform.

2.4 NST in Thailand

Recognizing the importance of nanotechnology to the development of human resources and national competitiveness, in 2002, the Cabinet of the Government of Thailand ordered the Ministry of Science and Technology (MOST) and the Ministry of Information and Communication Technologies (MICT) to coordinate and jointly investigate the feasibility of nanotechnology promotion and development in Thailand. In response, MOST assigned the National Science and Technology Development Agency (NSTDA) to tackle this crucial task. As a result, the establishment of a brand new National Nanotechnology Center (NANOTEC) under the umbrella of NSTDA was proposed and won approval from the Cabinet on August 13, 2003.

The mission of NANOTEC encompasses as follow:

- Prepare a comprehensive national road map on nanotechnology for Thailand.
- Act as a national coordinating body between the academia, government and private sectors, and promote their linkages.
- Set up collaborative research network by assembling and producing a critical mass of high-caliber researchers and educators on nanotechnology.
- Identify and focus on niche areas and products in nanotechnology, thus enhancing Thailand’s international competitiveness.
- Disseminate and transfer new and existing knowledge in nanotechnology to the industrial and governmental sectors.
- Carry out research in selected core or common areas of nanotechnology.

- To facilitate nanotechnology research needs, set up and provide analytical and testing services that require expensive sophisticated analytical instruments.

Five years later, NANOTEC have been promoted the nanotechnology research in 12 areas: 1) Nano Delivery System Laboratory (NDS) 2) Nanomaterials for Energy and Catalysis Laboratory (NEC) 3)Nano-cosmeceutical Laboratory (NCM) 4) Hybrid Nanostructure and Nanocomposites Laboratory (HNN) 5) Nano Safety and Risk Assessment Laboratory (SRA) 6)Nano-Molecular Sensor Laboratory (NMS) 7) Nanoscale Simulation Laboratory (SIM) 8)Organic Nanomaterials Laboratory (ONM) 9) Nano-Molecular Target Discovery Laboratory (NTD) 10) Nano Characterization Laboratory (NCL) 11) Nano Functional Textile Laboratory (NFT) and 12) Engineering and Manufacturing (ENM).

Simultaneously, many universities under the supervision of the Commission on Higher Education are promoting research on the various topics in NST, providing special grants for universities to carry out the nanotechnology research and development (R&D). Moreover, the Commission on Higher Education also contributes the establishment of the various Collaborative Research Networks (CRN) in selected science and technology fields, including Clean Technology, Particle Technology, Catalysis, Medical Engineering, and Nanotechnology to enhance the international competitiveness of Thailand.

2.5 NST education in Thailand

Although Thai government had been established NSTDA to promote nanotechnology knowledge to public, there are small numbers of science researchers who have good background in nanotechnology. As human resource population of science and technology researchers in Thailand is reportedly around 3.3 per 10,000 whereas the corresponding number in Singapore is 30-40 and Japan 70.7 (Pornsinsirirak 2005,Kerdcharoen 2007,Wiwut 2005). Therefore, there is urgent need for raising the number of NST human resources. That need has been fulfilled by the 2004 -2013 Thai National Nanotechnology Strategic Plans with five maing strategies:

1) Drive forward nanotechnology to support strategic cluster, 2) Accelerate human resources development in nanotechnology, 3) Increase the investment in nanotechnology R&D, 4) Develop basic infrastructure, and 5) Create proper public awareness and understand about nanotechnology.

According to the second strategy as mentioned earlier, many universities launched curricula related to NST in master and PhD programs. In addition, the Cabinet had s approved a 5-year plan of MOST to provide 1,500 full-expense scholarships for Thai students to go abroad to advance their study in science and technology including NST. Also,
NANOTEC and vocational education commission (VEC) had initiated a formal partnership agreement in which both entities will conduct faculty training and research project competition, and include nanotechnology information in the curriculum. The partnership is designed to increase awareness and knowledge of nanotechnology for both faculty and students.

However, NST education in Thailand is weak. Most of NST scientists work in major universities and there is a relative lack of high school science teachers who understand NST concepts. Viriyavejakul (2008) studied the situation and readiness of integration of nanotechnology in Thai education and found that: 1) Thai people are getting connected to nanotechnology by search engine websites, libraries, magazines, books, and discussions with experts; 2) Curriculum integration of nanotechnology should be integrated in many branches of engineering such as industrial, computer, civil, chemical, electrical, and mechanical; 3) Resources of nanotechnology knowledge for educators should be spread in academic circles by publications and the internet websites; and 4) Teachers should be trained by experts in nanotechnology and researchers from the National Nanotechnology Center. Moreover, for the plans, the strategies, and guidelines for educational reform to adapt nanotechnology to the present system, the study revealed that the world nanotechnology situation might have an effect on Thai society. As human resource development should be worked with the present technology and use the country’s resources to produce many products of nanotechnology such as handicrafts, decorations, gifts, agricultural products, beverages, and textiles.

Chuankrerkkul (2008) studied the status of nanotechnology research and educational activities in Thailand and found that most of the research activities have been done at the postgraduate level in various universities. On the contrary, there is a lack of basic knowledge in nanotechnology for teacher or lecturer in secondary school or at undergraduate level.

In 2010, NANOTEC launched the teacher trainer in nanotechnology (TTN) to train science teachers for promoting the transfer of knowledge in nanoscience and nanotechnology to schools and universities throughout Thailand. The TTN members have reported that they have transfer knowledge and awareness in nanoscience and nanotechnology to over 100,000 people through various activities from organizing exhibition to workshops. TTN is now an independent identity with NANOTEC and NSTDA playing a minor facilitating/supporting role. This is a significant step forward for the promotion of nanoscience and nanotechnology awareness in Thailand.

2.5.1 NST education in high school and undergraduate levels in Thailand

As a fast growing studies which have been impacting on our daily lives, it is required that the educational community has to have a commensurate response in increasing students' understanding of NST. Therefore, there are many NST curricula being created for postgraduate level in various universities; but there is a lack of NST curricula for secondary and undergraduate levels.

In last a few years, there are numerous NST programs existed at the undergraduate level. However, there is a strong need for NST education in earlier grades for preparing students further study in the field. In designing the NST units for high school students, it is important to start with analyzing the content and setting up the goals and learning objectives. In this research study, the core concepts of nanomaterial are analyzed, by looking in particular at the unique properties of materials when they are in nano-scale. The activities is including of size and dependent properties, nano surface, magic sand, nitinol (Shape Memory Alloy) nano-bubbles, nanotechnology tools, and CD and DVD grating. The curriculum has been designed and developed that focuses on to design the nanoscience and nanotechnology curriculum (NSTC) based on students' understanding and interests, to determine the effect of the NST curriculum and the appropriation of learning activities, and to explore the students' opinions into the NST learning activities. All activities are in line with the Thai national science curriculum standards. The basic science concepts of NST can address the learning standards mentioned in three basic education core curriculum (2008) as below:

Strand 3: Substances and Properties of Substances

Standard Sc 3.1: Understanding of properties of substances; relationship between properties of substances and structures and binding forces between particles; having investigative process for seeking knowledge and scientific reasoning; and communicating acquired knowledge that could be applied for useful purposes.

Standard Sc 3.2: Understanding of principles and nature of change in the state of substances; solution formation; chemical reaction; having investigative process for seeking knowledge and scientific reasoning; and communicating acquired knowledge that could be applied for useful purposes.

Table 2.5 presents the correspondence between the concepts in the NSTC and the national science curriculum standards.

Table 2.5 Concepts in the NSTC and the national science curriculum standards

Nanosceince and nanotechnology	The standards it can address
Size and dependent properties	Chemical reactions.
Nano-surface	Surface tension, structure and properties of matter, hydrophobic and hydrophilic surface.
Magic sand	Structure and properties of matter. Hydrophobic and hydrophilic surface. Concepts of surfactant molecules. Coating materials with monolayer.

Table 2.5 Concepts in the NSTC and the national science curriculum standards. (cont.)

Nanosceince and nanotechnology	The standards it can address
Nitinol (Shape Memory Alloy)	Structure and properties of matter. Structure of atoms ,kind and number of elementary particle of atom.
Nano-bubbles	
	Structure and properties of matter. Surface tension. Diffraction of light.
Nanotechnology tools	
	Structure of atoms, molecules. Interaction forces in the molecular world
CD and DVD grating.	
	Diffraction of light. Memory storage.

The NSTC has been designed which is divided into 3 main phases

Phase1: Capturing science teachers' views about teaching and learning nanoscience and nanotechnology in both the basic education levels (grade 1-12) and undergraduate level.

Phase 2: Development of Nanosceince and Nanotechnology Curriculum

Phase 3: Implementation of Nanosceince and Nanotechnology Curriculum

Those three phases are divided into 4 stages: Planning and Analysis, Design and Development, Implementation, and Evaluation. The first two stages are set into phase I and phase II and the last two stages are set into phased III. The holistic view of the structure of research in presented as follows Figure 2.1

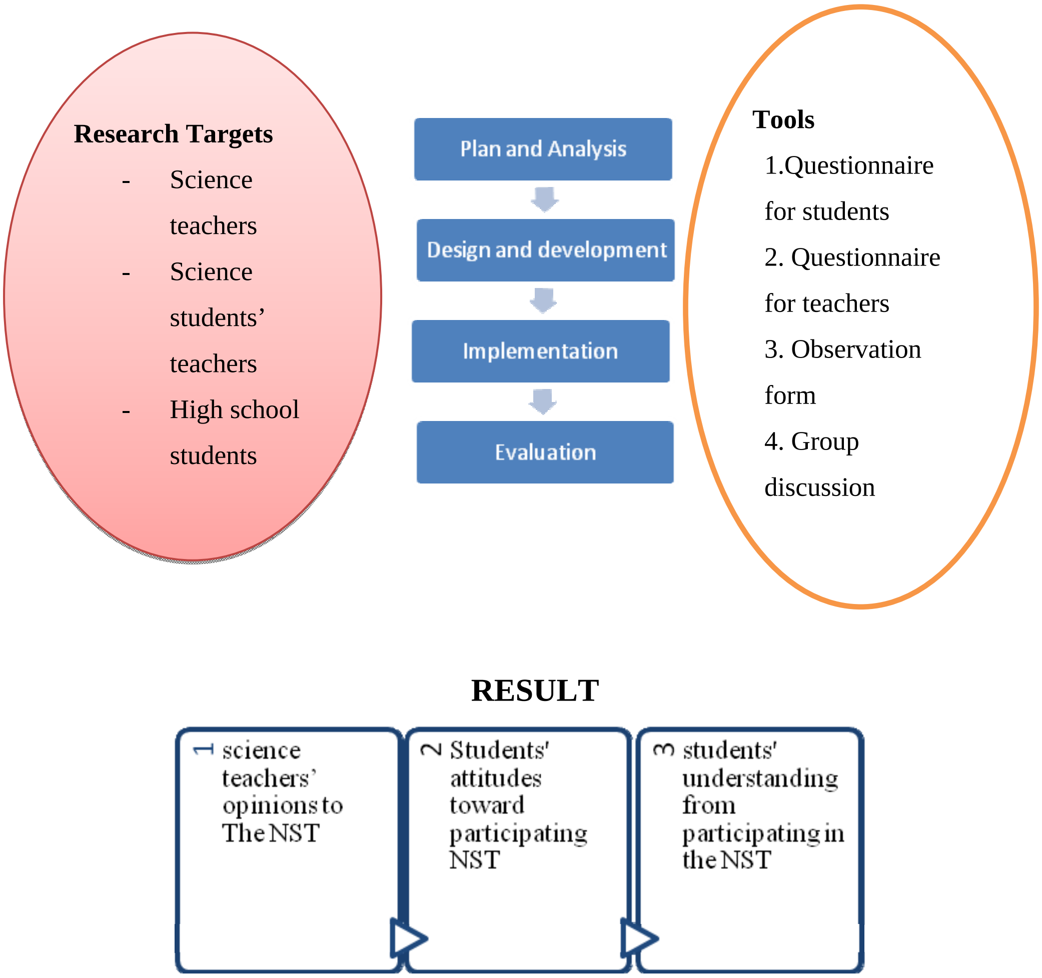

Figure. 2.1 Structure of NSTC development

CHAPTER III
METHODOLOGY

This research focuses on the development of the nanoscience and nanotechnology curriculum (NSTC) for high school and undergraduate students. This is a multiple case study conducted in one high school and one university located in the Eastern region of Thailand. There are three phases of this study.

3.1 Phase 1: Science teachers' opinions about NSTC

This phase aims to explore science teachers' opinions about teaching and learning about NST for high school and undergraduate students.

3.1.1 Instrument

The instrument used in this phase is the Nanoscience and Nanotechnology Learning Questionnaire (NSTLQ), which is consisted of three sections. The first section consists of four items that asks the respondents about general information such as gender, age, education background and teaching and learning experience. The second section focuses on the respondents' knowledge about NST and pedagogical strategies for teaching NST. The items used are both multiple-choice and rating scale items, that is, two items for asking about teachers' knowledge based on teaching NST, eight items for asking about NST curriculum, 12 items for asking about subtopics of NST, and three items for asking about teaching and learning about NST. The overall results from this survey were the respondents' knowledge about pedagogical strategies, teaching orientations, and attitudes toward teaching NST. The final section aims to explore in-depth information about the respondents' views toward NST curriculum such as preferred topics and teaching strategies for NST. In addition, the respondents are asked to express their opinions and expectations about integration

NST into science curriculum in Thailand. The items used are open-ended questions. The items of NSTLQ are shown as Appendix A, the content of NSTLQ was validated by three experts, two science educators and one professor in NST. The reliability of NSTLQ was .87

3.1.2 Participants

There were 35 science teachers from 10 public high schools and one university (25 high school and 10 university teachers). Two high schools located in the Central, five from the North-Eastern, two from the Eastern, and one from the Southern of Thailand. In addition, 10 teachers teaching biology, chemistry and physics at the Faculty of Science and Technology from one university were asked to participate in this phase.

Twenty-five teachers were female. The respondents' education background ranged from a bachelor to a master degrees (18 bachelors and 17 masters). The age of respondents ranged from 20 to 60 years. There were 12 teachers aged between 20 to 30 years old, 17 teachers aged between 31 to 40 years old, four teachers aged between 41 to 50 years old, and two teachers aged over 50 years old. There are 16 participants who had science teaching experience less than six years. Ten, four, and five teachers, respectively, taught science for six to 10 years, 11 to 15 years, and more than 16 years.

3.1.3 Data collection

The NSTLQ was distributed to 100 respondents by post and the number of returned questionnaires was 35.

3.1.4 Data analysis

The responses in rating scale items were analyzed by counting for frequency and calculating for percentage. The open-ended responses were coded and grouped into categories, and, finally, counted for frequency.

3.2 Phase 2: Development of NST curriculum

The NSTC is constructed by the following steps.

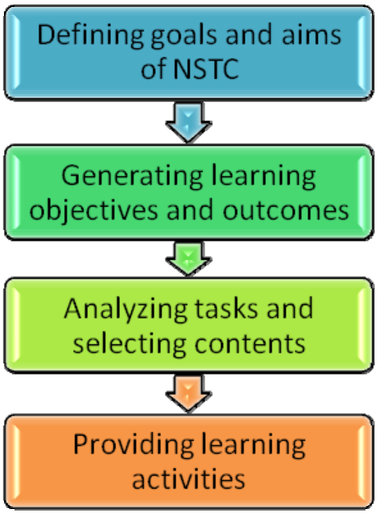

Figure 3.1 The steps of the NSTC development

Step 1: Defining goals and aims

The researchers analyzed exiting nanotechnology curriculum for high school and undergraduate students. In addition, the results from the phase I of this study about science teachers' opinions about NSTC for high school and undergraduate students were used in this step to define the goals of NSTC.

Step 2: Generating learning objectives and outcomes

After that, the learning objectives and outcomes of NSTC were set.

Step 3: Analyzing tasks and selecting contents

The next step is to determine the learning tasks and contents of NSTC to match with the learning objectives and outcomes set previously in step 2.

Step 4: Providing learning activities

Specifically, the learning activities cover all contents of NSTC were designed. Each learning activity includes lesson plan, learning materials, and assessment.

The NSTC was validated by a team of experts. The comments and suggestions from the experts were utilized for improving the NSTC. The necessary changes were made. The table 3.1 below presents the outline of NSTC.

Standard SC3.1 : Understanding of principles and nature of change in the state of substances; solution formation; reaction; investigative process for seeking knowledge and scientific mind; and communication of acquired knowledge that could be applied for useful purposes.

Table 3.1 The outline of NSTC.

Key stage indicators	**Examples of Learning Activities**	**Basic Knowledge Requirements / Science Focus**
1. Explain the meaning of nanoscience and nanotechnology 2. Compare the size of matters and understand scales 3. Explain how surface area affects reaction rates. 4. Investigate how the surface area-to-volume ratio of a substance is affected as its shape changes. 5. Explain how catalysts work involves studying	**Task:1 Size and Surface Area (3 hours)** **Learning objective:** Students discover about enormous scale differences in our universe, and investigate how the surface area-to-volume ratio of a substance is affected as its shape changes. **Learning activities:** **Stage 1 (1.30 hours)** 1. Complete the pretest. 2. Ask the students to define “what is nanotechnology” and find any words using a “scale” prefix 3. Students compare size of the materials on the work sheet.	**Basic Knowledge Requirements** - Familiarity with atoms, molecules and cells. - Knowledge of basic units of the metric system and prefixes. - Ability to manipulate exponential and scientific notation - Ability to calculate surface area and volume of a cube,

Key stage indicators	**Examples of Learning Activities**	**Basic Knowledge Requirements / Science Focus**
chemical reactions at the molecular and atomic scale.	4. Students work in groups to do experiments - Pour colored water from the pitcher into each measuring cup and remove two Sandoz Forte +D calcium tablets from their container. - Break one in half, and drop it into a cylinder. Then, break the other tablet into many smaller pieces, and put it in the other cylinder. - At the same time, pour the water from each cup into both cylinders. - Students observe which one fizzes up faster? - Break a Sandoz Forte +D calcium tablet into four approximately equal pieces. - Put one piece into a canister and crush another piece with the back of the metal spoon, and put the crushed one into the other canister. - Pour water into both canisters at the same time	box, ball, and cylinder **Science Focus** - Chemical reactions. - Surface area. - Structure and properties of matter.

Key stage indicators	**Examples of Learning Activities**	**Basic Knowledge Requirements / Science Focus**
	until it's about half full, then immediately snap the lid on tight and stand back to observe. - Discuss which canister was the first to explode and which cylinder fizzed up faster. 5. Discuss the relation between particle size and reaction rates. **Stage 2 : (1.30 hours)** 6. Student works on activities : - Press the clay into a cube and measure the size of each side. - Press the clay into a flat, rectangular box and measure the size of each side. - Roll the clay into a ball and use the calipers to measure the ball's diameter. - Roll the clay into a cylinder and measure the diameter of the cylinder and write your measurement in the table . 7. Calculate the surface area and volume on each shape.	

Key stage indicators	Examples of Learning Activities	Basic Knowledge Requirements / Science Focus
	8. Calculate the ratio of the surface area to volume by dividing the surface area by the volume and write this ratio in the table. 9. Discuss which shape had the smallest surface area-to-volume ratio and which shape had the largest surface area-to-volume ratio. 10. Discuss which shape you would recommend as the most reactive catalyst. 11. Conclude by introducing students to the understanding of how surface area relates to the properties and characteristics of nanoparticles. 12. Complete the post-test and score satisfaction activity survey.	
1. Explain how different structure surfaces make different properties. 2. Explain the difference between super hydrophobic ,	**Task 2 : Nano surface (3 hours)** **learning objective:** Students are exposed to understand hydrophobic and hydrophilic surfaces and discover how nanotechnology can improve materials in our everyday lives as well as how scientists mimicked	**Basic Knowledge Requirements** - Ability to calculate contact angle of droplets - Ability to compare how

Key stage indicators	**Examples of Learning Activities**	**Basic Knowledge Requirements / Science Focus**
hydrophobic and hydrophilic surfaces. 3. Calculate the contact angle of the water droplets on each surface. 4. Explain how nanotechnology can improve materials in our everyday lives and how scientists mimicked nature’s surfaces and used it to improve materials.	nature’s surfaces and used it to improve materials. **Learning activities:** **Stage 1: Lotus effect (1.30 hour)** 1. Complete the Nano surface pretest. 2. Introduce students to discuss the products which are made from nanotechnology processes. Give an example of a nano fabric which is self-cleaning. 3. Conduct students to observe this phenomena in nature. 4. Students go out to get some leaves from outsides in the school are or bring leaves from home before class begins (one lotus leaf for each group is required) 5. Label the different piles of leaves so that students can refer to them by name during the assignment. 6. Submerge the leaves into a container of water and record any other observations.	the shape of the water droplets are different. - Surface tension. - The distinctiveness of hydrophobic and hydrophilic surface. **Science Focus** - Surface tension. - Contact angle. - Structure and properties of matter - hydrophobic and hydrophilic surface

Key stage indicators	Examples of Learning Activities	Basic Knowledge Requirements / Science Focus
	7. Use the pipette to drip droplets of similar volumes onto the surface of the various leaves. 8. Draw the shape of the drops as viewed from the side for each type of leaf. Which leaves have water droplets that are most spherical. 9. Place the leaves flat on the table. Use the pipette to drip droplets of similar volume onto the surface of the leaves. Slowly lift one side of each leaf (do one at a time) and observe, record observations (optional - use a protractor to more precisely determine the angle). 10. Place a droplet of honey or syrup on the surface of the different leaves, then try to wash the honey off into the empty container. Observe which leaf cleans up more easily. 11. Rub the hydrophobic leaf (the leaf with the most spherical water droplets), but not so hard as to tear it.	

Key stage indicators	Examples of Learning Activities	Basic Knowledge Requirements / Science Focus
	12. Repeat the above experiments with the other leaves. 13. Explain to students how the experiment in this activity is exploring the "Lotus Effect" – the hydrophobic or water repellent property seen in some plants and insects and most famously in the lotus leaf. 14. Discuss some possible advantages of having surfaces with this hydrophobic effect for plants and insects. 15. Students use magnifying glasses or microscopes to observe leaves and draw the surface of the hydrophobic leaf at the nanoscale level. 16. Discuss why the water droplets are different shapes on different surfaces. **Stage 2 : Making nano surfaces (1.30 hour)** 17. Make a surface slide by passing brown sand through a sieve to a glued slide. 18. Repeat by using magic sand, all-purpose flour, and powder on each other slides.	

Key stage indicators	Examples of Learning Activities	Basic Knowledge Requirements / Science Focus
	19. Light a candle and make soot from the candle by using a tong (Do not hold the slide by hand) 20. Cut fine sand paper and rough sand paper the same as the slide size. 21. Predict the shape of the water droplet on each surface and draw onto the work sheet. 22. Drop water onto the slides of different surfaces (magic sand , brown sand, fine sand paper , rough sand paper, all-propose flour, powder , soot , blue cotton and nano fabric) and observe the shape of the water droplet. 23. Calculate the contact angles of the water droplets on each surface. 24. Discuss why the shapes of the water droplets are different. 25. Use a magnifying glass and microscope to observe the surfaces. 26. Discuss which slides are hydrophobic and hydrophilic. 27. Discuss how nanotechnology	

Key stage indicators	**Examples of Learning Activities**	**Basic Knowledge Requirements / Science Focus**
	can improve materials in our everyday lives and how scientists mimicked nature's surfaces and used it to improve materials. 28. Complete the post-test and score activity survey.	
1. Explain the Concepts of hydrophobic and hydrophilic behavior. 2. Explain why the polarity of a solvent can affect the behavior of the solute. 3. Explain the concepts of polar and non-polar molecules. 4. Explain the importance of the hydrophobic affect. 5. Learn how to make magic sand	**Task: 3 Magic Sand (3 hours)** **Learning objective:** Students understand how the polarity of a solvent can affect the behavior of the solute and expose the concept of polar and non-polar molecules and also learn how to make magic sand. **Learning activities:** **Stage 1: Magic sand in solvents (1.30 hour)** 1. Complete pre-test. 2. Introduce students to discuss about the molecular world such as polar and non-polar molecules and how they relate to the hydrophobic and hydrophilic effects. 3. Conduct the students to observe brown sand and	**Basic Knowledge Requirements** - Concept of hydrophobic and hydrophilic behavior. - Concept of polar and non-polar molecules - Concept of surfactant molecules. - Coating materials with monolayer. **Science Focus**. - Structure and properties of matter. - Hydrophobic

Key stage indicators	Examples of Learning Activities	Basic Knowledge Requirements / Science Focus
	magic sand. 4. Students do the experiment: - Place each of the Petri dishes on the circles of the lab sheet. - Fill the beaker with water and pour some water in each of the Petri dishes: - The first dish is labeled brown sand and water. - The second dish is labeled magic sand and water. - The third dish is labeled magic sand, water, and oil. - The fourth dish is labeled brown sand, water, and oil. - The last dish is labeled magic sand and surfactant. - Open the bottle of brown sandand sprinkle a small amount into the first dish labeled brown sand and water. Then, observe what happens	and hydrophilic surface. - Concepts of surfactant molecules. - Coating with monolayer.

Key stage indicators	Examples of Learning Activities	Basic Knowledge Requirements / Science Focus
	and note this on the worksheet. - Add some additional brown sand into the dish and use a stir rod to press down on the surface of the sand and mix the sand and water with the rod. Then, observe what happens and note this on the worksheet. - Open the bottle of Magic Sand and sprinkle a small amount into the second dish labeled Magic Sand and water. Then, observe what happens and note this on the worksheet. - Add some additional Magic Sand into the second dish and use a stir rod to press down on the surface of the magic sand and mix the magic sand and water with the rod. Then, observe what happens	

Key stage indicators	Examples of Learning Activities	Basic Knowledge Requirements / Science Focus
	and note this on the worksheet. - Sprinkle magic sand into the third dish labeled Magic Sand, water, and oil. Then, observe what happens and note this on the worksheet. - Sprinkle brown sand into the fourth dish labeled Magic Sand, water, and oil. Then, observe what happens and note this on the worksheet. - Take the bottle labeled “surfactant” and add several drops to the fifth dish labeled Magic Sand, water, and surfactant. Then, sprinkle a small amount of Magic Sand. Observe what happens and note this on the worksheet. 5. Discuss the experimental result the properties brown sand and magic sand will	

Key stage indicators	**Examples of Learning Activities**	**Basic Knowledge Requirements / Science Focus**
	have when they are mixed with different solvents (water, oil ,surfactant). 6. Discuss polar and non-polar molecules. 7. Discuss the advantage of magic sand. **State 2: Making magic sand (1.30 hour)** 1. Place some clean sand in a pan. 2. Put the sand pan in the microwave oven to remove any water from its surface or stir the sand by using a metal container with a hot plate. 3. Remove the sand from the oven and allow it to cool. 4. Work with the baking pan or spread the sand on some newspaper in a well-ventilated area. 5. Spray color to dye the sand and put it in the microwave oven to bake and make it dry. 6. Spray the sand with rain repelling spray, stir, and allow to dry.	

Key stage indicators	Examples of Learning Activities	Basic Knowledge Requirements / Science Focus
	7. Spray again and allow to dry. 8. Test your home made Magic Sand using the investigation in the first part of this experiment. 9. Complete post-test and score activity survey.	
1. Explain the unique properties of an alloy called Nitinol 2. design an experiment by using Nitinol. 3. Explain the connection between Nitinol's atomic structure and its physical characteristics. 4. Discuss Nitinol's applications. 5. Investigate the	**Task:4 Shape Memory Alloy (3 hours)** **Learning objective:** Students will investigate the unique properties of an alloy called Nitinol, design an experiment using Nitinol, and understand the connection between Nitinol's atomic structure and its physical characteristics. Then, learn about Nitinol's applications. **Learning activities:** **Stage 1: Exploring Shape Memory Alloy (1 hours)** 1. Complete pre-test. 2. Discuss properties of general alloy materials 3. Students do the experiment: - Students observe 3-4 different kinds of	**Basic Knowledge Requirements** - Memory metal phenomenon. - Definition of an alloy. - Transition temperature. - Crystal structure of materials **Science Focus**. - Structure and properties of matter. - Structure of atoms - Kind and

Key stage indicators	Examples of Learning Activities	Basic Knowledge Requirements / Science Focus
transition temperature of Nitinol. 6. Explain the concept of the crystal structure of shape memory alloy.	wires(included Nitinol) by trying to bend and shape them. - Ask students if the wires are easy or difficult to bend. - Try to straighten the wires back out. - Put the wires in the hot water bowl and observe each wire. - Ask students which wire changes shape. - Use two tongs to try to bend the Nitinol wire (the wire changes its shape) while it is in the hot water. - Take the Nitinol wire out of the hot water using the tongs. - Discuss how the Nitinol wire is now different from its room temperature state. - Bend the Nitinol wire. - Clip one end of an alligator clip lead onto the positive terminal of	number of elementary particle of atoms.

Key stage indicators	Examples of Learning Activities	Basic Knowledge Requirements / Science Focus
	the battery. (Be careful not to pinch fingers in the clips) - Attach the other end of the lead to one end of the bent piece of Nitinol. - Attach one end of the other lead to the other end of the Nitinol. - Nitinol can get very hot when using electricity, don't touch the wire as it is heating. - Hold the alligator clips by the insulated covers and gently touch the other end of that alligator clip to the negative battery terminal. 4. Discuss what happens to the wire and compare it to when you blow a hairdryer on a piece of Nitinol or put it in hot water. 5. Discuss about other materials in your house that has memory wire	

Key stage indicators	Examples of Learning Activities	Basic Knowledge Requirements / Science Focus
	Stage 2: Transition temperature (30 minutes) 6. Predict what is the transition temperature of Nitinol wire. 7. Students do the experiment: - Bend the wire and put it in water. - Measure the water's temperature and record the data on the work sheet. - Heat the water and measure the water temperature and observe when the wire starts to reshape. 8. Discuss the concept of the transition temperature of Nitinol wire. **Stage 3 : Making toys from Shape Memory Alloy (SMA)(1.30 hours)** 9. Students work in groups. 10. Brainstorm how to design the toys from SMA.	

Key stage indicators	**Examples of Learning Activities**	**Basic Knowledge Requirements / Science Focus**
	11. Each group presents the toys, self- assesses the toys, and votes for the best toy in the class. 12. Discuss how the temperature affects the atoms inside the metal when the material varies in temperature. 13. Discuss how memory wire behaves differently from other wires and what are the differences between memory wire and other wires. 14. Discuss two ways engineers might use these memory metals to make something. 15. Discuss how to share questions generated by the investigation. 16. Complete post-test and score the activity survey.	
1. Explain concept of diffraction of light on bubble wall. **2.** Explain how	**Task: 5 Nano bubble (1.30 hours)** **Learning objective:** Students understand the concept of light diffraction on the bubble wall	**Basic Knowledge Requirements** - Diffraction of light - Optical

<table>
<tr><th>Key stage indicators</th><th>Examples of Learning Activities</th><th>Basic Knowledge Requirements / Science Focus</th></tr>
<tr>
<td>do optical property change at the nanoscale.
3. Explain how the colored changing of bubbles connect to nanotechnology.</td>
<td>and understand how to change properties at the nanoscale such as types of properties and optical properties.
Learning activities :
1. Complete pretest.
2. Introduce student by discussing:
- What colors do soap bubbles have?
- Are they rainbow colored or clear?
- Where do the beautiful colors come from?
3. Mix the ingredients using the following ratios.
<table>
<tr><th>Mild detergent</th><th>Starch</th><th>Glycerin</th><th>Distilled water</th></tr>
<tr><td>1</td><td>4</td><td>0</td><td>10</td></tr>
<tr><td>1</td><td>2</td><td>0</td><td>3</td></tr>
<tr><td>5</td><td>3</td><td>1</td><td>0</td></tr>
</table>
4. Make bubbles from each formula
5. Make you own formula ratios in order to blow</td>
<td>properties of materials.
- Molecule structure of bubble wall.
Science Focus.
- Structure and properties of matter.
- Surface tension.
- Concepts of surfactant molecules.
- Diffraction of light.</td>
</tr>
</table>

Key stage indicators	Examples of Learning Activities	Basic Knowledge Requirements / Science Focus
	better bubbles. 6. Observe the color of the bubbles from each ratio. 7. Discuss how the thickness of the bubble wall affect the color of the bubbles. - how bubbles change color when the bubble size is changed. - how the changing of the bubble's color connect to nanotechnology. 8. Discuss the concept of diffraction of light on the bubble wall. 9. Conduct students to discuss how the properties change at the nanoscale, such as types of properties: Optical (color, transparency), Electrical (conductivity) ,Physical (hardness, melting point),Chemical (reactivity, reaction rates). 10. Discuss how the concept of optical properties of nanomaterials change similar to the changes in	

Key stage indicators	**Examples of Learning Activities**	**Basic Knowledge Requirements / Science Focus**
	the color of bubbles when the thickness of the bubble wall is changed. 12. Complete post-test and score activity survey.	
1. Explain how the atomic force microscope works. 2. Explain how interactive forces work in the molecular world. 3. Explain the advantages of the atomic force microscope.	**Task: 6 Nanotechnological tools** **Learning objective:** Students understand how Atomic force microscope work and expose to interaction forces between the tip and the sample such as a short-range chemical bonding force, a long-range van der Waals force, an electrostatic as well as a magnetic-dipole force. **Learning activities :** **State 1: Atomic force microscope (AFM) (1.30 hour)** 1. Complete pretest. 2. Introduce students to discuss about nanotechnological tools that are used to image molecular structures. 3. Student's experiment: - Hand out small dry beans and grains	**Basic Knowledge Requirements** - Familiarity with atoms, molecules. - Interaction forces in the molecular world such as a short-range chemical bonding force, a long-range van der Waals force, and an electrostatic as well as a magnetic-dipole force. **Science Focus.** - Structure of

Key stage indicators	**Examples of Learning Activities**	**Basic Knowledge Requirements / Science Focus**
	- Students make “Nano” letters using beans and grains. - Usually beans are large enough to pick with their bare hands but the grains are too small - Instead of using their hands, let the students make letters with a tweezer. - Discuss how the nano-size tool is necessary to produce nano-size materials. - Give the structure of the unknown sample surface (magnets are fixed in the wood plates as an unknown sample, the sample surfaces are covered with a piece of paper) and probed (the syringe with a magnet glued at the end of the syringe’s rod) - Ask students to predict the structure of the unknown sample surface. - The students work in groups to scan and record the vertical position change of	atoms, molecules. - Interaction forces in the molecular world.

Key stage indicators	Examples of Learning Activities	Basic Knowledge Requirements / Science Focus
	the syringe's rod when it moves up or down while scanning the sample surface. - Two different sizes of syringe tips are provided for each group. - The students learn how using a syringe tip in scanning an unknown surface lets them feel the attractive force between the tip and the surface; it helps them to imagine the figure/structure of the sample surface. - Students construct a plasticine model of the sample surface following their recorded data. - Students used the level of tip which is repulsive to construct model of sample surface that will have different levels because the magnets on the wood have different sizes which will have different repulsive forces.	

Key stage indicators	Examples of Learning Activities	Basic Knowledge Requirements / Science Focus
	- Ask all of the students to match the components of the real AFM with the AFM model and explain operations of the AFM non-contact modes. 4. Discuss how the tip size is significant for scanning sample surfaces. 5. Discuss how the real AFM works. 6. Discuss how to introduce students to interaction forces between the tip and the sample such as a short-range chemical bonding force, a long-range Van Der Waals force, an electrostatic as well as a magnetic-dipole force. **Stage 2: Manipulating Nanoparticles (30 minutes)** 1. Discuss how "we can arrange the atoms the way we want and what would happen if we could arrange the atoms one by one" 2. Students experiment : - Give The AFM tip to	

Key stage indicators	Examples of Learning Activities	Basic Knowledge Requirements / Science Focus
	students. It is represented by an electromagnet and the specific nanoparticles were represented by one-baht coins made of iron, while the silver coins represented another type of nanoparticle that could not be picked up by using this electromagnet (tip). - Discuss an example of manipulating randomly deposited gold particles on a mica substrate, The 15 nm diameter gold particles were pushed from an initial random position to form the IL logo. - Students learned that tasks such as pushing and pulling or cutting and indenting can be performed. Also, nanoscale objects can be mechanically moved by the AFM probe tip. 3. Complete post-test and score activity survey.	

In addition, the NSTC was tried out with two groups of undergraduate students. The first group was 25 second-year undergraduate students majoring in physics (10 male and 15 female) at university A (pseudonym) located at the North-East region. The second group was 30 third-year undergraduate students majoring in physics education (12 male and 18 female) at university B (pseudonym) located at the North-East region. From this trial, the researcher improved the activities in the NSTC such as the clarity of contents, the appropriateness of materials, teaching approaches and research instruments.

3.3 Phase 3: Implementation of NSTC

This phase aims to implement the NSTC and investigate its effectiveness regarding student understanding of NST and attitudes about NST activities.

3.3.1 Participant

The NSTC was implemented with 38 high school students (20 female and 18 male) from one demonstration school and 41 third-year undergraduate students majoring in physics education (15 male and 26 female) at one university that located at Chonburi province.

3.3.2 Data collection

To establish methodological triangulation, various data collection methods were employed, that is, an self-assessment questionnaire, an attitude questionnaire, classroom observation, interview, and student artifacts.

To measure the effectiveness of NSTC in helping students attain correct concepts of NST, the nanoscience and nanotechnology questions (NSTQ) were used. The items are open-ended questions, which cover all contents in each activity of NSTC. The content validity of NSTQ was checked by two science educators. The NSTQ were tried out with 50 high school and 55 undergraduate students and its reliability was .87.

The attitude questionnaires were used after finished each activity in order to get students’ feedbacks or comments about the activity. The questions used consist of both rating scale and open-ended questions.

During implementation of NSTC, the classroom observation was made to give information about how students learn, classroom environment and teaching and learning interactions. Field notes were used in accompany with video recording.

The informal interviews were also used to get students’ reflections and comments about the NSTC. The students were interviewed during and after activity.

Finally, student artifacts done in each activity were collected to assess their understanding of NST.

3.3.3 Data analysis

The quantitative data derived from rating-scale questionnaire were analyzed by frequency and percentage; while the open-ended questions were coded and grouped and calculated for percentage.

The qualitative data derived from observations, interviews, and documents (e.g., student reports, group projects, and homework) were analyzed by content analysis.

CHAPTER IV

RESULTS

This chapter presents the results of this study, which are divided into three main parts: a) NSTC science teachers' views about NST teaching and learning, b) and the effectiveness of the nanoscience and nanotechnology curriculum (NSTC), and c) overall reflection about NSTC.

4.1 Science teachers' views about NST teaching and learning

The NSTLQ was used to survey science teachers' views about teaching and learning of NST for both basic and higher education. The results from this survey can be presented as follows.

Table 4.1 Background of science teachers

Background		**Frequency (n=35)**	**Percentage (%)**
Gender	Male	10	28.6
	Female	25	71.4
Age	20-30	12	34.3
	31-40	17	48.6
	41-50	4	11.4
	>50	2	5.71
Education	Bachelor	18	51.4
	Master	17	48.6
Teaching Experience (Years)	<6	16	45.7
	6-10	10	28.6
	11-15	4	11.4
	16-20 or more	5	14.3

There were 35 science teachers from 10 public schools and one collage in one province located at the Northeast of Thailand responded to the NSTLQ. Most of them were female (71.4%). The number of respondents who graduated in Bachelor and Master degrees was quite similar, 51.4% and 48.6%, respectively. More than half of the teachers had taught science for more than six years.

When asking about the respondents' knowledge of NST and teaching pedagogies, the results were as Figure 4.1.

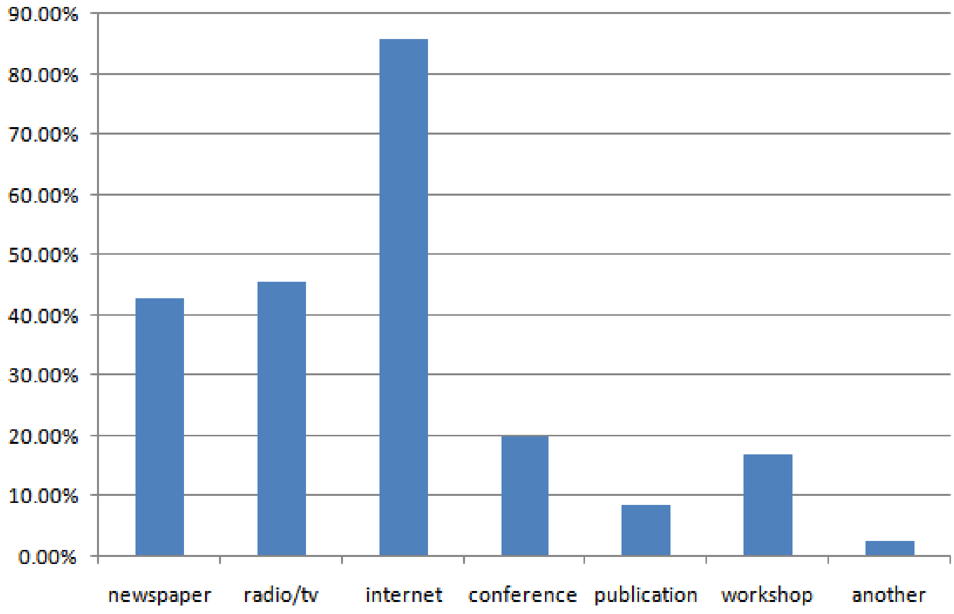

Figure 4.1 Sources of information about NST

There were 60% and 14% of science teachers identified themselves as having a medium and good knowledge of NST, respectively. All teachers stated that they had never learned about NST during their Bachelor degree. They got information about NST from various sources such as internet (90%), radio or television (45%) and newspapers (43%). Interestingly, only 20% of teachers indicated a professional conference as a source of information about NST. When being asked about potential in teaching NST, most of the teachers (80%) stated that they needed help regarding both conceptual understanding and teaching strategies.

When asking about the agreement of integrating NST into existing curriculum, the results were as Table 4.2.

Table 4.2 Levels of agreement on integrating NST into existing curriculum

Statement	Levels of Agreement				
	Strongly disagree	Disagree	Not sure	Agree	Strongly Agree
1. Basic knowledge of NST is needed for all students.	0.0%	8.6%	11.4%	54.3%	25.7%
2. Basic knowledge of NST is needed only for science students.	17.1%	40.0%	8.6%	28.6%	5.7%
3. NST content should be integrated into existing science curricula.	0.0%	2.8%	11.4%	57.1%	31.4%
4. NST should be set as a new subject or course.	2.8%	11.4%	20.0%	40.0%	25.7%
5. Basic knowledge of NST is needed for all students.	0.0%	8.6%	11.4%	54.3%	25.7%
6. Basic knowledge of NST is needed only for science students.	17.1%	40.0%	8.6%	28.6%	5.7%
7. NST content should be integrated into existing science curricula.	0.0%	2.8%	11.4%	57.1%	31.4%
8. NST should be set as a new subject or course.	2.8%	11.4%	20.0%	40.0%	25.7%

Most of the science teachers (80%) agreed that basic knowledge of NST is needed for all students. Most of them (88.5%) agreed that NST can be integrated into existing science curriculum; while, 65.7% stated that NST should be separated as a new subject. The teachers indicated that NST should be integrated into biology (17.9%), physics (26.3%), chemistry (25.0%) and general science (30.8%), respectively. In addition, most of the teachers (85.7%) agreed that NST should be taught in grades 10-12, and a half of them (54.3%) stated that it should be added for grade 7-9 students. However, more than half of them (68%) thought that NST should be introduced again for the first-year undergraduate students.

There were many subtopics proposed by the respondents to be included in NST curriculum as Figure 4.2.

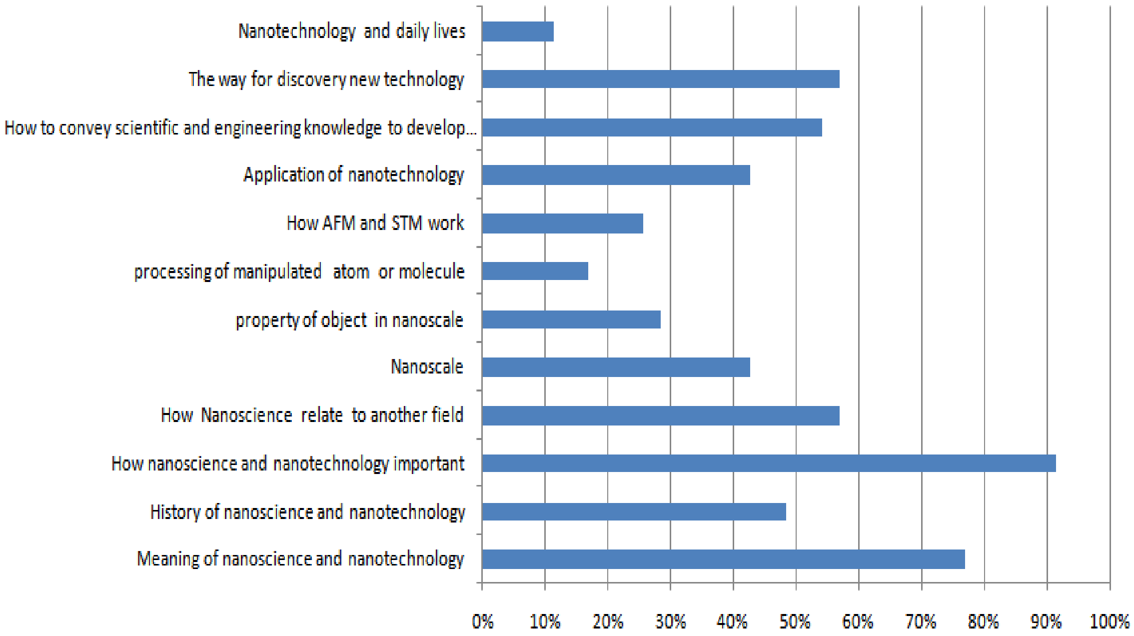

Figure 4.2 Subtopics of NST should be included in curriculum

The three-most subtopics should be included in NST curriculum were “Why we need to know about NST” (91.40%), “What is NST” (77%), and “How NST relate to other subjects” (57%), respectively.

The science teachers reflected their levels of agreement on teaching and learning NST as Table 4.3

Table 4.3 Levels of agreement on the teaching and learning of NST

Statements	Levels of Agreement (frequency/percentage)				
	Strongly disagree %	Disagree %	Not sure %	Agree %	Strongly Agree %
1. Learning NST would enhance students' critical thinking and problem solving skills.	0.00	0.00	8.60	48.60	41.00
2. Learning NST would enhance students' attitude toward science and technology.	0.00	0.00	8.60	62.80	28.60
3. Learning NST would enhance students' understanding of science and technology.	0.00	2.80	11.40	60.00	22.80

More than half of the teachers (65.7%) agreed that integration of NST in science curriculum would enhance students' critical thinking and problem solving skills. In addition, 62.8% of them agreed that students' attitudes toward science and technology would be developed through various issues concerning the utilization of NST enterprises.

According to the open ended question "How could we teach NST?", the teachers identified various teaching orientations, for example, demonstrations, active learning or hands-on activities, conceptual change, activity-driven, discovery, project-based science, inquiry and simple experiments. A half of the teachers (50%) concerned that there are only few people who know about NST at present. NST should be taught to grades 9-10 students in order to inspire them to continue further study in the field of NST. It could be beneficial for the development of NST in Thailand in the near future, a higher numbers of students continue learning NST at the undergraduate level.

When being asked "What are the aspects of learning outcomes of NST?", the teachers remarked that students should know about new discoveries in science and technology, be able to propose ideas to develop simple NST projects, and discuss about NST in daily lives, and have positive attitudes toward science and technology.

4.2 Implementation of NSTC

This part presents the results from the implementation of NSTC for high school and undergraduate students according to NSTC how students learn NST and the effectiveness of NSTC for promoting students' understanding of the NST and the students' opinions toward learning with NSTC. This part will be divided into two sub-headings, i.e., the results of implementation of NSTC for undergraduate students and for high school students.

4.2.1 Implementation of NSTC for undergraduate students

After finished each activity, the participating undergraduate students were asked to answer the questionnaire to reflect their attitudes toward learning with that activity. The following tables will present their learning attitudes in each activity in the NSTC.

Table 4.4 Undergraduate student response to nano-surface activity

Question	Strongly disagree (%)	Disagree (%)	Neither agree nor disagree (%)	Agree (%)	Strongly agree (%)
I enjoyed the nano- surface activity so much that I wanted to learn more	0.00	0.00	0.00	51.28	48.72
I could figure out how to do each step of the activity, after the teacher gave the directions.	0.00	0.00	2.56	46.15	51.28

Table 4.4 Undergraduate student response to nano-surface activity. (cont.)

Question	**Strongly disagree (%)**	**Disagree (%)**	**Neither agree nor disagree (%)**	**Agree (%)**	**Strongly agree (%)**
I think that the nano-surface activity is suitable to use for teaching nanotechnology concepts	0.00	0.00	7.69	43.59	48.72
I think the nano-surface activity helped expand my view of nanotechnology.	0.00	0.00	5.13	48.72	46.15
I would like teachers to be able to introduce the nano-surface activity to their science classes.	0.00	0.00	5.13	43.59	51.28
I think that learning about the nano -surface activity helped me to understand how different material surfaces correlate with different physical properties.	0.00	0.00	5.13	43.59	51.28
I feel that the Nano-surface activity helped me to understand the concepts of nanotechnology necessary to create the nano fabric industry.	0.00	0.00	7.69	46.15	46.15

All students enjoyed the nano-surface activity and want to learn more. Most of them (97%) could figure out how to do the activity after the teacher gave the directions. The students (92%) agreed that this activity is suitable for teaching nanotechnology concepts and they felt that the activity helped them to understand the concepts of nanotechnology is necessary to create the nano fabric industry. Furthermore, almost all students (95%) agreed that teachers should introduce this activity to the science class and the nano-surface activity helped expand their view of nanotechnology. Most of them (95%) gave feedback that learning about the nano - surface activity helped them to understand how different material surfaces correlate with different physical properties.

Table 4.5 Undergraduate student response to size and dependent properties activity

Question	**Strongly disagree (%)**	**Disagree (%)**	**Neither agree nor disagree (%)**	**Agree (%)**	**Strongly agree (%)**
I enjoyed the size and dependent properties activity so much that I wanted to learn more	0.00	0.00	2.44	36.59	60.98
I could figure out what to do with each step of the activity after the teacher gave the directions	2.44	0.00	2.44	51.22	43.90
I think that the size and dependent properties activity is suitable to use for teaching nanotechnology concepts	0.00	0.00	2.44	29.27	68.29

Table 4.5 Undergraduate student response to size and dependent properties activity. (cont.)

Question	Strongly disagree (%)	Disagree (%)	Neither agree nor disagree (%)	Agree (%)	Strongly agree (%)
I think the size and dependent properties activity helped expand my view of nanotechnology	2.44	0.00	4.88	26.83	65.85
I would like teachers to be able to introduce the size and dependent properties activity to their science classes.	0.00	2.44	7.32	24.39	65.85
I think the size and dependent properties activity greatly helped me to understand how a material can act differently when it's nanometer-sized.	2.44	0.00	2.44	31.71	63.41

Almost all students (98%) enjoyed the topic of the 'size and dependent properties' and wanted to learn more. They agreed that this activity is suitable to use for teaching nanotechnology concepts. Moreover, 95% of them could figure out how to do the activity after the teacher gave the directions and they mentioned that this activity helped them much to understand how a material can act differently in nanometer-sized. Most of the students believed that the 'size and dependent properties' activity helped them expand their view of nanotechnology (93%) and should be introduced to science classes (90%).

Table 4.6 Undergraduate student response to Magic Sand Activity

Question	Strongly disagree (%)	Disagree (%)	Neither agree nor disagree (%)	Agree (%)	Strongly agree (%)
I enjoyed the Magic Sand activity so much that I wanted to learn more.	0.00	0.00	0.00	34.21	65.79
I could figure out what to do each step of the activity, after the teacher gave the directions.	0.00	0.00	2.63	34.21	63.16
I think that the Magic Sand activity is suitable to use for teaching nanotechnology concepts	0.00	0.00	5.26	60.53	34.21
I think that the Magic Sand activity helped expand my view of nanotechnology.	0.00	0.00	7.89	44.74	47.37
I would like teachers to be able to introduce the Magic Sand activity to their science classes.	0.00	0.00	5.26	52.63	42.11
I think that learning about the Magic Sand activity greatly helped me to understand the polar and Non-polar concepts.	0.00	0.00	5.26	39.47	55.26

Table 4.6 Undergraduate student response to Magic Sand Activity. (cont.)

Question	Strongly disagree (%)	Disagree (%)	Neither agree nor disagree (%)	Agree (%)	Strongly agree (%)
I Think that the Magic Sand activity helped me to understand the concepts of monolayer coating.	0.00	0.00	2.63	50.00	47.37

All students enjoyed the magic sand activity, and almost all of them (97%) could figure out how to do the activity by themselves and agreed that this activity helped them to understand the concepts of monolayer coating. Almost all students (95%) reflected that this activity is suitable for teaching nanotechnology concepts and suggested to teachers that they should introduce this activity to the classroom. Moreover, they also mentioned that this activity greatly helped them understand the polar and non-polar concepts. In addition, 92% of them stated that this activity helped expand their view of nanotechnology.

Table 4.7 Undergraduate student response to Nano-bubbles Activity

Question	Strongly disagree (%)	Disagree (%)	Neither agree nor disagree (%)	Agree (%)	Strongly agree (%)
I enjoyed the Nano bubbles activity so much that I wanted to learn more.	0.00	0.00	0.00	44.12	55.88
I could figure out what to do each step of the activity, after the teacher gave the directions.	0.00	0.00	2.94	64.71	32.35

Table 4.7 Undergraduate student response to Nano-bubbles Activity. (cont.)

Question	**Strongly disagree (%)**	**Disagree (%)**	**Neither agree nor disagree (%)**	**Agree (%)**	**Strongly agree (%)**
I think that the nano-bubbles activity is suitable to use for teaching nanotechnology concepts	0.00	0.00	8.82	44.12	47.06
I think the Nano bubbles activity helped expand my view of nanotechnology.	0.00	0.00	11.76	32.35	55.88
I would like teachers to be able to introduce the Nano bubbles activity to their science classes.	0.00	0.00	5.88	44.12	50.00
I think the Nano bubbles activity greatly helped me to expand my understanding of diffraction of light concepts	0.00	0.00	0.00	41.18	58.82

All students enjoyed the topic of the nano -bubbles activity and mentioned that this activity helped them expand their understanding diffraction of light concepts . Almost all students (98%) could figure out how to do the experiment after the teacher gave the directions. Almost all students (94%) agreed that the teachers should be able to introduce the activity to their science class. Most students (91%) believed that this activity is suitable for teaching nanotechnology concepts. Furthermore, 88% of the students agreed that the nano -bubbles activity helped expand their view of nanotechnology.

Table 4.8 Undergraduate student response to nitinol activity

Question	Strongly disagree (%)	Disagree (%)	Neither agree nor disagree (%)	Agree (%)	Strongly agree (%)
I enjoyed the topic of the nitinol activity so much that I wanted to learn more.	0.00	0.00	0.00	44.83	55.17
I could figure out what to do each step of the activity, after the teacher gave the directions.	0.00	0.00	3.45	51.72	44.83
I think that the nitinol activity is suitable to use for teaching nanotechnology concepts.	0.00	0.00	0.00	44.83	55.17
I think the nitinol activity helped expand my view of nanotechnology.	0.00	0.00	3.45	48.28	48.28
I would like teachers to be able to introduce the nitinol activity to their science classes.	0.00	0.00	6.90	31.03	62.07
I think that the nitinol activity greatly helped me expand my view on how the nanotechnology products will introduce new properties.	0.00	0.00	0.00	41.38	58.62

Table 4.8 Undergraduate student response to nitinol activity. (cont.)

Question	Strongly disagree (%)	Disagree (%)	Neither agree nor disagree (%)	Agree (%)	Strongly agree (%)
I think that knowledge of the nitinol activity will be very useful to society in the near future.	0.00	0.00	0.00	31.03	68.97

All participants enjoyed the topic of the nitinol activity. They also mentioned that this activity is suitable for teaching nanotechnology concepts and that this activity also helped them expand their view on how the nanotechnology products will introduce new properties. Furthermore, all students agree that the knowledge from this activity will be very useful to society in the near future. Almost all students (96%) could figure out how to do the experiment after they had the directions and they believed that this activity helped expand their view of nanotechnology. Almost all students (93%) agreed that teachers should introduce this activity to their science students.

Table 4.9 Undergraduate student response to AFM activity

Question	Strongly disagree (%)	Disagree (%)	Neither agree nor disagree (%)	Agree (%)	Strongly agree (%)
I enjoyed the topic of the AFM activity so much that I wanted to learn more	0.00	0.00	5.56	61.11	33.33
I could figure out what to do each step of the activity, after the teacher gave the directions.	0.00	0.00	5.56	61.11	33.33

Table 4.9 Undergraduate student response to AFM activity (cont.)

Question	**Strongly disagree (%)**	**Disagree (%)**	**Neither agree nor disagree (%)**	**Agree (%)**	**Strongly agree (%)**
I think the AFM activity helped expand my view of nanotechnology	0.00	5.56	0.00	38.89	55.56
I think that the AFM activity is suitable to use for teaching nanotechnology concepts.	0.00	0.00	5.56	38.89	55.56
I would like teachers to be able to introduce the AFM activity to their science classes.	0.00	5.56	0.00	38.89	55.56
I think the AFM activity greatly helped me to understand how Nano technological tools produce a topographic image of atomic and molecular surfaces	0.00	0.00	5.56	33.33	61.11
I think the AFM activity helped expand my understanding of the atomic and molecular interaction forces.	0.00	0.00	5.56	38.89	55.56

Almost all students (94%) agreed that they enjoyed the topic of the AFM activity, they could figure out how to do the activity, and it helped expand their view of nanotechnology. They also mentioned that this activity is suitable for teaching nanotechnology concepts and the teachers should bring this topic into science classes. Almost all students (94%) gave the feedback that this activity helped them understand how nanotechnology tools produce a topographical image of atomic and molecular surfaces and the atomic and molecular interaction force concepts.

4.2.2 Implementation of NSTC for high school students

After finished each activity, the participating high school students were asked to answer the questionnaire to reflect their attitudes toward learning with that activity. The following tables will present their learning attitudes in each activity in the NSTC.

Table 4.10 High school student response to nano-surface Activity

Question	Strongly disagree (%)	Disagree (%)	Neither agree nor disagree (%)	Agree (%)	Strongly agree (%)
I enjoyed the Nano- surface activity so much that I wanted to learn more	0.00	0.00	11.11	63.89	25.00
I could figure out how to do each step of the activity after the teacher gave the directions.	0.00	0.00	16.67	55.56	27.78
I think that the Nano- surface activity is suitable to use for teaching nanotechnology concepts	0.00	2.78	13.89	55.56	27.78
I think the Nano-surface activity helped expand my view of nanotechnology	0.00	2.78	19.44	50.00	27.78
I would like teachers to be able to introduce the Nano-surface activity to their science student	0.00	0.00	36.11	36.11	27.78

Table 4.10 High school student response to nano-surface Activity. (cont.)

Question	**Strongly disagree (%)**	**Disagree (%)**	**Neither agree nor disagree (%)**	**Agree (%)**	**Strongly agree (%)**
I think that learning about the Nano -surface activity helped me to understand how different material surfaces correlate with certain physical properties.	0.00	2.78	19.44	55.56	22.22
I feel that the Nano-surface activity helped me to understand the concepts of nanotechnology necessary to produce the nano fabric industry.	0.00	5.56	13.89	47.22	33.33
I think that knowledge of the Nano -surface activity will be very useful for my daily live	0.00	11.11	30.56	33.33	25.00

Most of the students (89%) enjoyed the nano-surface activity and want to learn more. Most of them could figure out how to do the activity after the teacher gave the directions and agreed that this activity is suitable for teaching nanotechnology concepts (83%), and felt that the activity helped them to understand the concepts of nanotechnology is necessary to create the nano fabric industry (80%). Most of them gave feedback to learn about the nano-surface activity will help them to understand how different material surfaces correlate with different physical properties (78%), and helped expand view of nanotechnology (71 %). In addition more than half of the students agreed that teachers should introduce this activity to the science class (65%) and knowledge from this activity will be very useful for their daily lives (58 %).

Table 4.11 High school student response to size and dependent properties activity

Question	Strongly disagree (%)	Disagree (%)	Neither agree nor disagree (%)	Agree (%)	Strongly agree (%)
I enjoyed the topic of the size and dependent properties activity so much that I wanted to learn more	0.00	2.33	25.58	67.44	4.65
I could figure out what to do with each step of the activity after the teacher gave the directions	0.00	2.33	25.58	46.51	25.58
I think that the size and dependent properties activity is suitable to use for teaching nanotechnology concepts	2.33	2.33	18.60	60.47	16.28
I think the size and dependent properties activity helped expand my view of nanotechnology	0.00	4.65	27.91	60.47	6.98
I would like teachers to be able to introduce the size and dependent properties activity to their science students.	2.33	2.33	41.86	44.19	9.30
I think that the size and dependent properties activity greatly helped me to understand how a material can act differently when it’s nanometer-sized.	0.00	2.33	20.93	53.49	23.26

Table 4.11 High school student response to size and dependent properties activity. (cont.)

Question	Strongly disagree (%)	Disagree (%)	Neither agree nor disagree (%)	Agree (%)	Strongly agree (%)
I think that knowledge of the size and dependent properties activity will be very useful for my daily live	0.00	9.30	20.93	48.84	20.93

Most of the students (77%) agreed that the 'size and area surface' activity is suitable to use for teaching nanotechnology concepts and greatly helped them to understand how a material can act differently when it's nanometer-sized. Most of them (72%) agreed that they enjoyed this activity and wanted to learn more, moreover they also could figure out how to do the activity after the teacher gave the directions. More than half of the students (67%) said that this activity should be introduced to science classes.

Table 4.12 High school student response to Magic Sand Activity

Question	Strongly disagree (%)	Disagree (%)	Neither agree nor disagree (%)	Agree (%)	Strongly agree (%)
I enjoyed the topic of the Magic Sand activity so much that I wanted to learn more	0.00	0.00	10.34	62.07	27.59
I could figure out what to do each step of the activity, after the teacher gave the directions.	0.00	3.45	10.34	55.17	31.03

Table 4.12 High school student response to Magic Sand Activity. (cont.)

Question	Strongly disagree (%)	Disagree (%)	Neither agree nor disagree (%)	Agree (%)	Strongly agree (%)
I think that the Magic Sand activity is suitable to use for teaching nanotechnology concepts	0.00	3.45	10.34	62.07	24.14
I think that the Magic Sand activity helped expand my view of nanotechnology.	0.00	3.45	24.14	58.62	13.79
I would like teachers to be able to introduce the Magic Sand activity to their science students	0.00	6.90	34.48	34.48	24.14
I think that learning about the Magic Sand activity greatly helped me to understand the polar and Non-polar concepts	0.00	3.45	6.90	55.17	34.48
I Think that the Magic Sand activity helped me to understand the concepts of monolayer coating.	0.00	10.34	17.24	51.72	20.69
I think that knowledge of the Magic Sand activity will be very useful for my daily live	0.00	6.90	31.03	37.93	24.14

Nearly all of the students mentioned that the magic sand activity greatly helped them to understand the polar and non-polar concepts (90%) and enjoyed the topic of the magic sand activity (89%). Most of them could figure out how to do the activity by themselves and agreed that the magic sand activity is suitable for teaching nanotechnology concepts (86%) and believed that this activity helped them to understand the concepts of monolayer coating and helped expand their view of nanotechnology (72%). Meanwhile, 62% thought that knowledge from this activity will be very useful for my daily live and 58% agreed that the teachers should introduce the activity to the classroom.

Table 4.13 High school student response to nano-bubbles activity

Question	**Strongly disagree (%)**	**Disagree (%)**	**Neither agree nor disagree (%)**	**Agree (%)**	**Strongly agree (%)**
I enjoyed the topic of the Nano bubbles activity so much that I wanted to learn more	0.00	0.00	4.00	32.00	64.00
I could figure out what to do each step of the activity, after the teacher gave the directions.	0.00	0.00	8.00	48.00	44.00
I think that the Nano bubbles activity is suitable to use for teaching nanotechnology concepts.	0.00	4.00	12.00	44.00	40.00
I think the Nano bubbles activity helped expand my view of nanotechnology.	0.00	0.00	24.00	32.00	44.00
I would like teachers to be able to introduce the Nano bubbles activity to their science students.	0.00	0.00	12.00	36.00	52.00
I think the Nano bubbles activity greatly helped me to expand my understanding of diffraction of light concepts.	0.00	0.00	20.00	28.00	52.00

Table 4.13 High school student response to nano-bubbles activity. (cont.)

Question	**Strongly disagree (%)**	**Disagree (%)**	**Neither agree nor disagree (%)**	**Agree (%)**	**Strongly agree (%)**
I think the Nano bubbles activity helped expand my understanding about the optical properties of materials depend on the material size.	0.00	4.00	8.00	40.00	48.00
I think that knowledge of the Nano bubbles activity will be very useful for my daily live.	4.00	4.00	24.00	28.00	40.00

Nearly all students (96%) enjoyed and wanted to learn more in the topic of the nano-bubbles. Nearly all of them (92%) could figure out how to do the experiment after the teacher gave the directions. Moreover, 88% agreed that the teachers should be able to introduce the activity to their science class and believed that this activity helped expand their understanding about the optical properties of materials depend on the material size**.** Most of them believed that the activity is suitable for teaching nanotechnology concepts (84%) and mentioned that this activity helped expand their understanding diffraction of light concepts (80%). Most of the students agreed that the nano-bubbles activity helped expand their view of nanotechnology (76%) and pointed that knowledge from the activity will be very useful for my daily live (68%.)

Table 4.14 High school student response to nitinol activity

Question	Strongly disagree (%)	Disagree (%)	Neither agree nor disagree (%)	Agree (%)	Strongly agree (%)
I enjoyed the topic of the nitinol activity so much that I wanted to learn more	0.00	0.00	9.52	42.86	47.62
I could figure out what to do each step of the activity, after the teacher gave the directions.	0.00	0.00	14.29	47.62	38.10
I think that the nitinol activity is suitable to use for teaching nanotechnology concepts.	0.00	0.00	9.52	66.67	23.81
I think the nitinol activity helped expand my view of nanotechnology.	0.00	0.00	14.29	66.67	19.05
I would like teachers to be able to introduce the nitinol activity to their science students.	0.00	0.00	23.81	38.10	38.10
I think that the nitinol activity greatly helped me expand my view on how the nanotechnology products will introduce new properties	0.00	0.00	4.76	52.38	42.86
I think that knowledge of the nitinol activity will be very useful to society in the near future.	0.00	0.00	14.29	66.67	19.05

Most participants (96%) could figure out how to do the experiment after they had the directions and 95% said that this activity also helped them expand the view on how the nanotechnology products will introduce new properties. Nearly all of them enjoyed and want to learn more in this activity (91%) and mentioned that this activity is suitable for teaching nanotechnology concepts. Furthermore, 86% of them believed that this activity helped expand their view of nanotechnology and agreed that the knowledge from this activity will be very useful to society in the near future. In addition, 76% of the students launched that teachers should introduce this activity to their science students.

Table 4.15 High school student response to CD and DVD grating activity

Question	**Strongly disagree (%)**	**Disagree (%)**	**Neither agree nor disagree (%)**	**Agree (%)**	**Strongly agree (%)**
I enjoyed the topic of the CD and DVD grating activity so much that I wanted to learn more.	0.00	3.85	34.62	46.15	15.38
I could figure out what to do each step of the activity, after the teacher gave the directions.	0.00	0.00	38.46	50.00	11.54
I think that the CD and DVD grating activity is suitable to use for teaching nanotechnology concepts	0.00	3.85	30.77	46.15	19.23
I think the CD and DVD grating activity helped expand my view of nanotechnology.	0.00	3.85	30.77	42.31	23.08

Table 4.15 High school student response to CD and DVD grating activity. (cont.)

Question	Strongly disagree (%)	Disagree (%)	Neither agree nor disagree (%)	Agree (%)	Strongly agree (%)
I would like teachers to be able to introduce the CD and DVD grating activity to their science students.	0.00	11.54	50.00	26.92	11.54
I think the CD and DVD grating activity greatly helped me to expand my understanding of diffraction of light concepts.	0.00	7.69	15.38	65.38	11.54
I think the CD and DVD grating activity helped expand my understanding of the memory storage.	0.00	3.85	23.08	50.00	23.08
I think that knowledge of the CD and DVD grating activity will be very useful for my daily live.	0.00	3.85	34.62	46.15	15.38

The results showed that most of the students agreed that the CD and DVD grating activity helped expand their understanding of diffraction of light concepts and memory storage, 77% and 73% , respectively. Furthermore, 65% agreed that this activity is suitable to use for teaching nanotechnology concepts and helped expand their view of nanotechnology. Most of the students (61%) enjoyed this activity could figure out what to do each step after the teachers gave the directions, and they thought that knowledge from this activity will be very useful for their daily live. However, only 38% would like teachers to be able to introduce this activity to the science students.

4.3 Overall reflection about NSTC

4.3.1 Undergraduate student overall reflection about NSTC

The participating undergraduate students were asked to respond to the open-ended questions after finished all activities of NSTC. The results are presented as follows.

NST knowledge gained from NSTC

Table 4.16 the nanotechnology knowledge before doing the activities

Pre- activities of nanotechnology	***Student comments (%)**
My nanotechnology concepts before I did the activities that I really don’t know about what is nanotechnology?	41.4
I don’t really understand the nanotechnology concepts even if I took some courses which related to nanotechnology.	31
I only knew the nanotechnology is a small thing in 10^{-9}	13.8
I have never known that the nanotechnology is all around us.	6.9
I have never known about its advantages.	3.4
I have never understood how nanoparticle’s behaviors.	3.4
I only knew “nano is prefix of unit.	3.4
I never known how to use nanotechnology knowledge in daily live.	3.4
I only knew the nanotechnology is a new technology.	3.4

Table 4.16 the nanotechnology knowledge before doing the activities. (cont.)

Pre- activities of nanotechnology	***Student comments (%)**
I only knew that the nano things have a surface tension which interacts between molecules and molecules.	3.4

*Students can give comments more than one item.

Interestingly, from student overall reflection, nearly half of the participants (41.4%) reflected that, before attended the NSTC, they really don’t know what is nanotechnology. Even though took some courses related to nanotechnology before, 31% stated that they did not really understand the nanotechnology concepts.

Table 4.17 the nanotechnology knowledge after finishing the activities

Post-activities of nanotechnology	***Student comments (%)**
I have been expanded many nanotechnology concepts, I have known, the nanotechnology products should be controlled from 1-100 nanometer.	86
The nanotechnology activities helped me to conceptually see the big picture of nanotechnology which increased my understanding of nanotechnology ideas	24
The activities introduced me to some new properties of various nano-materials and helped expand my views on how nano-particles act.	17.2
After I did the experiment I have known various concepts of nanotechnology	13.8
I realized that nanotechnology is all around me and everything is related to nanotechnology	10.3
My idea is to use simple things in nature to create lab experiments	10.3

Table 4.17 the nanotechnology knowledge after finishing the activities. (cont.)

Post-activities of nanotechnology	***Student comments (%)**
I want to create the nanotechnology activities to disseminate to the students	6.9
I began to ask questions like: What is nanotechnology?, Why does nanotechnology exist this way?, and How does nanotechnology occur?	6.9
My knowledge of nanotechnology has totally changed since doing the experiments	3.4
I was very surprised to see how bubbles can explain nanotechnology concepts.	3.4
I like nanowire (nitinol) that is an amazing thing. When It is heated, it will reshape seems like elastic thing. This activity is a good example for nano devices	3.4
After I joined the workshop, I realized that nanotechnology is an inescapable part of modern everyday life.	3.4
I know why the water droplets can be rolling on lotus leaves but this phenomenon cannot occur with some leaves.	3.4
I just realized that many new products are made from nanotechnology process.	3.4

*Students can give comments more than one item.

A majority of student reflection (86%) showed that the NSTC helped the participating students expanded their nanotechnology concepts and knew the nanotechnology products should be controlled from 1-100 nanometer. One-fourth of the students (24%) responded that the nanotechnology activities in the NSTC helped them conceptually see the big picture of nanotechnology which increased their understanding of nanotechnology ideas and 17.2% stated that the activities introduced them to some new properties of various nano-materials and helped expand the views on how nano-particles act.

Feelings about NSTC

Table 4.18 Students thoughts and feelings about the nanotechnology activities

Student thoughts and feeling	***Student comments (%)**
I have been very enjoyed doing the nanotechnology activities, I am very excited to learn more, the activities are not boring.	82.8
I really like the activities and I am so happy to have the opportunity to join.	27.6
I gained various knowledge of nanotechnology.	24.1
The experiments are so easy but they can introduce me to get the concepts of nanotechnology	24.1
I have learned many new things	20.7
There are various activities that attracted me to join the class which are not boring	17.2
The activities are very creative and unexpected. I have never done those activities before.	13.8
The activities introduced me to practice some critical thinking and promoted me to learn by myself.	10.3
The knowledge of the activities are a benefit to improve daily life technology	6.9

Table 4.18 Students thoughts and feelings about the nanotechnology activities. (cont.)

Student thoughts and feeling	***Student comments (%)**
The concepts from each activity are appropriate, related, and connected.	6.9
The teaching team was very kind, friendly, stress free, and helped the students to be brave in stating opinions and questions.	6.9
Some activities were boring and I fell asleep	6.9
I learned more about working in a group with other people	6.9
I want you to develop the further activities and keep to promote the nanoscinece and nanotechnology curriculum	6.9
I have created my own concepts of nanotechnology	3.4
The activities promoted the idea to use simple things in nature to create lab experiments	3.4
I felt so lucky to have the opportunity to join the activities. It is not easy to get that chance.	3.4
I would like you to add more concepts of nanotechnology into the activities and explain more detail	3.4
nanotechnology activities are suitable for all people and particular pre-service teachers because the activities are very interesting.	3.4
I have never attended the activities like these in my life.	3.4
The activities are benefit for the science camps because students will have both fun and scientific knowledge in the same time.	3.4

Table 4.18 Students thoughts and feelings about the nanotechnology activities. (cont.)

Student thoughts and feeling	***Student comments (%)**
I just knew there are lot things which are relative to nanotechnology, honestly I was very happy so much.	3.4

*Students can give comments more than one item.

A majority of the students (82.8%) stated that they enjoyed the nanotechnology activities because they are not boring and very excited to learn more. More than one-fourth (27.6%) agreed that they really like the activities and they were so happy to have the opportunity to join and 24.1% of them reflected that the experiments were easy and helped them get the correct concepts of nanotechnology.

Further questions about NST

Table 4.19 Students' questions and curiosities about nanotechnology.

Student questions	***Students' comments (%)**
Can I make nano-products? How will I make them by myself?	13.8
I want to see real nano- products and make them in classroom.	13.8
How we will know which products are come from nanotechnology and which products are not.	6.9
What *will happen* If we don't have nanotechnology?	6.9
I want to know about the advantages and disadvantages of nanotechnology.	6.9
I want to know how to make nanowires and how atoms and molecules in nanowires are arrangement.	6.9

Table 4.19 Students' questions and curiosities about nanotechnology. (cont.)

Student questions	***Students' comments (%)**
How will the innovation of nanotech be developed and what are the future foci of technology.	6.9
How will advances in nanotechnology impact the world positively?	6.9
I want to know: How will I lose my weight with nanotechnology? and how will the cosmetics make from nanotechnology?	6.9
I want to know, when I can join the further activities of nanotechnology again.	3.4
How nanotechnology is used to improve the environment. This includes cleaning up existing pollution, improving manufacturing methods to reduce the generation of new pollution, and making alternative energy sources more cost effective.	3.4

*Students can give comments more than one item.

The data showed that the participating students were curious about nanotechnology. They asked many interesting questions about NST such as making nano-products and integrating nano-products in classroom (13.8%), differentiating nano-products from non nano-products and stating advantages and disadvantages of nanotechnology (6.9 %).

Benefit of NST

Table 4.20 Students' opinions about the benefits from the nanotechnology activities

Benefits from nanotechnology activities	**Students' comments (%)**
I can apply the activities for demonstration to another student or people who interest in nanotechnology.	75.9
I will do science show when I have opportunity.	31
We can make new toys from the concepts of nanotechnology which I gained from the experiments.	24.1
I have known to apply nanotechnology concepts to my everyday life my class, and my research project.	17.2
I am pretty sure these activities are very useful for science classes.	17.2
I have known nanotechnology is very closed to our everyday life.	13.8
I realized the nano bubbles activity is very interesting and easy to introduce students to know nanotechnology concepts.	6.9
The activities helped expanded my views about nanotechnology.	6.9
I gained various benefits from the activities.	6.9
I have many ideas how to explain what is nanotechnology with easy ways.	3.4
I will use the knowledge from the activities to study on my project research.	3.4
I learned how to practice some creative thinking and performing from the activities.	3.4

Table 4.20 Students' opinions about the benefits from the nanotechnology activities. (cont.)

Benefits from nanotechnology activities	**Students' comments (%)**
In near future, I will use the knowledge from the activities to make some nanotechnology cosmetics.	3.4

*Students can give comments more than one item.

A majority of the participating students (75.9 %) reflected that they could apply the activities in the NSTC for demonstration to other people. Twenty-one percents of them agreed that they would do science show when they had opportunity. Nearly one-fourth of them (24.1%) responded that the NST concepts they gained from the NSTC can be applied to make new toys.

Necessity of NST for undergraduate students

Table 4.21 Students' opinions about the necessity of nanotechnology for undergraduate students.

Necessity of nanotechnology for undergraduate student	***Students' comments (%)**
Nanotechnology is necessary for all students in collage.	48.1
Nanotechnology is such a new field and needs to be included to the science curriculum for undergrad students.	22.2
Students need to know about nanotechnology world to expand their views of the new technologies.	22.2
Nanotechnology is all around us and everything is related to nanotechnology.	18.5

Table 4.21 Students' opinions about the necessity of nanotechnology for undergraduate students. (cont.)

Necessity of nanotechnology for undergraduate student	***Students' comments (%)**
Nanotechnology should be brought to science class for helping expand the scientific and technological knowledge of students. Students will apply nanotechnology concepts for creating new devices and products for near future.	18.5
The nanotechnology activities are benefit for dissemination the new knowledge to other people.	18.5
Everyone needs to know about nanotechnology because The commercialization of the nanotechnology has become a key focus in government and corporate R&D strategy in many countries.	14.8
Nanotechnology has the potential to change every part of our lives. Nanotechnology affects all materials: fabric, metals, polymers, and biomaterials. Therefore, students need to know about nanotechnology world to prepare themselves to live in global competitiveness.	11.1
The nanotechnology should be integrated into science class in college because it is benefit for students who want to study in graduated school and want to develop the scientific knowledge.	11.1
Nanotechnology will increase the scientific and technological knowledge of students.	7.4
Nanotechnology should be integrated to the science curriculum in college because many topics which relate to the new technology cannot find in the books.	7.4
Nanotechnology activities will help students to practice some creative and critical thinking skills.	3.7

Table 4.21 Students' opinions about the necessity of nanotechnology for undergraduate students. (cont.)

Necessity of nanotechnology for undergraduate student	***Students' comments (%)**
The nanotechnology activities will promote students to understand more about scientific and technological knowledge.	3.7
The nanotechnology is very interesting field which relates to physic education.	3.7
The knowledge from the activities can be used for studying on my project research.	3.7
Nanotechnology needs to be included to the science curriculum for undergraduate students because it will help to accelerate sustainable economic growth and international competitiveness.	3.7
Nanotechnology should be brought to science class or high school curriculum for helping expand the scientific knowledge of students and preparing them to study in higher education.	3.7
The nanotechnology should be integrated to the mainstream education in college because some non-science students don't have opportunity to study nanotechnology in the classes. The activities are easy to understand and they can perfectly link to nanotechnology concepts.	3.7
The nanotechnology curriculum in college should teach more in detail.	3.7

*Students can give comments more than one item.

Nearly half of the students (48.1%) commented that nanotechnology is necessary for all undergraduate students. Nearly one-fouth of the students (22.2%) reflected that nanotechnology is such a new field that needs to be included to the science curriculum for undergrad students and students need to know about nanotechnology world to expand their views of the new technologies. Furthermore, 18.5% gave feedbacks that; (1) nanotechnology is all around us and everything is related to nanotechnology; (2) nanotechnology should be brought to science class for helping expand the scientific knowledge of students;(3) students will apply nanotechnology concepts for creating new devices and products for near future; and (4) the nanotechnology activities are benefit for dissemination the new knowledge to other people.

4.3.2 High school student overall reflection about NSTC

The participating high school students were asked to respond to the open-ended questions after finished all activities of NSTC. The results are presented as follows.

NST knowledge gained from NSTC

Table 4.22 The nanotechnology knowledge gained from the activities.

Nanotechnology knowledge gained from activities	***Students' comments (%)**
I have been expanded many nanotechnology concepts and understand more.	31.6
I realized that there are various benefits of nanotechnology.	26.3
After I did the experiment I have known various concepts of nanotechnology.	21.1
I realized that nanotechnology is all around me and everything is related to nanotechnology.	21.1

Table 4.22 The nanotechnology knowledge gained from the activities.(cont.)

Nanotechnology knowledge gained from activities	***Students' comments (%)**
I gained many fundamental concepts of nanotechnology.	21.1
I gained much new knowledge which I have never learned before.	15.8
I gained new knowledge of nanotechnology surface.	10.5
I gained new knowledge of nanotechnology by using bubbles for explanation.	10.5
I gained new knowledge of nanotechnology by using nitinol to explain how nano-materials act.	10.5
I have learned more about many scientific skills.	10.5
I have learned how to use simple things in nature to create lab experiments and explain more detail about nanotechnology.	5.3
I can use the new knowledge from the activities to apply and create new devices and products in near future.	5.3
The activities introduced me to some new properties of various nano-materials and helped expand my views on how nano-particles act.	5.3
I have learned more about concepts of the chemical reaction.	5.3
I have learned more about concepts of the diffraction.	5.3

Table 4.22 The nanotechnology knowledge gained from the activities.(cont.)

Nanotechnology knowledge gained from activities	***Students' comments (%)**
The nanotechnology activities helped me to conceptually see the big picture of nanotechnology which increased my understanding of new technology ideas.	5.3
I have learned more about concepts of the nano-fabric.	5.3

*Students can give comments more than one item.

Nearly one-third of the students (31.6%) commented that they expanded their nanotechnology concepts and understood nanotechnology more. In addition, 26.3 % stated that there realzed various benefits of nanotechnology, and 21.1% pointed that the experiments helped them understand various concepts of nanotechnology, and realized that nanotechnology is all around

Feelings about NSTC

Table 4.23 The thoughts and feelings of students about the nanotechnology activities.

Student thoughts and feeling	***Student comments (%)**
I have been very enjoyed doing the activities, I am very excited to learn more, the activities are not boring and stress free.	84.2
Some activities were boring and I fell asleep.	36.8
I really like the activities and I am so happy to have the opportunity to join.	26.3

Table 4.23 The thoughts and feelings of students about the nanotechnology activities. (cont.)

Student thoughts and feeling	***Student comments (%)**
I have learned many new things, the activities are pretty new.	15.8
I gained various knowledge of nanotechnology.	10.5
I want join the further activities again.	10.5
Nano-Bubble activity is the most enjoyable.	10.5
The activities promoted me to learn and perform by myself.	5.3
I learned more about working in a group with other people.	5.3
I felt I have been introduced to get the concepts of nanotechnology for preparing to study in advance steps.	5.3
The activities perfectly answered my questions about nanotechnology.	5.3
Some activities require some basic concepts before doing experiments because that will be easy to understand and more fun.	5.3
I want to join other nanotechnology activities.	5.3
The teaching team is very good organization.	5.3

*Students can give comments more than one item.

Most of the students (84.2%) enjoyed the activities in the NSTC. They stated that the activities were very excited, fun, and relax. In particular, 26.3% said they really liked the activities and they were so happy to have the opportunity to join, and 15.8% said that the activities were pretty new and they learned many new things. However, some students (36.8%) stated that some activities were boring and they felt asleep.

Further questions about NST

Table 4.24 The questions or curiosities of students about nanotechnology.

Questions or curiosities about nanotechnology	**Students' comments (%)**
I have no question	63.2
I would like you to add more concepts of nanotechnology into the activities and explain more in detail	15.8
What *will happen* If we don't have nanotechnology	5.3
How will advances in nanotechnology impact the world positively?	5.3
Can I make nano-products? How will I make them by myself?	5.3
I want to know more about concepts of light diffraction.	5.3

*Students can give comments more than one item.

More than a half of the students (63.2%) reflected that they were clear about nanotechnology. In addition, 15.8 % stated they would like the teachers add more concepts of nanotechnology into the existing activities and explain more in detail and 5.26% asked what will happen if there is no nanotechnology and how nanotechnology impacts the world positively.

Benefit of NST

Table 4.25 Student's opinion about the benefits gained from the activities.

Benefits gained from activities	***Students' comments (%)**
I gained various knowledge of nanotechnology.	68.4
The activities introduced helped expand my views on the benefits of nanotechnology.	21.1
I have had a good time and been joyful.	21.1
I have practiced how to apply the scientific knowledge for developing and creating new things.	15.8
I can apply the new knowledge from the activities for improving my live.	10.5
I learned more about working in a group with other people.	10.5
I have learned many new things and gained variously new knowledge.	5.3
I realized that nanotechnology is all around us.	5.3
I have learned more about many scientific methods and skills.	5.3

*Students can give comments more than one item.

Most of the students (68.4%) stated that they gained various knowledge of nanotechnology. Nearly one-fourth of the students (21.1%) stated that the activities of the NSTC helped them expand their views on the benefits of nanotechnology and they had good time and were enjoy. In addition, 15.8% of them pointed out that they had experience to apply the scientific knowledge for developing and creating new things.

Necessity of NST for high school student

Table 4.26 Students' suggestions after finishing the activities.

Student suggestions	**Students' comments (%)**
All activities are perfectly and suitable for participants	26.3
We needed more time to do experiments.	21.1
I want you add more interesting topics and exciting activities.	15.8
I want you explain more to students for perfectly understanding and being clear in the concepts because the nanotechnology is pretty new.	15.8
There are so many questions that make me felt boring and don't want to write drown.	5.3
I want you translate when an American teacher taught us because all topics are very interesting.	5.3
I want to do the activities outside classroom.	5.3

*Students can give comments more than one item.

About one-fourth of the students (26.3%) stated that all activities of the NSTC were perfect and suitable. However, some participants suggested many things for the NSTC such as . more time for experiment (21.1%) more interesting topics and activities (15.8%), more detailed explanation about each NST activity, and deletion of some open-ended questions or conducting the activities outside classroom (5.26%).

Summary

The findings showed that a majority of the science teachers agreed with the integration of NST in the existing science curriculum because it could enhance students' critical thinking and problem solving skills. In addition, they agreed students' attitudes toward science and technology would be developed through various issues concerning the utilization of NST topic.

For students, the NSTC helped them understand more about the nano-scale phenomenon and had more positive attitudes toward learning science. The NSTC was interesting and advantage for everyday lives from both undergraduate and high school students as being shown from this quotation:

Formerly, before attended the NSTC, I really don't know about what nanotechnology is. I knew just nanotechnology is a small thing in a 10^{-9} scale. I also had no ideas about how nano-particles behave and its advantages. After I joined the NSTC, I realized that nanotechnology is an inescapable part of my live. Many new modern technology products are made from nanotechnology process. I can truly say that this is my great opportunity to learn with the NSTC which help expand my concepts of nanotechnology. (Undergraduate student 01)

This study also showed that it is possible to integrate the NST concepts into the existing science curriculum for Thai students in both high school and undergraduate levels. However, students and teachers must spend more time and effort according to the inquiry-based pedagogy used in the NSTC. Be remind, as Hingant and Albe (2010) pointed out that there are two advantages of providing NST education: 1) providing students' future career and 2) providing tools to make decision and utilization of NSTC in everyday lives.

Importantly, to implement the NSTC, science teachers or even student science teachers must be prepared to incorporated the NST concepts and activities in their classrooms. Thus, the design of effective science teacher professional development for NST is appeared as the next key challenge for contribution of NST education in Thailand.

CHAPTER V

DISCUSSION, CONCLUSIONS, AND IMPLICATIONS

This chapter discusses the findings emerged from this study in relation to two research questions mentioned earlier in Chapter 1:

1) What are high school students and student science teachers' understanding from participating in the nanoscience and nanotechnology curriculum (NSTC)?

2) What are high school students and student science teachers' attitudes toward participating in the NSTC?

Consequently, the discussion is divided into two main sections as follows.

5.1 High school students and student science teachers' understanding after participated in the NSTC

The results reveal that the activities in the NSTC help the students understand nanoscience and nanotechnology (NST) easily, expand their views about NST as being important to their currents or futures, and encourage them to apply science concepts in nanotechnology contexts. These positive results may be originated from these reasons.

For high school students and, even for, students science teachers, NST embed many exciting properties or phenomena showed by many activities in the NSTC that can stimulate their interest in learning science. In addition, when learning with the activities in the NSTC, the students are given opportunities to learn with *active learning with inquiry* that can lead them to deeper understanding about NST. including both conceptual and procedural knowledge. The literature suggests an active learning as helpful in developing student science learning achievement. In addition, a combination of inquiry with simple nanomaterials being commercially available for the students (such as nitinol wire and robot arms, nano-shirts and the lotus effect) is an important connections between basic concepts of nanoscience and their applications (nanotechnology). It is a link between science and technology. This allows the students to see science for themselves, and then learn and understand the theoretical explanation of what they see (Orgill and Crippen, 2009; Ban and Kocijancic, 2011). However, there are other effective teaching approaches that can be used in the curriculum for teaching NST such as context-based, problem-based, and project-based learning (O'Connor & Hayden, 2008).

In addition, this study shows that NST can be integrated into Thai science curriculum. Or, the NSTC is in alignment with Thai science curriculum standards. This research suggests that merging NST content into Thai science curriculum is practical and fruitful for both high school and undergraduate levels. The use of new and exciting NST applications shows a success with both groups. However, those NST applications must be simplify for high school students about how they work and relate to high school science concepts. High school students tend to resist when introducing too deep concepts about atomic structures of nanomaterials. The balance between micro structure and related macro properties should be carefully taken into account. Then, new information about NST will be easier to understand for high school students. As Ellis, Zenner and Crone (2005) discussed, when the more connections being made between the NST content and its related science concepts, high school students will feel more related to NST curriculum.

The NSTC utilizes ideas from Krajcik, McNeil and Reiser (2008) and Blumenfeld et al. (2006) in selection of content, setting learning goals and selecting learning. This study shows the possibility of setting NST as learning goals for Thai student and selecting materials to motivate students. However, some considerations need attention from NST curriculum developer, that is, a) defining basic prior knowledge about NST that students must attain before learning in the NSTC (Hingant and Albe, 2010), b) simplifying NST concepts for high school students, c) making difficult NST concepts be concrete, and d) searching and preparing nano-materials as products from nanotechnology.

In sum, the NSTC is useful and helpful for both high school students and student science teachers to understand the basic science concepts of NST and have positive attitudes toward learning science. Moreover, it may help students live happily with NST, and, maybe, to further their study in a NST related fields. So, it is worthwhile to integrate NST into existing science curriculum.

5.2 High school students and student science teachers' attitudes toward the NSTC

The activities in the NSTC show positive effect on the students' attitudes toward learning science. Such positive attitudes may be originated from new and exciting characteristics of NST phenomena. In addition, the students may gradually realize the relationship between NST and their daily lives until, at final, they fully realize that NST affects their lives. The responses for the attitude survey shows that the activities in the NSTC based on collaborative active learning with inquiry affect student engagement in learning. Some students are impressed after they had compared their prior knowledge with what they gained from the NSTC. They reflected that they learned so much and, subsequently, felt positive to the NSTC.

However, some students critique some activities in the NSTC. They are: a) giving more time to do experiments, b) adding more interesting topics and exciting activities, c) adding outdoor activities, d) explaining more in some difficult topics, and e) deleting some boring questions. These are things NSTC developers should consider for the revision of the NSTC in the future. In particular to high school students, for example, they face difficulty to understand how particular nano-materials work because of their limitation of basic knowledge in NST.

In addition, there are many interesting questions left by the students such as "How do we know which products are nano or not? What *will happen* if there is no nanotechnology? What are the advantages and disadvantages of nanotechnology? How can nanotechnology improve the environment (e.g. pollution, alternative energy)? These questions can be added as challenging questions for the next revision of the NSTC.

5.3 Conclusions and Implications

The NSTC based on active learning with inquiry is effective in enhancing high school students' and undergraduate student teachers' understanding about NST and positive attitudes toward learning science. The activities included in the NSTC are adapted from University of Wisconsin-Madison Materials Research Science and Engineering Center (UW MRSEC) that uses examples of nanotechnology and advanced materials to explore fundamental science and engineering concepts at the college and high school levels. Although many activities are adapted from aboard, this study shows an alternative way to integrate NST content into existing Thai high school and undergraduate curriculum. However, the nature of active learning with inquiry employed in the NSTC demands a considerable amount of extra time and effort from both science teachers and students. In this case, the advantages of utilizing the NSTC should be realized by, especially, science teachers. Hingant and Albe (2010) suggest two advantages for including NST into high school curriculum, that is, providing students a potential future career, and a tool to utilize NST in their everyday lives. Therefore, the NSTC should be widely conducted in order to promote NST knowledge in students or public audience in Thailand. The NSTC can be used to build human resource in NST development and will help to drive national strategies and policies for NST in ways that yield concrete and sustainable development.

Although the NSTC is found effective in many desirable ways, the implementation of the NSTC, or the revision of the NSTC to be better ones, to the larger population needs some considerations.

First, integrating NST content into existing science curriculum at the high school and undergraduate levels needs the cooperation from involved stakeholders such as curriculum developers, science teachers, school or university administrators, and science educators. This research study showed the success of NSTC in fostering student understanding of NST and attitude towards the NST learning. The framework of NSTC can be used and adapted to other science classroom as well. Also, the other NST topics should be considered to add into the existing NSTC to suit students with various backgrounds and interests.

Second, the science teacher professional development program must be designed to help science teachers effectively implement the NSTC in their own classrooms. Looking forward, effective teacher professional development may be the next key challenge for contributions of NST education in Thailand by developing materials, workshops and opportunities to practice teaching NST. Especially for teacher-centered teachers who want to use the NSTC, they must be trained about active learning with inquiry which is different from traditional instruction. Teachers must understand the new pedagogy and new roles and practice the student-centered pedagogy well before implementing the NSTC. For example, during the learning activities of NSTC, teachers play important roles such as guiding, giving feedback, challenging, explaining key concepts to help students construct their knowledge by themselves. Another is class atmosphere. It should be flexible and allow slow learners with more time, and guidance than fast learners.

Third, new pedagogies to support the integration of NST into science curriculum should be further explored in the science research community. Some topics, maybe, are the design and implementation of the NSTC for other levels of students, the design and implementation of the NST workshop for science teachers, the inclusion of other learning approaches with the NSTC, the effects on the NSTC on other variables, and so on.

Fourth, to put the NSTC into practice, the policy makers can support by launching the policy for NST education, and research at high school and undergraduate levels. and as well as primary school considering the research fund to design and develop innovation for education, science education in particular.

Fifth, the NSTC should be disseminated to a larger audience including both public and private sectors via numerous ways such as trainings, courses, websites, newsletter, research reports, conferences.

REFERENCES

Alford KJS, Calati F, Clarke A& Binks PN. "Creating a Spark for Australian Science Through Integrated Nanotechnology Studies at St. Helena Secondary College." *Journal of Nano Education*, 2009: 68-74.

Bénédicte Hingant and Virginie Albeb. "Nanosciences and nanotechnologies learning and teaching in secondary education: a review of literature." *Studies in Science Education* 46, no. 2 (2010): 121–152.

Berger R. "The Atomic Force Microscope: A Low-Cost Model." *The Physics Teacher* 40 (2002): 502-503.

Blonder Ron and Dinur Merav. "Teaching Nanotechnology Using Student-Centered Pedagogy for Increasing Students' Continuing Motivation ." *Journal of Nano Education*, 2001: 51-61.

Brazell JT, Sykes ECH, Deguzman PC, Subaran S, Patel S, El-Kouedi M. "Cost Effective Nanostructured Materials for the Undergraduate Lab: Nanotextured Aluminum Surfaces." *Journal of Nano Education*, 2009: 42-47.

Bryan LA, Daly S, Hutchinson K, Sederberg D, Benaissa F, Giordano N. *A Design-Based Approach to the Professional Development of Teachers in Nanoscale Science.* West Lafayette, IN: Purdue University , 2007.

Charles Xie and Hee-Sun Lee. "A visual approach to nanotechnology education." *The International Journal of Engineering Education* 28 (2012): 5.

Chih-Kuan L, Tsung-Tsong W, Pei-Ling L & Shihkuan H. "Establishing a K–12 Nanotechnology Program for Teacher Professional Development." *IEEE Transactions on Education.* 49 (2006): 141-146.

Choudhury J, Rawat K, Seetharaman G, Massiha G. " Initiating A Program In Nanotechnology Through A Structured Curriculum." *Proceedings of the 2003 IEEE International Conference on Microelectronic Systems Education*, 2003.

Chuankrerkkul, Nutthita. *Status of Nanotechnology Research and Educational Activities in Thailand* . Bangkok: Metallurgy and Materials Science Research Institute,Chulalongkorn University, 2008.

CIESE. *curriculum materials.* 2008. http://ciese.org/ (accessed January 11, 2013).

College S, Alford KJS, Calati F, Clarke A, Binks PN. "Creating a Spark for Australian Science Through Integrated Nanotechnology Studies at St. Helena." *Journal of Nano Education*, 2009: 68-74.

Dyehouse MA, Diefes-Dux HA, Bennett DE, Imbrie PK. "Development of an Instrument to Measure Undergraduates' Nanotechnology Awareness, Exposure, Motivation, and Knowledge." *J Sci Educ Technol* 17 (2008): 500-510.

Ernst, Jeremy V. " Nanotechnology Education: Contemporary Content and Approaches." *The journal of technology studies* 35 (2009): 1-6.

Hersam MC, Luna M, Light G. "Implementation of Interdisciplinary Group Learning and Peer Assessment in a Nanotechnology Engineering Course ." *Journal of Engineering Education,* 2004: 49-57.

James Trefil and Robert M. Hazen. *The sceinces an intregrated approach.* Edited by 4. George Mason University, 2004.

Jang-Long Lin ; Horng, L. ; Yu-Tai Shih ; Jong-Ching Wu ; Yu-Der Wen ; Chun-Chuan Chang ; Fu-Mei Lin. "Construction of concepts and proposition statements in high school nanotechnology curriculum." *Nanotechnology (IEEE-NANO), 2011 11th IEEE Conference on.* IEEE Conference Publications , 2001. 953-957.

Jones MG, Andre T, Kubasko D, Bokinsky A, Tretter T, Negishi A, et al. " Remote Atomic Force Microscopy of Microscopic Organisms: Technological Innovations for Hands-On Science with Middle and High School Students." *Science Education* 88, no. 1 (2004): 55-71.

Jones MG, Andre T, Superfine R, Taylor R. " Learning at the Nanoscale: The Impact of Students' Use of Remote Microscopy on Concepts of Viruses, Scale, and Microscopy." *Journal Of Research In Science Teaching* 40, no. 3 (2003): 3033-22.

Jones MG, Andre T, Superfine R, Taylor R. "Learning at the Nanoscale: The Impact of Students’ Use of Remote Microscopy on Concepts of Viruses, Scale, and Microscopy." *Journal Of Research In Science Teaching* 40, no. 3 (2003): 303-322.

Kerdcharoen T. *Nanotechnology In Thailand.* August 13, 2008. http://nano-in-Thailand.blogspot.com/2007/08/blog-post_13.html. (accessed July 2, 2012).

Krajcik, J., McNeill, K. L. & Reiser, B. "Learning-goals-driven design model: Curriculum materials that align with national standards and incorporate project-based pedagogy." *Science Education* 92, no. 1 (2008): 1-32.

Lu, Chow-Chin & Sung, Chia-Chi. *Effect of Nanotechnology Instructions on Senior High School Students.* Asia-Pacific Forum on Science Learning and Teaching, 2011.

Lyshevski SE, Andersen JD, Boedo S, Fuller L, Raffaelle R, Savakis A, et al. " Multidisciplinary Undergraduate Nano-Science: Engineering and Technology Course. ." *Nanotechnology2006 Sixth IEEE Conference.* 2006. 399-402.

Mahbub Uddin and A. Raj Chowdhury. " Integration of nanotechnology into the undergraduate engineering curriculum ." *International Conference on Engineering Education.* Oslo,Norway, 2001. 8B2-6-9.

MCOT. *Thailand aims for nanotech excellence.* September 21, 2012. http://www.mcot.net/cfcustom/cache_page/406610.html (accessed September 21, 2012).

Michael C, Jonathan G, Amy CP, Arthur BE, Cynthia GW, Thomas FK, & George CL. "Student-centered, Nanotechnology-enriched Introductory College Chemistry Courses for Engineering Students." *International Journal of Engineering Education* 18 (2002): 550-556.

Milo Koretsky, Danielle Amatore, Schoichi Kimura, Alexandre Yokochi. " Development of a Nanotechnology Curriculum at Oregon State." *American society for engineering education*, 2007.

Murriello S, Contier D, Knobel aM. " NanoAventura: An Interactive Exhibition on Nanoscience and Nanotechnology as an Educational Tool." *Journal of Nano Education,* 2009: 96-105.

Nanotec. *NANOTEC partners VEC to include nano in curriculum.* March 7, 2011. http://www.nanotec.or.th/en/?p=1811 (accessed march 30, 2012).

—. *Nanotechnology development in Thailand.* November 29, 2010. http://www.nanotec.or.th/en/?page_id=1016 (accessed September 24, 2012).

—. *research focus.* April 10, 2010. http://www.nanotec.or.th/en/?page_id=29 (accessed September 24, 2012).

NSF. " K-12 & Informal Nanoscale Science and Engineering Education (NSEE) in the U.S ." USA, 2005.

O’Connor C & Hayden H. "Contextualizing nanotechnology in chemistry education." *Chemical Education Research and Practice* 9 (2008): 35-42.

O’Neill, G. and McMahon, T. "Student-centred Learning: What does it mean for Students and Lecturers?" *All Ireland Society for Higher Education (AISHE).*, 2005.

Ong, E., Razdan, A., Garcia, A., Pizziconi, V., Ramakrishna, B. and Glauninger, W. "Interactive nano-visualization of materials over the internet." *Journal of Chemical Education,*, 2002: 1114-1115.

Planinsic G & Kovac J. "Nano goes to school: a teaching model of the atomic force microscope." *Physics Edu* 43, no. 1 (2008): 37-45.

Pornsinsirirak TN & Supaka N. *Nanotechnology Development in Thailand.* Pathumthani,Thailand: The National Nanotechnology Center, 2005.

Porter LA, Jr. "Chemical Nanotechnology: A Liberal Arts Approach to a Basic Course in Emerging Interdisciplinary Science and Technology." *Journal of Chemical Education.* 84, no. 2 (2007): 259-264.

Powers, S. E. & DeWaters, J. "Creating project-based learning experiences university-k-12 partnerships." *the American Society for Engineering Education Frontiers in Education Conference.* Savannah, GA, 2004. Session F3D.

Roco, MC. "Converging science and technology at the nanoscale: opportunities for education and training." *Nature Biotechnology* 21 (2003): 124-129.

Ryu CY. *Bringing Nanotechnology To The Classroom: Capturing High School Students' And Teachers' Nanotech Interest.* LosAngeles, USA.: 2nd US-Korea NanoForum, 2005.

Samet C. "A Capstone Course in Nanotechnology for Chemistry Majors." *Journal of Nano Education*, 2009: 15-21.

Semih Ozel & Yelda Ozel. " nanotechnology in education." *5th wseas / iasme international conference on engineering education (EE'08).* Heraklion, Greece, 2008.

Skonchai Chanunan,Manat Boonprakob, Piniti Ratananukul,Sirinoot Teanrungroj. *The Epistemic Platform for Science Learning with a Computer Game for High School Students in Learning Fundamental Nanoscience and Nanotechnology.* Bankok: Science Education Center, Srinakharinwirot University, 2001.

SRI. *NanoSense Curriculum Unit.* August 17, 2008. http://nanosense.org/activities/NanoPublicationInfo.pdf (accessed January 15, 2013).

SRI. *NanoSense Curriculum Series : Size Matters:Introduction to Nanoscience.* November 15, 2007. http://nanosense.org/activities/sizematters/ (accessed January 15, 2013).

Stevens S, Shin N, Delgado C, Cahill C, Yunker M & Krajcik J. " Fostering students' understanding of interdisciplinary science in a summer science camp." 2007.

Stevens S, Shin N, Delgado C, Krajcik J, Pellegrino J. "Using Learning Progressions to Inform Curriculum." *Instruction and Assessment Design* (University of Michigan), 2007.

Sullivan TS, Geiger MS, Keller JS, Klopcic JT, Peiris FC, Schumacher BW, et al. "Innovations in Nanoscience Education at Kenyon College." *IEEE Transactions* 51, no. 2 (2008): 234-241.

Susan J. Lea, David Stephensona,Juliette Troya. "Higher Education Students' Attitudes to Student-centred Learning: Beyond 'educational bulimia'?" *Studies in Higher Education* 28, no. 3 (2003): 321-334.

Tahan C, Leung R, Zenner GM, Ellison KD, Crone WC & Miller CA. "Nanotechnology and Society: A discussion-based undergraduate course." *American Journal of Physics* 75, no. 5 (2006): 443-448.

Tanthapanichakoon W. *An overview of nanotechnology in Thailand.* Pathumthani, Thailand: The National Nanotechnology Center, 2005.

Tanthapanichakoon W and Chaikittisilp W. "Nanotechnology Activities in Thailand: Present and Future Perspectives." *Journal of Metals*, 2003: 23-30.

Timothy A. Laubach, Lee A. Elizondo, Patrick J. McCann, and Shahryar Gilani,. "Quantum Dotting the “i” of Inquiry: A Guided Inquiry Approach to Teaching Nanotechnology." *The Physics Teacher* 48 (2010).

Tomasik JH, Jin S, J R, Hamers, Moore JW. " Design and Initial Evaluation of an Online Nanoscience Course for Teachers." *Journal of Nano Education*, 2009: 48-67.

Tretter T, Jones M.G , Andre T, Negishi A, & Minogue J. "Conceptual boundaries and distances: Students’ and experts’ concepts of the scale of scientific phenomena." *Journal of Research in Science Teaching*, 2006: 282-319.

Vinck, D. *Les nanotechnologies.* Paris: Le Cavalier Bleu., 2009.

Viriyavejakul, Chantana. *The effect of nanotechnology on education.* Bangkok: Department of Industrial Education, Faculty of Industrial Education,King Mongkut’s Institute of Technology Ladkrabang, 2008.

Wansom S, Mason TO, Hersam MC, Drane D, Light G, Cormia R. "A Rubric for Post-Secondary Degree Programs in Nanoscience and Nanotechnology: National Center for Learning and Teaching (NCLT) in Nanoscale Science and Engineering." 2006.

Wongchoosuk C, Unai S, Katanyukunanon K, Kerdcharoen T. . *Demonstration Apparatus Of Atomic Force Microscope For Nanoscience StudyThailand.* Bangkok,Thailand: Department of Physics and Center of Nanoscience and Nanotechnology,Faculty of Science, Mahidol University, n.d.

APPENDICSES

APPENDIX A
THE NANOSCIENCE AND NANOTECHNOLOGY LEARNING QUESTIONNAIRE (NSTLQ)

แบบสำรวจความคิดเห็นของครูผู้สอน
เรื่อง หลักสูตรความรู้พื้นฐานทางนาโนเทคโนโลยี

……

คำชี้แจง

แบบสอบถามชุดนี้จัดทำขึ้นตามโครงการวิจัยเรื่อง **การพัฒนาหลักสูตรความรู้พื้นฐานทางนาโนเทคโนโลยี** โดยมีจุดมุ่งหมายเพื่อสำรวจความคิดเห็นของท่านเกี่ยวกับหลักสูตรความรู้พื้นฐานทางนาโนเทคโนโลยี ซึ่งข้อมูลที่ได้รับจากท่านจะเป็นประโยชน์อย่างยิ่งต่อการพัฒนาหลักสูตรความรู้พื้นฐานทางนาโนเทคโนโลยีสำหรับผู้เรียนวิทยาศาสตร์ในประเทศไทยในอนาคต ในการนี้จึงใคร่ขอความกรุณาท่านให้ข้อมูลและแสดงความคิดเห็นของท่านโดยแท้จริง ทั้งนี้ ข้อมูลของท่านจะถูกเก็บไว้เป็นความลับและใช้ประโยชน์เพื่อการวิจัยเท่านั้น

แบบสอบถามนี้ประกอบด้วย 3 ส่วน ดังนี้

ส่วนที่ 1 ข้อมูลทั่วไปของผู้ตอบแบบสอบถาม

ส่วนที่ 2 เนื้อหาด้านนาโนเทคโนโลยี

ส่วนที่ 3 ความคิดเห็นเพิ่มเติม

ส่วนที่ 1 ข้อมูลทั่วไปของผู้ตอบแบบสอบถาม

คำชี้แจง โปรดทำเครื่องหมาย ✓ ในช่อง ☐ ที่ตรงกับความต้องการของท่าน

1. เพศ ☐ ชาย ☐ หญิง

2. อายุ

☐ ต่ำกว่า 26 ปี ☐ 26 - 30 ปี ☐ 31 - 35 ปี ☐ 36 - 40 ปี

☐ 41 - 45 ปี ☐ 46 - 50 ปี ☐ 51 - 55 ปี ☐ 56 ปีขึ้นไป

3. ระดับการศึกษาสูงสุด

☐ ปริญญาตรี ☐ ปริญญาโท ☐ ปริญญาเอก ☐ อื่นๆ
(ระบุ……….....…..…)

4. ช่วงชั้นที่สอน

☐ ช่วงชั้นที่ 4 (ม.4 - 6) ☐ ปริญญาตรี ☐ ปริญญาโท ☐ ปริญญาเอก

5. รายวิชาที่สอน

☐ ชีววิทยา ☐ เคมี ☐ ฟิสิกส์

☐ อื่นๆ (ระบุ……...…..…..…)

6. ประสบการณ์การสอนโดยทั่วไป (หากมีประสบการณ์การสอนวิทยาศาสตร์ด้วยขอให้ระบุในข้อ 3)

☐ ต่ำกว่า 6 ปี ☐ 6 - 10 ปี ☐ 11 - 15 ปี ☐ 16 - 20 ปี

☐ 21 - 25 ปี ☐ 26 - 30 ปี ☐ 30 ปีขึ้นไป

7. ประสบการณ์การสอนเฉพาะวิชาวิทยาศาสตร์

☐ ต่ำกว่า 6 ปี ☐ 6 - 10 ปี ☐ 11 - 15 ปี ☐ 16 - 20 ปี

☐ 21 - 25 ปี ☐ 26 - 30 ปี ☐ 30 ปีขึ้นไป

ส่วนที่ 2 เนื้อหาด้านนาโนเทคโนโลยี

คำชี้แจง โปรดทำเครื่องหมาย ✓ ในช่อง ☐ ที่ตรงกับความต้องการของท่าน

1. ท่านคิดว่า ตนเองมีความรู้ความเข้าใจเกี่ยวกับ**นาโนเทคโนโลยี** อยู่ในระดับใด

☐ ไม่มี ☐ น้อย ☐ ปานกลาง ☐ ดี ☐ ดีมาก

2. ท่านมีโอกาสเรียนรู้และพัฒนาความรู้ความเข้าใจเกี่ยวกับนาโนเทคโนโลยีจากแหล่งใดบ้าง (เลือกได้มากกว่าหนึ่งแหล่ง)

☐ หนังสือพิมพ์ ☐ วิทยุ/โทรทัศน์ ☐ อินเตอร์เน็ต ☐ ประชุม/สัมมนา

☐ อบรม ☐ ทำวิจัย ☐ อื่นๆ (ระบุ...)

3. ท่านคิดเห็นว่า ผู้เรียนของท่าน (นักเรียนระดับมัธยมศึกษาตอนปลาย / นักศึกษาระดับปริญญาตรี) ควรมีความรู้ความเข้าใจเกี่ยวกับนาโนเทคโนโลยี ในเรื่องใดบ้าง (เลือกได้มากกว่าหนึ่งคำตอบ)

☐ ความหมายของวิทยาศาสตร์นาโน และนาโนเทคโนโลยี

☐ ประวัติความเป็นมาของนาโนเทคโนโลยี

☐ ความสำคัญของนาโนเทคโนโลยี

☐ ความสัมพันธ์ของนาโนเทคโนโลยีกับศาสตร์อื่น ๆ

☐ ขนาดของอนุภาคระดับนาโนสเกล

☐ คุณสมบัติของวัตถุเมื่อมีการเปลี่ยนแปลงขนาดในระดับนาโน

☐ วิธีการศึกษาหรือเคลื่อนย้ายเพื่อเปลี่ยนโครงสร้างในระดับโมเลกุลหรืออะตอม

☐ หลักการทำงานของ Atomic Force Microscope (AFM) กับ Scanning Tunneling Microscope (STM)

☐ การพัฒนานาโนเทคโนโลยีกับวิทยาศาสตร์และสังคม

☐ การนำหลักการด้านวิทยาศาสตร์และวิศวกรรมศาสตร์มาพัฒนาความรู้ด้านนาโนเทคโนโลยี

☐ แนวทางในการค้นพบเทคโนโลยีใหม่

☐ อื่น ๆ โปรดระบุ..................………………………………………………………………………

4. จากข้อความ โปรดทำเครื่องหมาย ✓ ในช่องที่ตรงกับความคิดเห็นของท่านมากที่สุด

ข้อความ	**ระดับความคิดเห็น**				
	ไม่เห็นด้วยอย่างยิ่ง	ไม่เห็นด้วย	ไม่แน่ใจ	เห็นด้วย	เห็นด้วยอย่างยิ่ง
1. ความรู้พื้นฐานด้านนาโนเทคโนโลยีจำเป็นต่อผู้เรียนของท่านทุกคน					
2. ความรู้พื้นฐานด้านนาโนเทคโนโลยีจำเป็นต่อผู้เรียนของท่านที่เรียนในสาขาวิทยาศาสตร์เท่านั้น					
3. การจัดการเรียนรู้เกี่ยวกับหลักการพื้นฐานด้านนาโนเทคโนโลยี ควรส่งเสริมให้ผู้เรียนเกิดการพัฒนาในด้าน					
- กระบวนการคิด					
- กระบวนการสืบเสาะหาความรู้					
- กระบวนการแก้ปัญหา					
- การมีความรู้อันเป็นสากล รู้เท่าทันการเปลี่ยนแปลง และความเจริญก้าวหน้าทางวิทยาการ					
- การสร้างองค์ความรู้					
- เจตคติที่ดีต่อวิทยาศาสตร์และเทคโนโลยี					
- คุณธรรมจริยธรรม					
- ค่านิยมที่เหมาะสมเกี่ยวกับวิทยาศาสตร์ เทคโนโลยี และสังคม					
4. ควรจัดการอบรมเชิงปฏิบัติการเพื่อพัฒนาให้ผู้เรียนมีความรู้พื้นฐานด้านนาโนเทคโนโลยี					

5. ควรแทรกความรู้พื้นฐานด้านนาโนเทคโนโลยีเข้าไปในหลักสูตรวิทยาศาสตร์เดิมที่มีอยู่					
6. ควรจัดให้ความรู้พื้นฐานด้านนาโนเทคโนโลยีเป็นรายวิชาใหม่ในหลักสูตร					
7. ความรู้พื้นฐานด้านนาโนเทคโนโลยีจะส่งเสริมให้ผู้เรียนมีความรู้ ความเข้าใจในวิทยาศาสตร์พื้นฐานมากขึ้น					
8. การจัดการเรียนรู้เกี่ยวกับความรู้พื้นฐานด้านนาโนเทคโนโลยีควรมีการบูรณาการความรู้ความเข้าใจในชีววิทยา เคมี และฟิสิกส์					

5. ท่านคิดเห็นว่า ความรู้พื้นฐานด้านนาโนเทคโนโลยีสำหรับผู้เรียนควรสอดแทรกไว้ในรายวิชาใด (เลือกได้มากกว่าหนึ่งคำตอบ)

☐ ชีววิทยา ☐ ฟิสิกส์ ☐ เคมี ☐ วิทยาศาสตร์และเทคโนโลยี

☐ สิ่งแวดล้อม ☐ อื่นๆ โปรดระบุ..

6. ท่านคิดว่า การเรียนการสอนความรู้พื้นฐานด้านนาโนเทคโนโลยีเหมาะสมกับผู้เรียนในระดับใด (เลือกได้มากกว่าหนึ่งคำตอบ)

☐ ช่วงชั้นที่ 1 (ป.1 - 3) ☐ ช่วงชั้นที่ 2 (ป.4 - 6) ☐ ช่วงชั้นที่ 3 (ม.1 - 3) ☐ ช่วงชั้นที่ 4 (ม.4 - 6)

ปริญญาตรี

☐ ชั้นปีที่ 1 ☐ ชั้นปีที่ 2 ☐ ชั้นปีที่ 3 ☐ ชั้นปีที่ 4

ส่วนที่ 3 ความคิดเห็นเพิ่มเติม

1. ท่านคิดว่า ลักษณะของกิจกรรมการเรียนการสอน เรื่อง ความรู้พื้นฐานนาโนเทคโนโลยี ควรเป็นอย่างไร

....

....

....

....

....

....

2. ท่านคิดว่า เมื่อผู้เรียนได้เรียนรู้ เรื่อง ความรู้พื้นฐานนาโนเทคโนโลยี แล้ว ควรมีลักษณะเป็นอย่างไร

....

....

....

....

....

....

*** ขอขอบคุณที่กรุณาตอบแบบสอบถาม ***

APPENDIX B

AN SELF-ASSESSMENT QUESTIONNAIRE, AN ATTITUDE QUESTIONNAIRE

แบบสอบถามความคิดเห็นในกิจกรรม พื้นผิวนาโน (Nano Surface)

เพศ ○ **ชาย** ○ **หญิง**

อายุ ☐ 14 - 16 **ปี** ☐ 17 – 19 **ปี**
☐ 20 – 22 **ปี** ☐ 23 - 25 **ปี** ☐ **อื่นๆ**............

กรุณาแสดงความคิดเห็น ในกิจกรรม โดยทำเครื่องหมาย ✓ ในตาราง

รายการ	ระดับความคิดเห็น				
	ไม่เห็นด้วยอย่างยิ่ง	ไม่เห็นด้วย	ไม่แน่ใจ	เห็นด้วย	เห็นด้วยอย่างยิ่ง
คุณรู้สึกอยากมีส่วนร่วมกิจกรรมเกี่ยวกับ **พื้นผิวนาโน**					
เนื้อหาและขั้นตอนการทำกิจกรรมทำได้ง่ายและชัดเจน					
คุณคิดว่าแต่ละ กิจกรรม **พื้นผิวนาโน** นี้มีความเหมาะสม ในการเรียนการสอนเนื้อหา นาโนเทคโนโลยี					
คุณคิดว่ากิจกรรม**พื้นผิวนาโน**ช่วยให้เข้าใจเกี่ยวกับนาโนเทคโนโลยีมากขึ้น					

คุณต้องการให้นำกิจกรรม **พื้นผิวนาโน** เข้ามาสอนในห้องเรียนจริง					
คุณคิดว่ากิจกรรม **พื้นผิวนาโน** ช่วยให้มีความเข้าใจเกี่ยวกับลักษณะพื้นผิวของวัสดุที่ต่างกันจะมีคุณสมบัติทางกายภาพต่างกัน มากขึ้น					
คุณคิดว่ากิจกรรม**พื้นผิวนาโน**ช่วยให้เข้าใจหลักการทำงานของนาโนเทคโนโลยีที่นำมาใช้กับอุตสาหกรรมด้านเส้นใยนาโน มากขึ้น					
คุณสามารถนำความรู้จากกิจกรรมนี้ไปใช้ชีวิตประจำวันได้					

กรุณาเขียนแสดงความคิดเห็น

1. ท่านได้เรียนรู้สิ่งใดบ้างจากกิจกรรมพื้นผิวนาโน

....

....

2. ท่านอยากเรียนรู้หรือมีข้อสงสัยอะไรบ้างจากการทำกิจกรรมพื้นผิวนาโน

....

....

3. ท่านรู้สึกอย่างไรต่อกิจกรรมเรื่อง พื้นผิวนาโน

....

....

4. ข้อเสนอแนะ ในการพัฒนากิจกรรมให้ดีขึ้นอย่างไร

....

....

5. บอกประโยชน์ ที่ได้รับ จากการเข้าร่วมกิจกรรม พื้นผิวนาโน

....

....

APPENDIX C

AN QUESTIONNAIRE OF OVERALL REFLECTION ABOUT NSTC

กรุณาเขียนแสดงความคิดเห็นภาพรวมของกิจกรรมนาโน

1. ท่านได้เรียนรู้สิ่งใดบ้างจากกิจกรรมนาโนทั้งหมด

………

………

………

………

………

………

2. ท่านอยากเรียนรู้หรือมีข้อสงสัยอะไรบ้างจากการทำกิจกรรมนาโนทั้งหมด

………

………

………

………

………

………

3. ท่านรู้สึกอย่างไรต่อกิจกรรมเรื่องนาโนทั้งหมด

………

………

………

4. บอกประโยชน์ ที่ได้รับ จากการเข้าร่วมกิจกรรมนาโนทั้งหมด

…….

…….

……

…….

…….

……

5. จงบอกความจำเป็น หรือความสำคัญ ของนาโนเทคโนโลยีที่มีต่อหลักสูตรระดับปริญญาตรี

…….

…….

……

…….

…….

……

BIOGRAPHY

NAME	Miss Choojit Sarapak
DATE OF BIRTH	March 30 1979
PLACE OF BIRTH	Ubon Ratchathanee, Thailand
INSTITUTIONS ATTENDED	Surindra Rajabaht University, 1997-2000 Bachelor of Physics Chiang Mai University, 2000-2002 Master of Science Education (physics) Mahidol University, 2008-2012 Doctor of Philosophy (Science and Technology Eduaction)
RESEARCH GRANTS	The Commission on Higher Education
HOME ADDRESS	Surindra Rajabaht University Muang, Surin,3200 Email:sinesuay@hotmail.com
EMPLOYMENT ADDRESS	The faculty of science and technology Surindra Rajabaht University Muang, Surin,3200 Email:sinesuay@hotmail.com