Effect of nanotechnology instructions on senior high school students

Chow-Chin LU
Department of Science Education,
National Taipei University of Education, TAIWAN.
Email: luchowch@tea.ntue.edu.tw

And

Chia-Chi SUNG
Department of Engineering Science and Ocean Engineering,
National Taiwan University, TAIWAN.
Email: ccsung@ntu.edu.tw

Received 30 Oct., 2011
Revised 24 Dec., 2011

Contents

Abstract

In this research, we cooperate with senior high school teachers to understand current nanotechnology model of senior high school nanotechnology curriculum in Taiwan. Then design senior high school nanotechnology (nano-tech) curriculum to teach 503 senior high school students. After teaching the nano-tech curriculum we use the "Nanotechnology problem situation questionnaire" to measurement their learning.

The results showed: 1. Senior high school nanotechnology curriculum tends to introduce nanotechnology phenomenon we meet in daily life to students, the teachers explain which science lesson related to the curriculum and sum up the nanotechnology principle of the nanotechnology product in the end. 2. We receive 453 valid nanotechnology problem situation questionnaires (recoveries about 90.1%). Analyze the questionnaires, we found out around 17.89~27.59% of senior high school students can answer the contexts they learn in the nano-tech curriculum lesson, but the concept is incomplete; the other 43.26% to 53.99% students have alternative conceptions, they use their own experiences from daily life to finish the questionnaires which might be incorrect. 3. Some of the students have inveterate alternative concept which senior high school teacher thinks these alternative concepts might change when teacher conduct students to join a nano-tech science fair competition. In the competition, student needs to do the experiment and presentation all by themselves which can establish the right nano-tech concept for them. 4. Collecting all kinds of students' answers in the questionnaires, we can analyze their alternative conceptions to compile senior high school nanotechnology

conception diagnostic test, which can do a comprehensive test and use it as designing nano-science curriculum reference documents.

Keywords: Senior high school nanotechnology curriculum, Nanotechnology problem situation questionnaire, Alternative conception.

Introduction

Rationale and Importance of this study

Nano vitally interrelate with our daily life, and "Nanotechnology" is the power of new industrial in 21th century which gives impetus to county industrial and competitive. Thus, education of knowing nanotechnology knowledge is a pressing matter of the moment. In Taiwan, the government has promoted "National Science and Technology Program for Nano-science and Nanotechnology" around six years and still continuing. It is expected that it can become the main program of nanotechnology in Taiwan. "Nanotechnology Human Resource Development (NHRD) Program" is a program under the main program of "National Science and Technology Program for Nanoscience and Nanotechnology". In NHRD program, the aim is to cultivate a population as followed: (1) Leadership or implementation of nanotechnology; (2) the cognitive potential of nanotechnology, and become the manpower of industry and commercialization (Taiwan Ministry of Education, 2009). The government planned to extend the knowledge of "nanotechnology" down to K-12 grades education, and hope that the impetus to nanotechnology curriculum in senior high school in Taiwan can speed up the nanotechnology literacy of senior high school students, and promote the development of nanotechnology industry (Lu, Chang, & Sung, 2010).

In Taiwan, the senior high school nanotechnology curriculum outlines only introduce basic and little information about nanotechnology which can't conjunct with the original teaching materials (Lu, et al., 2010). Most of the senior high school teachers only heard about some nanotechnology concept terms, but not knowing the definition about it. These teachers also have doubts about the meanings, character and function of some nano-tech article (Lu & Sung, 2010). Our goal is to educate the population and pass on the knowledge to the qualified people to meet the needs of the country. Lu and Sung (2010) not only completed the nanotechnology expert concept map of senior high school but also transformed expert concept map into declarative knowledge statement, and developed

nanotechnology problem situation questionnaires. By using these senior high school nanotechnology expert concepts map, information of the declarative knowledge statements can be used to develop senior high school nanotechnology curriculum, which is an extension of senior high school student's teaching materials. Also we can use the nanotechnology problem situation questionnaires to examine the effectiveness of their learning and refine senior high school nanotechnology curriculum in the future. As a result, cultivate more nanotechnology talents, and develop more products of nanotechnology.

Research Objective

In this research, we cooperate with senior high school teachers to design a "senior high school nanotechnology curriculum", and then make an experimental teaching. After the teaching, we use "nanotechnology problem situation questionnaire" to examine what senior high school student have had learned in this lesson and supply the data to NHRD program and senior high school teachers for reference.

In the research, we inquire into 2 questions:

First, How to design a "senior high school nanotechnology curriculum" and make the experimental teaching?

Second, which level has senior high school student's conceptual development of nanotechnology?

Literature review

Senior High School Teaching Conception of Nanotechnology

Nanometer (nm) is the hottest noun in the 21 century. A nanometer, which we can't see with eyes and touch with hands, is equivalent billions of a meter under high resolution microscopy techniques. There is a lot of nano phenomena exist in nature, like gecko effect, nanotechnology magnetic navigation, photonic crystals, and moth eye effect etc. The most famous is the "Lotus effect." For example when water droplet drops on the lotus leaf, instead of spread out the droplets, it gathers together. The secret of why lotus leaf surface can gather the droplets is because the surface of lotus leaf has nano composition villus on it which makes the contact angle between water and leaf greater than 120 degrees. Therefore, when the leaf tilts a little, the droplets will roll away from the leaf surface and bring dirty dust away (Su,

2003). The origin concept of "Biological compass" is that scientist found nano-magnetic particles in some of the organism. These organisms can recognise the direction under the help of its nano-magnetic particles and geomagnetic field and can be used as a navigation system (Lu, &Sung, 2010). Another nano phenomenon "Nano Photocatalyst" comes from observing scales on butterfly wings. The scales are periodic structures and have around 10 to 12 layer thick. These nano-size periodic structures are the reason why butterflies can have dazzling color on their wings. Nano Photocatalyst is a periodic structure material that can interact with light, as the example in optical fiber and optical waveguide (Drane, Swarat, Light, Hersam, & Mason, 2009). We inquire into some nano photocatalyst product and found its titanium dioxide (TiO2) material which will produce electron will react with water and oxygen. When generates reactive hydroxyl radicals (OH-), peroxynitrite root Radical (HO2-) and superoxide ion radicals (O2-) react with water and oxygen, the electron hole will illuminated. These free radicals have the ability to decompose organic compounds.(Lu, et al., 2010) Gecko effect is also a nano phenomenon, which starts form watching gecko walking on the ceiling. Millions of spatula tipped setae on gecko footpads have spatula-like structures tiny cilium at the pointed end of the toes. Each seta provides a little attractive force, adding millions of them allow the attractive forces adsorb 120 kilogram on the surface (Lee, Lee, & Messersmith, 2007). In addition, there are a lot of nanotechnology products; for example, target drugs for cancer therapy is using gold nanoparticles to target organs and then kill the cancer cell to attain the effect of therapy with heat treatment (Xue, Lu, Wu, & Zeng, 2008).

The nanotechnology declarative knowledge statements and the teaching standards

Nanotechnology expert concept map of senior high school shows the declarative knowledge statements:

1. The definition of nanotechnology: Nanotechnology is define as using ways to combine materials, compositions, structures in between 1-100 nm, and emerge into new features and phenomena.
2. Natural phenomena: For example, the setae spatula on gecko's feet is a kind nano structure, which can form into van der Waals force and enhance the force between the surfaces it contacts.
3. Nanotechnology products: For example, we use hydrophobic of lotus effect to make cloth that is anti-pollution such as nano-necktie.

4. Skills development: Using barker ball to coat target drugs and the functional group on barker ball surface will be acidulated or alkalized, which is ease to pass though gastrointestinal and find the main organ that need to be treated.
5. Affective attitude: For example, we should pay attention to new types of pollutants, which is produced by new nanotechnology product and might cause lung disease if we inhale it (Lu & Sung, 2010).

Methodology

Research Design

This research is a part of "Nanotechnology student's understanding conceptions and effect factor of K-12 students in Taiwan" of the National Science Council. In this research, we invited six senior high school teachers and two nano-tech experts to join the focus grouping interview, which convene once a month, and discuss about the project. First, six senior high school teachers, who are familiar with nanotechnology teaching materials, design the "senior high school nanotechnology curriculum" together, based on the "Nanotechnology declarative knowledge statements and the teaching standards". The nano-tech teaching concept is settled by researcher and the high school teachers turned the concept, into a high school nano-tech curriculum, which includes descriptions of nano-tech phenomenon and nano-tech product. The teaching method like nano-science project camp (project-based learning), mix nano-tech curriculum into normal science class, thematic teaching, teaching the gifted education students, visited nano-tech lab etc… are the teaching methods senior high school teachers adopted in the research. Then, these teachers teach the nanotechnology lesson to twelve classes. After the lesson, we examine these students with "nanotechnology problem situation questionnaire" . Each student has 100 minutes to finish the questionnaires. Then, we use situational focus grouping interview to ask the students about their answers of the nano-tech concept and use these answer to lay down a criterion of the entire students and analyze the percentage of their correctness conception as well as the alternative conception. Finally, we discuss and analyze the alternative conception, according to the alternative conception category(Lu, 2003), which focuses on the guessing pattern, cognitive incorrect pattern, and answer correctly but incompletely pattern. In the end, we examine the matter from senior high school angles to analyze relation between high school nano-tech curriculum and high school student's nano-tech concept.

Research Instrument

In this research, we use "Nanotechnology Problem Situation Questionnaire(NPSQ)", which was designed by Lu and Sung (2010) to examine the senior high school students' learning on nanotechnology conception, which contained 17 proposition situations. First, we ask students to read the "proposition situation" and then answer one to three open-ended questions.

Samples

This study has chosen 503 senior high school students (12 classes) as sample. Students choosed from nanotechnology teaching schools, which join the NHRD program in Northern Taiwan. We choose 12 classes from 10 grades to 12 grades; all of them are participated this study.

Data Collection and Analysis

Qualitative data

At first, analyze how senior high school teachers design senior high school nanotechnology curriculum. Then the researcher observes in class to collect and analysis how teachers guide students to learn nanotechnology and sum up the science conception of nanotechnology.

Quantitative data

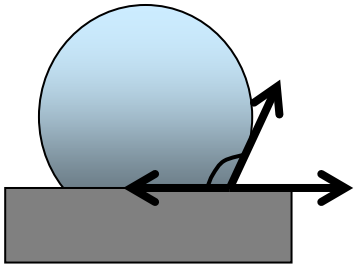
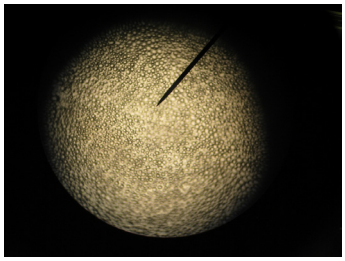
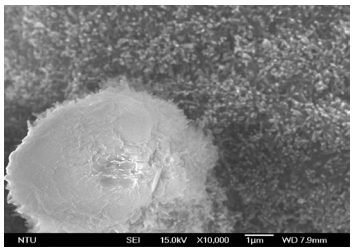
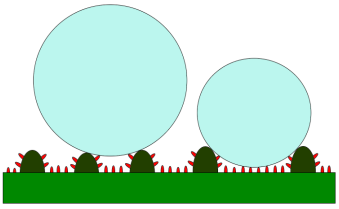
Collect answers from "nanotechnology problem situation questionnaire" and then classify as well as analysis the frequency of their answers to verify whether it correspond to the qualitative information. Analysis nanotechnology conceptions: Classify conception into correct conception, and alternative conception (guessing pattern, cognitive incorrect pattern, and answer correctly, but incompletely pattern). In order to ensure the reliability of the data, the analysis of these data were conducted by two nanotechnology university professors and six experienced senior high school science teachers independently, using a constant comparison between the data sources for each student and an established rubric. We then met and discussed our judgments to reach consensus on the category of nanotechnology concepts and calculated the proportion of each correct conception and alternative conception.

Results and discussion

Senior high school teacher's nanotechnology curriculum design

Senior high school teachers introduce nanotechnology phenomenon and nanotechnology technology products of daily life to students, and then extend the nanotechnology conception from science teaching materials which are mentioned in some science textbooks. In the end, students sum up what they have learned and put these nanotechnology products science concepts or principles in order. For example, Lotus effect curriculum was designed as Figure 1.

1. A lotus leaf can have a contact angle which is close to 90 degrees, making it hydrophobic, and extremely hydrophobic with a contact angle larger than 140 degrees (Figure 1a).
2. Spread glue on the lotus leaf surface to form a thin membrane (Figure 1b).
3. Use the microscope to take a micro-observation and found out that lotus leaf surface is covered with waxy crystals (Figure 1c).
4. Use the scanning electron microscope (SEM) to take a micro-observation and found that lotus leaf surface has a fine structure. Air can be trapped in fine structures, and reduced the contact area between the water droplet and solid surface (Figure 1d).
5. Dirt particles are picked up by water droplets due to a complex micro- and nanoscopic architecture of the surface, which minimizes adhesion (Figure 1e).

 1a	 1a	 1b
 1c	 1c	 1d
 蓮葉表面結構示意圖 1d	 www.lotusan.de/lotusan/_01_home/index.jsp 1e	 www.youtube.com/watch?v=rAif7o8pc38 1e

According to the senior high school nanotechnology curriculum design, Table 1 shows the extended science teaching materials from the original senior high school science lesson, and compares with the nanotechnology curriculum, science concept or principle exposition.

Table 1. Senior high school science extended lesson and nanotechnology curriculum design exposition

Nanotechnology Products	Senior high school science extended lesson	Science concept or principle exposition
1. Nano Photocatalyst	Chemicals I, II: Materials in daily life 5-3 Nano-tech materials	Nano Photocatalyst is made by photocatalyst TiO_2, produces electron and electron holes, which will react with water and oxygen to produce OH radical, peroxy radicals and superoxide radicals roots after lighting. These radicals are able to break down organic compounds and cause microbial decomposition to achieve antibacterial function.

2. Nano Car Spray	Physical III, IV: Surface tension 11-4 Contact angle	Hydrophobic principle of lotus effect is also used in making Nano Car Spray which is able to resist stains and let the water or dust not mount up on it.
3. Nano-target anti-cancer drugs	Chemicals I, II: Chemical batteries 4-4 Redox reaction	After nano-pharmaceutical, which carries target anti-cancer drugs, surface functional groups magnetized, nano-target anti-cancer drugs will follow the principle of nuclear magnetic resonance, adsorb cancer tissues (which have Fe_3O_2), and have medical effects.
4. Nano-disk	Physical V, VI：Light wave 3-2 Diffraction and double-slit interfere experiment	Nano-disk uses the gap structure to store information. Using quarter wavelength groove and tower of height to produce optical interference phenomena to read data. The gap structure size is on nanometer level and increases the density of recorded bits.
5. Nano sport shirts	Chemicals I, II: Materials in daily life 5-2 Clothing materials and chemistry	Clothing contains nano-holes that can exude perspiration and ventilating, often made into waterproof nano sports shirts.

From Table 1, we can find that senior high school teachers wish to bring out the nanotechnology science conception from science teaching materials that are relative to the ordinary lesson or extend from teaching materials, for example, when talking about the contact angle of surface tension, teachers let senior high school students measure the contact angle of lotus microvilli and water droplets. Students found that the angles are greater than 140 degrees, which can improve the water droplets are arising by microvilli and emerging from hydrophobic. So, they observe water and dirt that can't stick on it, but they can resist stains and drainage.

Senior high school student's nanotechnology-related conception development

We receive 453 valid nanotechnology problems for situational questionnaire answers; the questionnaire's recovery is 90.1%. We gather students' nanotechnology problem for situational questionnaire answers and analyze the correctness, alternative conception and the frequency of the alternative conception, which arrange as Table 2 (nanotechnology phenomenon) and Table 3 (nanotechnology technology products of daily life).

Table 2. Classify and analyze NPSQ answers of nanotechnology phenomenon

Nanotechnology problem situation questionnaire	Main alternative conception "Guessing pattern" (Percentage, Person)	Alternative conception "Cognitive incorrect pattern" (Percentage, Person)	Answer correctly, but incompletely(Cognitive incomplete pattern) (Percentage, Person)
1. Why are the nano-size waxy crystals on the surface of lotus can let water turn into droplets?	The villus on the science surface has smaller volume of water droplets, which prevent the water from penetrating (23.39%, 106 people)	The density of the villus will let the water not attach the surface and format into water droplets (22.97%, 104 people)	The villus can reduce the water that contact on the lotus surface (26.05%, 118 people)
2. What's the relation between geckos can walk on the wall without falling off and the gecko's valve on its toe?	The valve bristle on gecko's toe has a barbed that can increase the adsorption (22.08%, 100 people)	The valve bristle can increase the friction (23.39% , 106 people)	Because the spatula is on the valve which makes the effect (25.16%, 114 people)
3. What do living things that can identify directions have to do with the magnetic particles in the organisms?	The older living beings will teach younger ones to learn how to identify directions (21.41%, 97 people)	Because organisms have magnetic particles in their bodies (21.63%, 98 people)	Magnetic particles are able to identify the directions from magnetic effects (24.28%, 110 people)

4. What does the periodic nano-size photocatalyst scales on butterflies have to do with its color on the wing?	Because the angle of the lights cames in differently (22.30%, 101 people)	The nano-size photocatalyst can reflect different colors (26.27%, 119 people)	The nano-size photocatalyst has different angles that can reflect different colors of light (24.28%, 110 people)
5. What is the main reason that some of the moths have black eyes?	The cilium in moth's eyes is black (21.63%, 98 people)	Moth's eyes have cilium row tighter which can absorb lots of colors (24.39%, 105 people)	The nano cilium on moth's eyes can't reflect light (22.95%, 104 people)

Table 2 shows that after senior high school students learn nanotechnology phenomenon curriculum, around 20% to 25% can understand the science principle of nanotechnology phenomenon, but still can't answer the questionnaires completely. Most of the students can comprehend the lotus effect, because high school teachers tend to use pictures to explain nano-tech phenomenon, and do the lotus effect experiment to make students understand the lotus effect better. High school teachers consider that bring the nano-tech curriculum in the normal science lesson can extend students' learning, but would also cause lots of time pressures to the teachers. Some of the teachers conduct a science nano-tech camp and use a tematic teaching method to teach students. The lessons focus on a specific nano phenomenon like "nano photocatalyst". Teacher introduces nano photocatalyst and observes the phenomenon by experiment, then shifts to introduce and analyze the nano-tech product. These teaching methods can give more clearly conceptions, but the disadvantage is that it only tells few of the nano-tech phenomenons, but not the entire nano-tech phenomenon. There are 60 senior high school students who attended the nano-tech science camp. On average, half of the students have incomplete nano-tech concepts, a quarter of students use the experience in daily life to guess the answers, the rest of them have wrong nano-tech cognitions. Some of them have alternative conceptions which are impossible to change, for example, Euploea butterfly will produce blue-violet color after shining the sun. Watching the phenomenon, students

think that the nano-size nano photocatalyst on butterfly scales will reflex different colors and let us see.

Table 3. Classify and analyze NPSQ answers of nanotechnology technology products of daily life

Nanotechnology problem situation questionnaire	Main alternative conception "Guessing pattern" (Percentage, Person)	Alternative conception "Cognitive incorrect pattern" (Percentage, Person)	Answer correctly, but incompletely(Cognitive incomplete pattern) (Percentage, Person)
1. Why can TiO_2 Nano photocatalyst be antibacterial?	Cause the mould can't get into TiO_2 Nano Photocatalyst, which keeps the mould outside and burns to death. (28.47%, 129 people)	Anti-bacterial effect resulting because of the chemical reaction (25.52%, 116 people)	TiO_2 light reaction will produce OH radical, and kill germs. (27.59%, 125 people)
2. Why can Nano Car Spray resistance to stains and drainage?	Nano Car Spray has small gaps which make water and dirt unable to attach. (23.39%, 106 people)	Nano Car Spray can have decontamination effect after lighting (23.39% , 106 people)	Nano Car Spray is hydrophobic (25.16%, 114 people)
3. Why can Nano-target anti-cancer drugs attack cancer cells by not harming the normal ones?	Nano-target anti-cancer drugs have nano-magnet (21.63%, 98 people)	Chemical properties of Nano-target anti-cancer drugs will directly attack cancer cells (21.63%, 98 people)	Nano-target anti-cancer drugs are attracted to cancer organ (19.86%, 90 people)
4. What is the principle of Nano-disk reservoir saving?	Reduce the size of object to increase the surface area of storage capacity (23.39%, 106 people)	Application of compression principles in order to increase memory capacity (22.97%, 104 people)	Reduce the volume of stored materials to increase the memory capacity (17.89%, 81 people)

5. Why can Nano-sport shirt exude perspiration and ventilating?	Nano-sports shirt has big nano-holes and it easily can ventilate (28.47%, 129 people)	Nano-sports shirt can exude perspiration easily (23.39%, 106 people)	Nano-sports shirt has small nano-holes and it can ventilate easily (23.40%, 106 people)

From Table 3, we can see that senior high school students can't express a complete answer even after learning nanotechnology technology products curriculum. Around 17.89~27.59% of students can just tell simple nano-science principle which we classify it as "Cognitive incomplete pattern", examples like TiO2 nano photocatalyst can be antibacterial because of TiO2 light reaction will produce OH radical, and kill germs. Others, around 21.63~28.47% of students who don't know the answers but guess through their life experiences, which we classify it as "Guessing pattern", belonging to alternative conception, example like Nano-target anti-cancer drugs can attack cancer cells without harming the normal ones because Nano-target anti-cancer drugs has nano-magnet. Around 21.63~25.52% of students have alternative conception which are inconsistent with scientifically acceptable ideas, which we classify it as "Cognitive incorrect pattern", example like TiO2 nano photocatalyst can be anti-bacterial effect resulting because of chemical reaction.

Discussion

Scientists predicted the microcosmic world will have the most shocking evolution. Recently, US, Japan, Europe, Korea and even China have invested large founds in the national nanotechnology curriculum design (Lee & Tang, 2006). The focus of the K-12 Nanotechnology Program was to provide teachers information about nanotechnology and to develop materials to inspire students to learn about advanced technology. At the same time, the Five Higher Education Regional Centers of NHRD Program, developing Nanotechnology human resources in higher education and undertaking crucial tasks of personnel training (Taiwan Ministry of Education, 2009). Tasks included establishing Nanotechnology interdisciplinary curriculum programs, conducting equipment operation and training, hosting conferences and contests, and setting up international exchange programs (Wu, 2007). To apply nanotechnology concepts in teaching plans, school is the best place to strengthen citizens to understand nanotechnology knowledge through curriculum. We must apply a series of education plans to improve senior high school students learning nanotechnology curriculum.

Why do senior high school teachers design the nanotechnology curriculum in senior high school into the phenomenon-mechanism structure? Because they find the students are interested in phenomenon of nanotechnology, like lotus effect, and the students want to know what makes it hydrophobic. Finally, they know nano car spray is made by using hydrophobic principle of lotus effect and is able to resist stains and let water or dust can not mount up on it. Why the senior high school students couldn't understand nanotechnology complementally? Interviewing senior high school teachers, they think nanotechnology curriculum is an informal curriculum; using camp activities time to teach, students might think it's nothing to do with final examination or college entrance examination, which causes the result that student do neither review or be willing to strengthen the knowledge.

Conclusion and Recommendation

Conclusion

Senior high school teachers used to introduce nanotechnology phenomenon which we meet in daily life to students first, they explain which science lesson is related to it and sum up the nanotechnology product's science concept or principle in the end. Senior high school teachers think that letting students see the function of what nanotechnology products can do is the way to provoke their interests, and that desire of learning. Extending curriculum from senior high school science can not only can review their old experiences, but also build the scaffold to guide their learning, which students can attain the inventive principles of nanotechnology products, and be able to promote the application.

We find that analyzing the nanotechnology problem situation questionnaire answers that only 17.89~27.59% of senior high school students can just answer simple nano-science principle, the other 43.26% to 53.99% of students have alternative conceptions. And some of the concepts are difficult to change. Students might explain the natural nano-tech phenomenon with their own opinion; for example, when asking the relationship between the organisms that can identify directions and the magnetic particles in their body, students immediately think of the organisms have geomagnetic fields in their body, and have that ability to point out the direct of north and south just like the compass. Nanotechnology curriculum is an informal curriculum, senior high school teachers need to spend extra time and prepare extra equipments for the students. The students learn the nanotechnology

course in the camp activities, they may hear some nanotechnology terms from TV or magazines, but they don't have enough time to inquire principle of nanotechnology or some alternative conceptions.

Recommendation

If senior high school students want to have more complete concepts of nanotechnology and nanotechnology cognitions, Educators must aware the importance of combining education with nanotechnology, and apply nanotechnology in the official curriculum and teaching activities. The official curriculum and science fair can activate students' interests, and then achieve the nanotechnology concept learning goal. For example, directing students to work on making nano-dye-sensitized solar cells (DSSCs) in their science project can let them understand that dye-sensitized impregnated in nano-TiO2 gel films, and become stepping-stone after illuminated. The excited electron jump from valence band to the conduction band, then the electric conduct in the graphite layer and formed into coupling cell. Because finishing a science project includes an oral presentation which makes them figure out the basic principle of this project and the science meaning of each step, and also makes senior high school students integrated learning.

Collecting all kinds of senior high school students' answers from nanotechnology problem situation questionnaire, we can analyze their alternative conceptions to compile senior high school nanotechnology conception diagnostic tests, which can do a comprehensive test and use it as designing nano-science curriculum reference documents, and help them to learn more information about nanotechnology.

Acknowledgments

We give many thanks to those who made the completion of this study possible, including the National Science Council Taiwan, R.O.C. (NSC98-2120-S-002-003-NM, NSC99-2120-S-002- 003-NM, NSC100-2120-S-002-002-NM) who funded and supported the entire research team and the teachers who participated in and observed the process. Appreciation to the 10-12 grade students for assisted this research in Northern Taiwan.

Implication for research and practice

This research suggests several possible implications for future research and practice. These implications pertain most directly to higher education institutions, faculty,

students and researchers. At a management level, this case study calls for effective policies to make balanced investments and increase funding in higher education programs that will provide resources needed to effectively implement the use, integration and diffusion of ICT. Following the design of this investigation, which was based on a small sample size, the researchers suggest larger studies based on a more widespread survey, which may also involve multiple case studies. These limitations need to be considered when evaluating the findings of this study as they raise the possibility that some differences in opinion may be more a function of research design and contextual factors than a result of any differences in higher education studies. As with many other case studies, the findings should not be regarded as definitive but as offering faculty, educators, researchers, planners and administrators a view of the authors' reality.

References

Bowles, K. (2004). Teaching nanotechnology in the senior high school curriculum: *A teacher's guide*. Retrieved April 30, 2011, from http://tntg.org/Teaching nanotechnology in the senior high school curriculum.

Drane, D., Swarat, S., Light, G., Hersam, M., and Mason, T. (2009). An evaluation of the efficacy and transferability of a nanoscience module. *Journal of Nano Education*, *1*(1), 8-14.

Lee, H., Lee, B. P., & Messersmith, P. B. (2007). A reversible wet/dry adhesive inspired by mussels and geckos.*Nature*, 448, 338-341.

Lee, S. C.& Tang, S. M. (2006). The Regulation of the Potential Risks to Nanotechnology in Taiwan. *Asian Journal of Management and Humanity Sciences*, *1*(2), 293-308.

Lu, C. C. (2003).The development of skills and relevant concepts in the operation of microscope for high and elementary school students in the northern area of Taiwan. *Journal of National Taipei Teachers College*,*16*(2), 161-186.

Lu, C. C., and Sung, C. C. (2010). Development of expert's conception and problem situation questionnaire in senior high school nanotechnology curriculum. *Journal of Educational Practice and Research*, *23*(1), 85-114.

Lu, C. C., Chang, H. C., & Sung, C. C. (2010, June, 28-July, 2). *Development of Expert conception in senior high school nanotechnology curriculum in Taiwan*. Paper presented at Scientific Committee of World Conference STE 2010, Tartu, Estonia.

Su, J. Z. (2003). *Lotus effect*. Retrieved April 24, 2005, from http://nano.nchc.gov.tw/dictionary /lotus_effect.html.

Taiwan Ministry of Education (2009). *Nanotechnology Human Resource Development Program*. Retrieved September, 21, 2008, from http://www.nano.edu.tw.

Wu, M. K. (2007). National Nanotechnology Program Development in Current Condition. *Natural Sciences Newsletter*, *19*(4), 146-149.

Xue, F. S., Lu, F., Wu, Z. M., & Zeng, D. M. (2008). Gold drop – nano particle test. *Taizhong: GB national network bookstore*, Taiwan.