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Integration of a Project-Based Learning Strategy with Laboratory Activity: A Case Study of a Nanotechnology Exploration Project*

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This paper proposes a sputtered deposition-based technology to develop a nanotechnology project into a laboratory activity. This technology can make nanotechnology more appealing to students by enhancing the attractiveness of engineering curricula. In laboratory activity, nanotechnology courses using a laboratory platform and physical vapor deposition implemented nanotechnology exploration projects enhance interest and offer sufficient knowledge to students. Such courses can help students to understand nanotechnology concepts and the applications of sputtered deposition-based systems. This nanotechnology exploration project in the form of a laboratory activity has been evaluated successfully based on the evaluation results and responses to questionnaires: students and experts rated the nanotechnology laboratory activity highly, with mean values of 4.093 and 4.263, respectively. As for the Cronbach's alpha coefficient of the nanotechnology laboratory activity, questionnaire results showed that the satisfaction levels of experts and students in this study were 0.953 and 0.947, respectively. These results demonstrate the excellent reliability of the survey's internal consistency. Furthermore, more than 78.34% of the students, those with scores over 80, found the laboratory activity learning in the nanotechnology exploration project to be very good or excellent. Moreover, the students obtained very good academic results.

Keywords: nanotechnology; laboratory activity; physical vapor deposition; statistical questionnaire

1. Introduction

Nanotechnology is not a traditional discipline, but rather a combination of disciplines, involving physics, chemistry, biology, mathematics, engineering and technology. Nanotechnology offers cutting-edge applications that will revolutionize the way that disease is detected and treated, the way the environment is monitored and protected, the way energy is produced and stored and the way crop production and food quality is improved. This technology will also be used to build complex structures as small as an electronic circuit or as large as an airplane. Nanotechnology is an essential topic in the current technological world and it has experienced an explosive growth in the last few years, which revolves around precursor materials, fabrication processes and characterization techniques, instrumentation and equipment, theoretical modeling and control and the design and integration of structures into devices and systems [1–2]. Nanotechnology has attracted much attention as a process for applying protective coatings in many engineering fields, such as semiconductors, optical devices, tribological functions, displays, decoration, solar power and medical technologies. In this process, surfaces generate functional layers by thermal spraying, hardening, physical vapor deposition, or other similar procedures that improve the surface properties and protect the materials from the environment. Among these, vacuum-coating techniques can be used to apply coatings that have superior surface properties compared with those made of any metal. Currently, magnetron sputtering is widely preferred for physical vapor deposition technology, due to its greater deposition efficiency and the reduction in the waste of materials. In addition, magnetron sputtering is a useful technique for multilayer deposition. This technique allows good control of deposition parameters during the deposition process [3–6]. Almost all types of materials, including metals, ceramics, polymers, and composites, can be deposited onto similar or dissimilar materials. In particular, zirconium nitride coatings deposited using magnetron sputtering technologies have been extensively used in a number of industries, since they can enhance substrate properties and improve surface qualities, for both attractiveness and durability. Accordingly, physical vapor deposition technology for use in nanotechnology is a widely used technique. Thus, this technology has attracted growing interest in engineering education.

Nanotechnology provides an excellent way of learning to look at the amazing opportunities that arise when various fields of science and engineering converge. Thousands of articles are published every year in the field with new technology emerging in both print and virtual formats. Most of the cited

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literature and current authors discussing nanotechnology state that adding nanoscale perspectives to teaching leads to a better fundamental understanding [7–11]. Sharing of similar concepts and courses in various disciplines and areas of relevance can promote broader accessibility to science and technology. However, not enough nanotechnology-based learning courses have been developed. Teaching of nanotechnology to undergraduates in science and engineering can make use of simulation-based and hands-on educational laboratories. Users of simulation have argued that nanotechnology experiments are delicate, limited in availability and expensive to set up and maintain. Therefore, knowledge concerning the best practices in nanoscale science education is limited and current educators are faced with fundamental questions as to the nature of nanotechnology and where it fits into the already crowded current curriculum. Conversely, lectures are supported by laboratory work, where students carry out experiments. This enables them to practically apply the knowledge they gain from the lecture. Meanwhile, several studies have highlighted the importance of making use of hands-on experience to integrate nanotechnology into the undergraduate curriculum and several examples have brought practical nanotechnology module fabrication into the undergraduate curriculum [13–18]. Accordingly, previous experiences with laboratory activity favor the introduction of hands-on nanotechnology modules as an important role in engineering education. In addition, the development of a course in nanotechnology using experimental instruments, such as magnetron sputtering modules in a laboratory has been favorably reviewed in courses with a significant number of practical activities, where the students could verify and practice all of the analytical concepts and methods learned in theoretical engineering courses.

Recently, nanotechnology subjects have greatly improved when classroom teaching is supported by adequate laboratory courses and experiments, following the 'learning by doing' paradigm, which provides students with a deeper understanding of theoretical lessons [19–20]. It is believed that developments in nanotechnology will likely change the traditional practices of design, analysis, simulation and manufacturing of new engineering products. Students prefer a nanotechnology module over those used in traditional courses. In other words, labs for nanotechnology modules are an important academic setting for engineering students and provide in-depth training in engineering education, as most graduate students majoring in science/engineering must conduct experiments in a lab. However, the means by which students understand the importance of what they are doing and why they are doing it, is for students to engage in learning so that they feel that their experimental work is valuable and worthy of their efforts. This is important in a lab, because cognitive engagement in learning has been reported to be a robust indicator of improved student achievement and behavior in engineering education. Moreover, researchers in the field of nanotechnology have noted, with alarm, the lack of systematic studies of the technology's effects on engineering learning outcomes. Accordingly, understanding the effects of the introduction of new technologies into education in the sciences, particularly into science laboratory experiences, requires carefully designed study.

This study gives emphasis to the valuable support for teaching nanotechnologies that zirconium nitride modules can provide, and to introduce a case study project conducting in laboratory activity in nanotechnology courses. Through the design of modules and procedures of nanotechnology activities, this project-based scenario can guide the students to participate in hands-on tasks, analysis and reflection, and promote the absorption of textbook knowledge as well as the understanding and application of training to analyze and solve problems [23–24, 26]. The laboratory activity in this hands-on project includes an integrated development environment for nanotechnology and nanotechnology activity driven programming for task scheduling. These components are then integrated by students when performing their projects at the Institute of Engineering Science and Technology at National Kaohsiung First University of Science and Technology. This provides the students with a mechanism to observe, collect, interpret and seek understanding of real-life situations, within the natural setting of the classroom. In this study, three procedures support the laboratory platform to provide students with the experience of actually creating and implementing a complete experimental manipulation program in nanotechnology modules.

First, the students glean and sort various data and then integrate the experimental nanotechnology module via project work. Secondly, the students operate a magnetron sputtering system and select control parameters. Finally, the course connects the nanotechnology module with magnetron sputtering system devices to produce an experimental nanotechnology course with a group of integrated learning modules focused on zirconium nitride thin films. Furthermore, this study effectively develops hands-on nanotechnology modules with magnetron sputtering fabrication for an undergraduate curriculum and offer hands-on experience by integrating nanotechnology activities for students. However, the main objective of the nanotechnology exploration project course was to contribute to the nanotechnology production skills of students in creating and trying out effective education activities for their future classrooms. In addition, the purpose of the study was to explore the planning, design, development, analysis and evaluation problems, and processes that the students encountered while implementing their nanotechnology projects in a laboratory-rich learning environment. The research questions for this study were as follows.

1. How did the students' perceptions on the process of project laboratory activity learning take place in a nanotechnology project?
2. To what extent did the nanotechnology learning integrated into the project work equip the students with the employability skills needed in a laboratory-rich learning environment?
3. How did assessment and feedback support the nanotechnology courses in the laboratory activities?

2. Literature review

Laboratory activity is one of the most important experiences for undergraduate students, because it allows them to observe and explore real-world applications of fundamental theories and to connect theory to practice by developing a deep understanding of theoretical lessons. Several investigators have highlighted the importance of using hands-on experience to integrate nanotechnology into the laboratory in undergraduate curricula [17–19].

For example, in a previous study, students employed their collective knowledge to use physical vapor deposition in nanotechnology to develop new modular experiments; pedagogical methods were also used to introduce undergraduates to the field of nanoscale research in the laboratory [3–6]. Laboratory instruction, particularly in science and engineering disciplines such as nanotechnology, can help students to develop experimental skills and the ability to work in teams. This type of instructions also helps students to learn to communicate effectively, learn from failure and be responsible for their own results. Practical operation and experience can only be provided to students by using real equipment such as an industrial physical vapor deposition system or nanotechnology devices. This equipment facilitates the introduction of systematic curricula, which can effectively assist students to reach a holistic and meaningful understanding with the application of a knowledge map and curriculum-integrated teaching.

Several authors have integrated hands-on physical vapor deposition system fabrication into the undergraduate curriculum at the Institute of Engineering Science and Technology at National Kaohsiung First University of Science and Technology, using a group of integrated learning modules focused on nanotechnology [3–6]. Marwan *et al.* introduced a nanotechnology discovery course enriched with some nanotechnology modules and hands-on nanotechnology experiments to undergraduate students at the University of New Mexico in 2008–2009. These projects are all in favor of introducing hands-on experimental nanotechnology modules [25]. Most of the cited literature has reported that adding laboratory courses in teaching can lead to better fundamental understanding of similar concepts for courses in various disciplines and areas of relevance, and broader accessibility to nanotechnology. As mentioned above, during laboratory activities in nanotechnology learning, to engage students with technology-enhanced learning experiences we must pay more attention to the processes, rather than the mere outcome of the technology use. In this study, experimental activity in an engineering laboratory is an important resource for students, because it provides alternative methods to resolve issues or dilemmas by designing, critiquing, and evaluating concrete products. This method embodies John Dewey's conception of 'learning by doing', as students are responsible for planning and implementing their ideas and solutions. It engages them to ask questions, search for information, brainstorms, design, and test alternative solutions. Activities like these could help students to better construct knowledge. However, real laboratories cannot be put together with simulated tools, especially in fields such as nanotechnology, in which the actual behavior and response of the real elements in the experiments is crucial.

In this study, the laboratory courses in the experimental nanotechnology modules cover fabrication, processing, structure, composition and examination of the physical and mechanical properties of nanomaterials. In addition to the in-class and hands-on nanotechnology modules in the laboratory activity, participating students were also asked to prepare a term paper discussing a specific application of nanotechnology modules. The term papers were submitted individually, covering topics such as optical, electrical, magnetic, chemical, mechanical and thermal properties in the engineering applications of nanotechnology. In addition, expert assessment, self-assessment and teacher assessment were used so that students and teachers could make modifications during the project in order to be as successful as possible [12, 21–22]. We evaluated the intermediate reports of each student team to help instructors to verify the evolution and originality of the work. The final evaluation was based on the complete documentation of the system and project findings in the laboratory activity for the nanotechnology course during the semester.

3. Research and design

3.1 Instructional design of laboratory activity

The laboratory activity emphasizes the development of products to create a learning situation. This is a comprehensive approach to classroom teaching and learning. This type of activity should be designed to engage students in investigations of authentic problems. The instructor designed the project-based courses using a laboratory activity so that students could construct their own knowledge and skill by experiencing real-life situations. Within this framework, students could analyze previous literature, create a plan, perform related research, and summarize and share new knowledge. In particular, students pursued solutions to non-trivial problems in nanotechnology by posing questions, carrying out investigation, finding artifacts, examining findings and receiving feedback. However, the instructors emphasized their desire to modify students' concepts through laboratory activities, instead of teaching specific knowledge in nanotechnology. The project-based laboratory activity course is an important part of the curriculum at the Department of Mechanical Engineering at National Kaohsiung First University of Science and Technology because it is the last course before graduation, and it aims to provide students with the skills of project-based activity production and evaluation. To successfully completing a nanotechnology project in a laboratory activity, students are required to perform the following steps.

1. Define nanotechnology subject problems and tasks.
2. Develop a strategy in nanotechnology.
3. Collect information about nanotechnology modules from pertinent literature.
4. Investigate a given situation and implement the proposed project of thin films.
5. Provide feedback and revise the proposed nanotechnology project.
6. Present the nanotechnology project in written and/or oral form.
7. Reflect upon the project findings and evaluate the nanotechnology work.

In this study, the laboratory activity in nanotechnology was conducted over an 18-week session as part of a three-credit course taken by third-year university students. There were 28 college students (2 female and 26 male, aged between 19 and 21) who undertook the procedures in the study. In the course of the project, students were assigned to seven groups and tasked to propose a plan to provide evidence of the memory phenomenon through the laboratory activity in the nanotechnology courses. Each group had a well-trained teaching assistant who was familiar with the nanotechnology course and physical vapor deposition technology. The teaching assistants helped to facilitate student learning in the laboratory activity. Each team selected a nanotechnology topic and studied the same topic throughout the semester. Furthermore, students were asked to interview experienced students and instructors who had already completed a laboratory activity in a nanotechnology course.

Table 1 shows the details of each step of the project according to a weekly schedule. The concepts were first explained to the students through a lecture and then detailed instruction for the project was given through the laboratory activity. The laboratory activity of the project is composed of five procedures: planning the learning tasks, exploring physical vapor deposition, presenting the project process and project product, and reflecting upon and evaluating the project findings. At the end of the laboratory activity, the students then received feedback from other groups and carried out the task, and other measures such as the attitude scale, accuracy test and evaluation for the nanotechnology activity were administered. They presented their final work in class as the final stage of the project.

3.2 Implementing the nanotechnology activity in a sputtering system

This section describes the magnetron sputtering system requirements of the zirconium nitride modules in the experimental nanotechnology courses. The theoretical background for sputtering deposition techniques is demonstrated and their uses explained from the viewpoint of studies on the sputtering phenomena, planar diode glow discharge, balanced and unbalanced magnetrons and thin film growth. They are being used to develop a wide range of advanced functional properties, including physical, chemical, electrical, electronic, magnetic, mechanical, wear-resistant and corrosion-resistant properties on the required substrate surface. The sputtering system is shown generically in Fig. 1. The sputtering equipment includes a magnetron sputtering system with a vacuum subsystem, a cooling subsystem, a sputtering chamber subsystem and a digital control subsystem that allows for monitoring of the quality or content of zirconium nitride modules, gathering and storage of product information and detailed analysis and trouble-shooting of the system. Furthermore, in the context of deploying a sputtering deposition-based system laboratory, this study focuses on the

Table 1. The detailed contents of the nanotechnology tasks

Laboratory Activity	Instructional items of laboratory activity	Time
Step 1: Plan the learning tasks	**Nanotechnology course design, problems and tasks** Students are able to: (1) conduct a nanotechnology project with depth and breadth, (2) clarify the goals of nanotechnology task, (3) discuss related subject issues with thin films in PVD, (4) discuss topic has shifted into the core theme (ZrN).	2 week
	Develop sputtering system modules Students are able to: (1) write project proposal documents, including the project objectives, production types, time schedule, learning content analysis, each group member's task, (2) discuss the project schedules with modules division of PVD systems.	3 week
Step 2: Explore the physical vapor deposition	**Research and collect information for physical vapor deposition** Students are able to: (1) collect the information relevant to the subject, and explain how to preprocess, (2) analyze further information, and retrieve the key information required for project for preparing for substrate and targets.	3 week
	Investigate and implement Students are able to: (1) go into lab to explore, (2) observe the frameworks of magnetron sputtering environment and record it, (3) discuss with the group members and use modules division information to understand system principle based on project's needs, (4) review the previous plan and the observed data and revise.	3 week
Step 3: Present the project process	**Provide process and analysis** Students are able to: (1) understand magnetron sputtering modules, (2) summarize all the information related with the task, (3) operate steps for sputtered nitride zirconium modules, (4) produce the nanotechnology ZrN productions, (5) analyze and examine properties of ZrN film including AFM, SEM, wear, hardness and XRD, etc	3 week
Step 4: Identify the project product	**Provide feedback and revise** Students are able to: (1) construct the depositions of thin films and sputtering principles, (2) summarize all the information related with the task, (3) examination of surface texture, structure feature and composition in zirconium nitride modules, (4) produce the nanotechnology ZrN productions, (5) present oral, report and review.	3 week
Step 5: Reflect up and evaluate the project findings	**Reflect up and evaluate** Students are able to (1) evaluate the products' qualities after they have done their projects, (2) do the reflective thinking, (3) present evaluation and assessment reports, (4) discuss about the overall courses	1 week

following three main issues: (1) from a technological perspective, adaptation of concepts and techniques in physical vapor deposition are explored for possible use in laboratory activities; and (2) from an educational perspective, teaching physical vapor deposition manipulation principles requires familiarizing students with mechanical and material engineering concepts and skills; (3) from a integrated perspective, nanotechnology modules in teaching and learning are analyzed for the properties of thin films and a statistical questionnaire is designed for the laboratory courses. In a lecture on sputtering systems, the students are taught how to sputter depositions in the vacuum-coating process.

3.3 Sputtering depositions in the laboratory activity curriculum

The most important part of the laboratory activity curriculum is the implementation of physical vapor deposition technology. In this study, magnetron sputtering processes include the creation of material vapors by evaporation, sputtering, or laser ablation, and their subsequent condensation onto a substrate, to form the nanotechnology film. This process

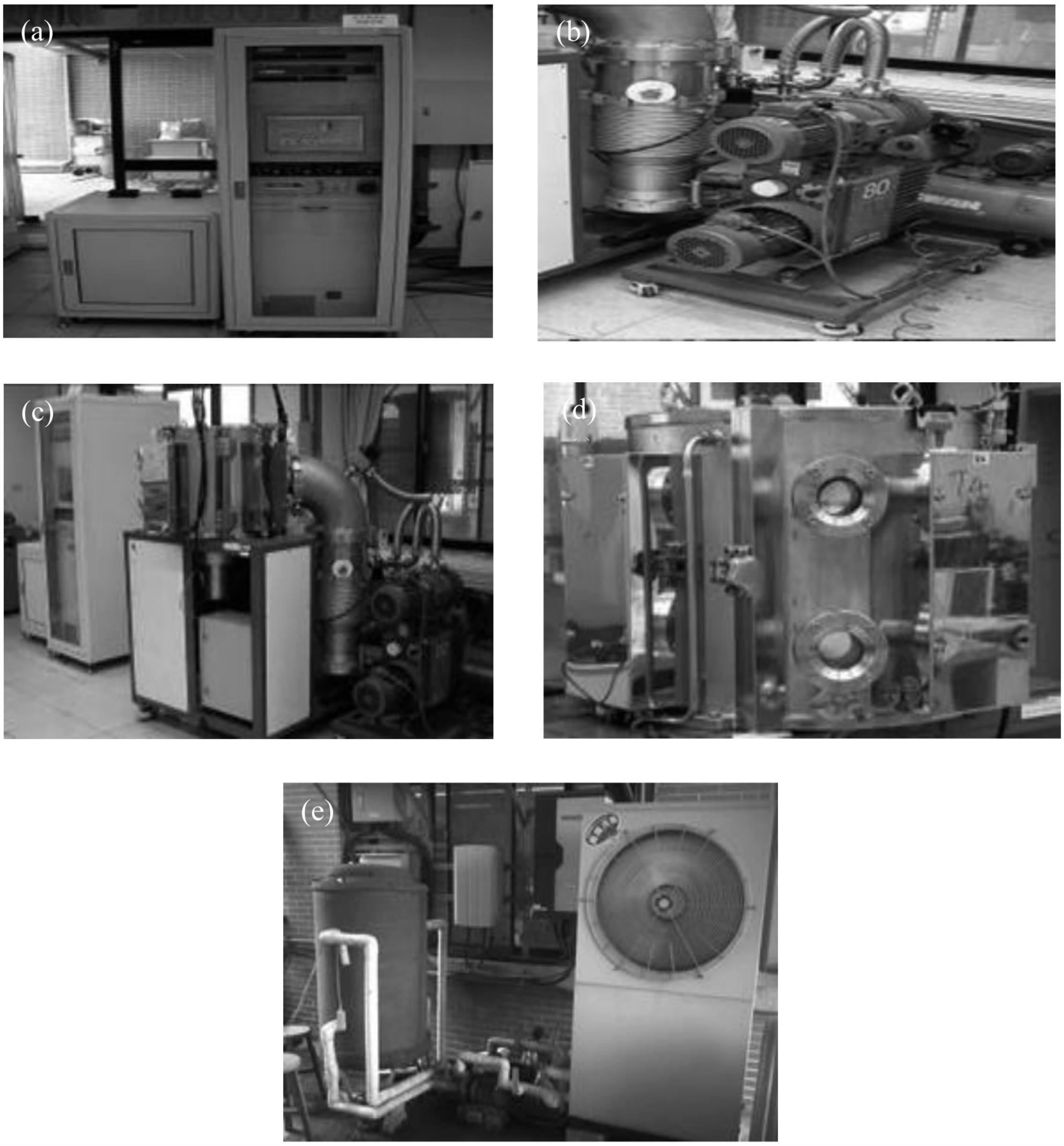


Fig. 1. Magnetron sputtering equipment used including a digital control subsystem (a), a vacuum subsystem (b), a magnetron sputtering system (c), a sputtering chamber subsystem (d) and a cooling subsystem (e) in project-based nanotechnology courses.

involves the condensation of the vapor species onto the substrate and subsequent formation of the film by nucleation and growth processes. However, the examples of zirconium nitride (ZrN) modules for a sputtering system are used in nanotechnology courses. In industrial applications, ZrN is becoming the most promising protective and decorative coating material for metal substrates, mostly due to its warmer golden color and better corrosion resistance in comparison to current commercial counterparts.

The students engage in active learning by performing experiments, which is as important as passive learning by attending a laboratory. For sputtering deposition of zirconium nitride modules, three basic sputtering systems can be used: (1) one magnetron with an alloyed target, (2) two magnetrons equipped with targets made of different elements\ alloys\ compounds or their combinations, or (3) a pulsed dual magnetron, which can easily control individual elements in the alloy nanotechnology or make it possible to deposit nonconductive materials. Furthermore, useful and commercially attractive development in surface engineering using zirconium nitride modules in their fabrication involves a number of stages (preprocessing, deposition and characterization), which are interdependent. It is clear that development of the fabrication equipment, process parameters, parameter limits and monitoring/control techniques ensures a good product yield.

3.4 Implementing the nanotechnology activity

Nanotechnology subjects are always greatly improved when classroom teaching is supported by adequate laboratory courses and experiments which follow the 'learning by doing' paradigm. This approach provides students with a deeper understanding of theoretical lessons. This nanotechnology project used a curriculum for introducing a physical vapor deposition system, fabricated zirconium nitride. The curriculum focuses on a hands-on experimental task, which addresses the problems of traditional subject-matter curricula. The integrated curriculum emphasizes knowledge in depth and in breadth. In this study, physical vapor deposition technology for use in nanotechnology in a laboratory curriculum provides integrated knowledge of materials science, helping students to apply their engineering knowledge through different exercises within a laboratory activity in nanotechnology focusing on zirconium nitride (ZrN) modules.

ZrN modules are actually experimental nanotechnology activities that are suitable for teaching courses in engineering education. The laboratory platform of ZrN modules are an educational tool for teaching students the basic principles of the performance of a series of experiments using physical vapor deposition technology. ZrN modules in the laboratory offer a platform where elegant scientific theories meet messy everyday reality. ZrN module observation helps explain why laboratory experiences are at the core of undergraduate education in science and engineering. The practical nanotechnology examples prepared for this are available upon request. This ZrN module introduces undergraduate students to the use of nanotechnology techniques for the characterization of the materials in coatings. Such an integrated system enables students to investigate the principles and application of physical vapor deposition for use in nanotechnology, which are commonly found in industry.

As shown in Table 2, the examination issues of the learning programs for ZrN modules are analyzed in an integrated curriculum and organized details in equipment used. The analysis for ZrN module in this nanotechnology course covers all aspects of ZrN modules including surface topography analysis by AFM, surface structure/thickness analysis by SEM/ TEM and material composition analysis by XRD/ GDOES. The emphasis of the study is on the aspects of the process flow that are critical to the reproducible deposition of ZrN module films that have the desired properties. Throughout these processes, the emphasis is on giving the students the opportunity to learn from their own experiences and learn by doing by carrying out the nanotechnology in laboratory activities.

3.5 Design of the statistical questionnaire

The design of a statistical questionnaire study begins with a discussion of the literature on nanotechnology related courses offered by colleges and universities and a competency analysis of zirconium nitride modules in nanotechnology. Such studies are further supported by approaches such as panel discussions, expert meetings, field work in the PVD industry and student surveys, to explore the nanotechnology module topic. In this study, the researchers designed a structural interview questionnaire, in accordance with literature discussions and qualitative research experience. The scaling technique used was the Likert scale (5–Strongly agree; 4–Agree; 3–Neutral, 2–Disagree; 1–Strongly disagree). There were a total of 16 items in a multiple-choice format. The items were content validated based on the objectives intended for the topic in the implementation of the nanotechnology activity.

Table 2. The examination procedures of the learning analysis programs for ZrN modules in the nanotechnology activity

Specification	Criteria	Equipment used	Units	Remarks
Surface topography	Roughness	AFM	nm/um	The measurement range was set in dimensions of 1 μm $\times$ 1μm square. The surface roughness of silicon substrate before deposition is ranged from 30 to 40 μm.
Surface structure	Micro\Nano structure	SEM/TEM	Å/nm/um	Microstructure and surface morphology were observed and characterized by the scanning electron microscopy (SEM; Hitachi S-2600H), field-emission scanning electron microscopy (FESEM; JEOL JSM-6700F) and transmission electron microscope (TEM, FEI Tecnai G2 20 S-Twin) at accelerating voltage of 200 kV.
Thickness	Module deposition rate	SEM	(nm/um) $hr^{-1} \cdot kW^{-1}$	Measured by the scanning electron microscopy (SEM; Hitachi S-2600H) and the field-emission scanning electron microscopy (FESEM; JEOL JSM-6700F).
Composition analysis	Module structure	XRD/GDOES	Intensity (a.u.)	X-ray diffraction (XRD), which was using a CuKα radiation (λ = 0.15405 nm) and a scan speed in 2θ of 4°/min.

The overall satisfaction questionnaire about the laboratory activity included sputtered deposition-based systems with 3 items, sputtering processes with 5 items, nanotechnology modules with 4 items, experimental examination and integrity with 4 items. On March 28th 2012, an expert meeting was held at which ten experts from universities and institutes reviewed the draft content, structure and usage of the sputtered deposition-based system and examined the nanotechnology module competences. The experts' opinions, obtained in three written documents, were repeatedly analyzed and arranged, until their opinions reached an agreement. The formal questionnaire including 16 questions on the main function of developing PVD for the use of zirconium nitride modules for a laboratory activity in nanotechnology courses was finalized. In the survey, the effectiveness of the laboratory activity platform was measured to determine whether or not the system accomplished its objectives. The students reported the insights they gained in every phase of the laboratory activity.

The evaluations have a marked impact on student motivation and encourage teachers to explore ways to improve individual learning attitudes. In order for assessment of student learning to work effectively, students must participate in determining the criteria that will be used for their feedback. Twenty-eight undergraduate engineering students finished the laboratory activity nanotechnology courses in 2012. SPSS20.0 statistical software was used to analyze and process data. To assess the reports of students about the skills and learning occurring throughout the project, the criteria of pedagogical assessment and the corresponding percentage grades in the laboratory activity nanotechnology courses were utilized. The achievements of project-based learning for nanotechnology courses were graded according to the criteria presented in Table 3. A survey was conducted about this project at the end of the course.

Table 3. Criteria of pedagogical assessment and the corresponding percentage grade for nanotechnology through laboratory activity learning

No.	Criteria	%
A	Presentation of physical vapor deposition plan and design of project process	10
B	Presentation of flowchart of nanotechnology courses in laboratory activity	7
C	Presentation of storyboards of nanotechnology courses in laboratory activity	8
D	Presentation of project product of nanotechnology in laboratory activity	20
E	Presentation of analysis reports of nanotechnology modules	15
F	Presentation of analysis reports for project-based nanotechnology learning	20
G	Presentation of evaluation and assessment reports for project findings	20

At the conclusion of the course, the student reports and project stories were compiled into an in-house publication format. It is worthwhile to note that throughout the semester the students sent all reports by e-mail to the instructors prior to deadlines. In addition, all the presentations, except for the ZrN product itself, were prepared using presentation reports, where teacher graded the portfolios using a rubric (Table 3) that measured their ability to incorporate the nanotechnology in the laboratory activity into their projects. The final project grade for each student was assigned on the basis of cumulative plan and design contributions (10%), flowcharts (7%), storyboards (8%), project results (20%), analysis reports (15%), and evaluation reports (20%) for midterms/finals and assessment reports (20%) for project findings.

4. Results and discussion

4.1 Nanotechnology activity

In this study, a nanotechnology module with a zirconium nitride (ZrN) was fabricated in a laboratory experiment. Experimental ZrN modules in nanotechnology can be set up by designing experimental contents including design, system and interface for experiments and instructions. The students used control factors to prepare their own control programs for their ZrN modules. In this experiment, a sputter deposition system with a magnetron gun and pulsed DC power supply was used. The planar sputtering gun, equipped with a rectangular target ($300 \times 100 \times 10$ mm^3), was operated in an unbalanced mode. The three targets: a zirconium target of 99.5% purity, a chromium target of 99.5% purity and a titanium target of 99.5% purity, were deposited. The substrates were ultrasonically cleaned in methanol and acetone for 10 min each, and fixed on a cylindrical sample holder in the vacuum chamber and then dried by ion bombardment in an Ar plasma discharge, before deposition. It was coated, in sequence, by a bonding Ti layer (15 min), and then a top ZrN film. A system pressure of 4×10^{-5} torr was used for each film deposition. Details of the magnetron sputtering procedures are described in the references. The experimental schemes used an orthogonal array table. Eight control parameters were chosen for the experiments with the magnetic sputtering modules. The deposition conditions for the ZrN thin films coated onto the stainless steel specimens are listed in Table 4. The substrate matrices used in the experiment were 306 stainless steel specimens with a dimension of 4 cm $\times$ 4 cm $\times$ 0.7 cm. The cross-sectional structures of the composite films were noted, using a field-

Table 4. Control factors and conditions of the experimental ZrN film in nanotechnology for the magnetron sputtering system

No.	Parameters	Conditions
1	Interlayer element	Ti
2	Ar (sccm)	25
3	Ti+Zr current (A)	3
4	N2 (sccm)	11
5	Sputtering distance (cm)	8
6	Substrate bias voltage (V)	40
7	Sputtering time (hr)	2.5
8	Rotate speed (rpm)	2

emission scanning electron microscope (JEOL JSM-6700F). Surface examination of the films involved the use of the digital instrument nanoscope of an atomic force microscope (Nanoscope Dimension 3100 SPM). In the experiment, two different spots were chosen for each film surface and a scan area of 5×5 mm^2 was measured. From the scanned area, the surface topographies and surface roughness of the various samples were determined and recorded. The roughness parameters of the root mean square (Rq), arithmetic mean deviation (Ra) and maximum roughness depth (Rmax) values were obtained at arbitrarily chosen positions on the film surface. The element depth profiles across both the zirconium nitride with Ti coatings and zirconium nitride with Cr coatings were researched by glow discharge optical emission spectroscopy. The elemental species were identified in the films by the assignment of corresponding signals marked with a high-resolution X-ray photoelectron spectrometer. The crystalline structures of thin films were identified by X-ray diffraction (XRD), using a CuKα source (λ = 0.15405 nm) and a scan speed of 2θ of 1°/min.

4.2 Project findings of the nanotechnology activity

A measurement of module properties is indispensable in the study of module materials and devices. Several methods are proposed for the measurement of thin films. Rapid progress has been made in evaluating the surface, structure and module composition of nanotechnology materials. There are many levels of film analysis, such as physical, chemical, optical and mechanical tests, as shown in Table 2. The level of the application involves measuring behavioral properties, or how the film interacts with its environment, including light, electrical and magnetic fields, chemicals, mechanical force and heat, as seen in Fig. 2. The deeper level involves probing structure and composition, which together determine module behaviors and thus provide a bridge of understanding between the deposition step and the module behaviors. Several examined methods are proposed for the evaluation of ZrN modules. Below is a description of the specific techniques used for analysis of the film structure, composition and properties. For example, one of the AFM images shown in Fig. 3 shows the surface morphology of the ZrN modules on 316 stainless steel substrates, with surface roughness (Rms) of 13.677 nm, in which the change in the nanotechnology depends on the different settings of the control parameters.

To examine surface topography features, microscopy is needed. Standard optical microscopy can reveal prominent features, such as cracks, bubbles and hillocks, but in nanotechnology topography, a field-emission scanning electron microscope (FESEM) is used. The surface morphology of the Ti interlayer of the ZrTiN thin films is examined using FESEM images, as shown in Fig. 5(a). The grain sizes of the ZrN nanoparticles on the surface of the modules with a Ti nanointerlayer are much smaller, with a diameter of less than 50 nm, and the surface is smoother.

Fractured cross-sectional FESEM micrographs of the specimens of the TiZrN modules are shown in Fig. 5(b), in which the vitreous fractured structures of the TiZrN modules with thick dimensions of 612.5 nm are clearly visible. There is even an amorphous growth structure on the TiZrN modules, where the Ti interface between the TiZrN modules and its substrate is well bonded, without any visible flaw. There is no evidence of a columnar

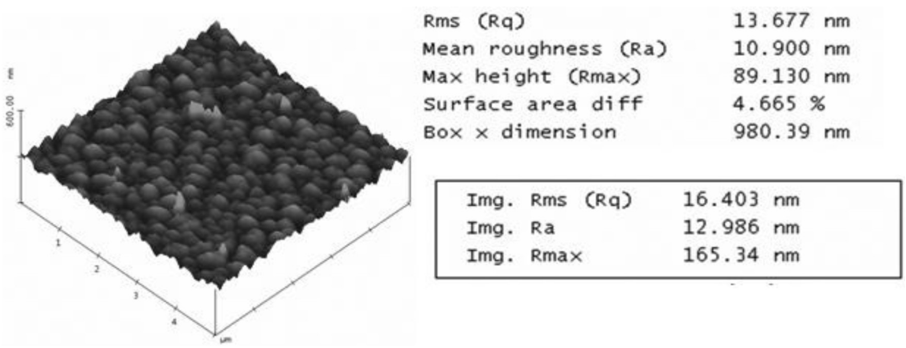
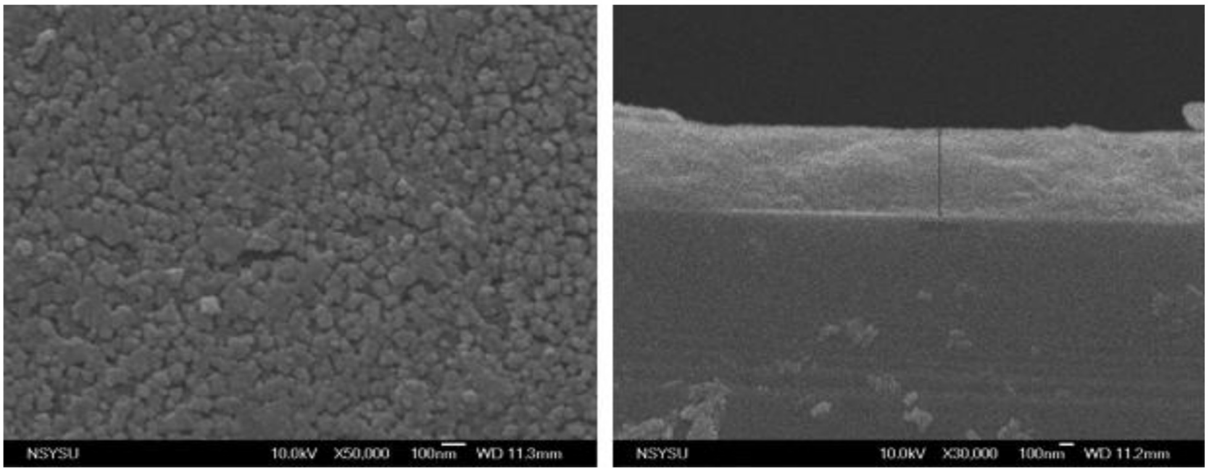


Fig. 2. AFM images of surface morphology.



(a) (b)

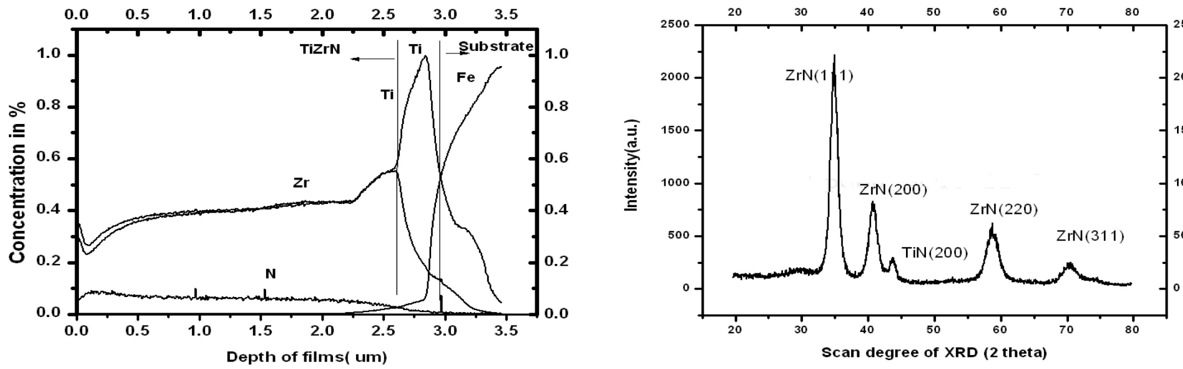
Fig. 3. Surface and fractured SEM images of nanotechnology using ZrN modules.

structure. These modules showed a visible tendency towards forming fractured amorphous glassy phases. In the experiment, the Ti interface was designed to minimize the variation in chemical composition and lattice structure between each adjacent layer. It is obvious that after nitrogen ions attack, some of the chromium atoms are bombarded deep into the substrate and the mixing of modules and substrate is clearly revealed by glow discharge optical spectroscopy (GDOES).

The film composition and thickness is determined by GDOES. A typical elemental depth profile is depicted in Fig. 4(a). The concentration distribution of the Zr, Ti, N, Cr and Fe elements of the modules with depth is determined from the depth profile. The occurrence of elements contained in the modules can be clearly seen, and it is in good agreement with the composition studied. As shown in Fig. 4, the total thickness of the TiZrN module is approximately 3.0 m and a titanium intermediate layer with a thickness value of 0.5 m is visible in the depth profile. The film composition stoichiometry reveals an *N* concentration of approximately 40%. It is seen that the relative proportion of the titanium elements progressively varies, from the surface to the interface to the substrate as shown in Fig. 4(a). It probably provides an efficient process for diffusion during the magnetron sputtering, which results in a strong mixing of the TiZrN films with the Fe that is present on the stainless steel. Figure 4(b) shows a series of XRD spectrums with ZrN modules. These principally exhibit three strong sharp peaks in the modules, located at 2θ of 33.898, 39.368 and 59.321. These peaks are attributed to diffraction of the ZrN(111), Zr(200) and ZrN(220) planes. The ZrN(311) peaks and TiN(200) peaks seem to be small. This implies that the module may be composed of Ti-doped ZrN with preferential orientation in (111), (200) and (220) directions.

4.3 *Questionnaire evaluation*

A learning evaluation system was used to test the efficacy of the system, in terms of teaching, learning and student achievement. It was determined whether or not the sputtering deposition-based system with zirconium nitride modules was useful



(a) (b)

Fig. 4. Material composition analyses of the (a) GDOES and (b) X-RAY of ZrN modules in the nanotechnology courses.

nanotechnology evaluation and whether the modules met their needs. The teaching and learning platform was evaluated by measuring teacher and student satisfaction. A survey was designed in order to obtain feedback from the students and the instructors about how essential the laboratory activity was to help enhance their creativity and innovation in the learning of nanotechnology. The responses to questionnaire items from the experts and students are shown in Table 5. The results for both are, not surprisingly, very similar. Based on the results of the evaluation, both groups rated the laboratory platform highly. The mean values of this questionnaire for both groups were found to be 4.093 and 4.263, respectively, showing a high level of satisfaction. The deviations among items are extremely close, showing that all participators were satisfied with the laboratory activity in the nanotechnology courses. Furthermore, the mean scores for students were between 'strongly agree' and 'agree', except for items 3, 10, 11 and 12. This finding suggests that students were confident in the ability of laboratory activity learning to enhance their analysis capabilities, to facilitate active nanotechnology learning, to develop thinking skills and to promote future learning. In addition, the mean scores for instructors were between 'strongly agree' and 'agree', except for items 7, 11, 12 and 16.

This finding suggests that instructors feel strongly that laboratory activity learning can promote students' interpersonal relations, improve their learning motivation in nanotechnology and enhance learning motivation in nanotechnology courses. All agreed that the laboratory activity in nanotechnology courses produced successful results for learning and teaching since more than 70% received grades over 4. Furthermore, the Cronbach's alpha reliability coefficient of the laboratory activity questionnaire results for satisfaction of the experts and students in this study were 0.953 and 0.947, respectively, demonstrating excellent reliability in the survey's internal consistency. Table 5 summarizes these results. Also, I interview several students through the laboratory activity of nanotechnology. On student seemed to prefer to work independently most of the time, another interacted many times with each activity with her teammates and the third had the great growth for understanding nanotechnology in his laboratory activity. All three students believed they could learn more by working with other students in the laboratory activity of nanotechnology courses. Overall, students responded

Table 5. t-test for the expert and student responses to the questionnaire

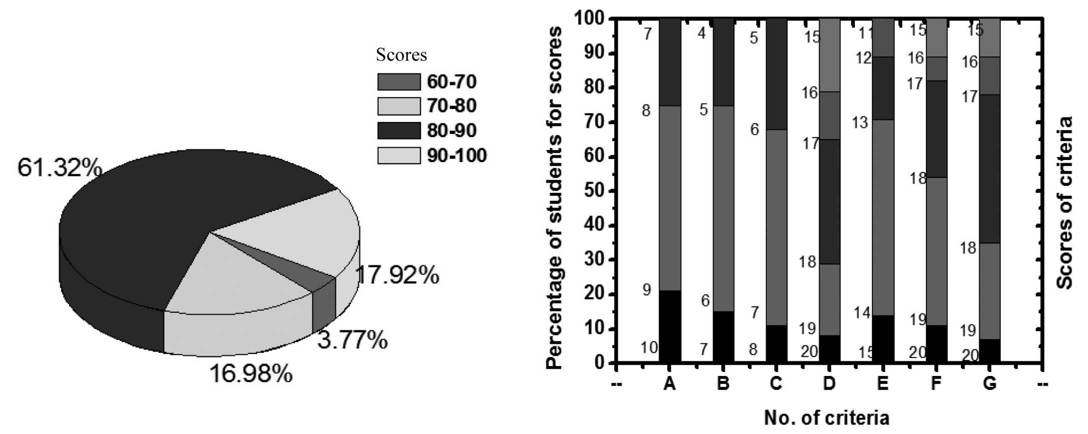
		Students (n = 28); α = 0.953		**Experts (n = 10); α = 0.947**		
No.	**Items**	**M**	**SD**	**M**	**SD**	***t*-test**
1	The sputtering deposition-based system guide was organized.	4.25	0.701	4.40	0.516	0.875
2	The sputtering deposition-based system operating guide was easy to understand.	4.20	0.630	4.10	0.568	–0.415
3	The sputtering deposition-based system goals were clear.	3.35	0.559	4.60	0.516	9.222*
4	The sputtered deposition-based system in engineering undergraduate courses was suitable for students.	4.30	0.460	4.70	0.483	1.552
5	The sputtered deposition-based system was helped in the teaching and learning nanotechnology courses.	4.70	0.460	4.60	0.516	–0.684
6	The sputtered deposition-based system was more interesting than traditional textbook learning.	4.65	0.559	4.50	0.527	–1.700
7	The sputtered deposition-based system was well designed and processed.	4.10	0.488	3.80	0.789	–1.255
8	The background information of sputtered deposition-based system was helpful to students.	4.35	0.559	4.30	0.483	–0.221
9	The operating steps for sputtered nitride zirconium modules were explained and understandable.	4.25	0.585	4.40	0.516	0.498
10	The properties of zirconium nitride modules were examined and tested in overall.	3.70	0.600	4.20	0.422	1.759
11	Typical applications of zirconium nitride modules were understood and clear.	3.55	0.576	3.70	0.483	1.033
12	The analysis of zirconium nitride modules in AFM, SEM, X-RAY and GDOE examination was understood and motivated as a whole.	3.45	0.576	3.80	0.632	1.174
13	The examination of surface texture, structure feature and composition in zirconium nitride modules was understood and clear.	4.35	0.488	4.7	0.483	3.100*
14	The experimental zirconium nitride modules were interesting for use in nanotechnology courses.	4.25	0.645	4.4	0.516	1.916
15	The assessments overall provide useful feedback on your nanotechnology courses.	3.95	0.663	4.1	0.568	1.026
16	The learning in nanotechnology courses was useful and motivating overall.	4.10	0.567	3.9	0.316	–1.615

$p < 0.05$.

positively. This seems to agree with the observation in Table 5. Based on our observations, students in this laboratory activity learning spent additional time to learn about many new types of technology in nanotechnology and completed their exploratory projects in 18 weeks, according to course expectations.

4.4 Evaluation results of the nanotechnology laboratory activity

Evaluations by the students were used to help determine the acceptability of the project, according to the following criteria: usability of the laboratory platform, the extent to which the students gained hands-on experience in nanotechnology modules and whether the project helped students learn about zirconium nitride modules in nanotechnology. The evaluation form was distributed to all students who had taken this course at the Institute of Engineering Science and Technology at National Kaohsiung First University of Science and Technology. Most students successfully performed the experiment and responded positively to the system. They reported that they enjoyed performing the projects, active learning, interpersonal relationships and mutual collaboration and found the laboratory activity in the nanotechnology courses interesting. They also suggested that the nanotechnology courses should continue to use project-based learning in the future. Since the sample size is small, the mean distribution of the difference between students and experts was used and the results are displayed in Table 5. The value, α, which represents the level of significance of the test, is usually set in advance, with a commonly chosen value being $\alpha = 0.05$, for which the corresponding two-tail critical value is ± 1.96. Based on the scores from the test, significant differences were found for item 3 ($t = 9.222, p < 0.05$) and item 13 ($t = 3.100, p < 0.05$) in the distribution of the difference between students and experts, but the others were not significantly different. In addition, the evaluation scores of students on questionnaire for items 3, 10, 11, 12 and 15 were much lower than the results that the experts expected. Further analysis showed that the students came from different engineering backgrounds. Such differences in background have a significant effect on students' learning performance in nanotechnology laboratory activities. As the survey results show, the students' responses were very positive and they encouraged further improvement of the nanotechnology courses. To measure the learning achievements of students in the nanotechnology laboratory activity, pedagogical assessment scores are shown in Table 2 and the learning achievement scores of students are shown in Fig. 5. It is clear that laboratory activity learning is helpful and enhancing for students in nanotechnology courses. As shown in Fig. 5(a), more than 79.24% [P1]of the students scored over 80, suggesting that they found the laboratory activity in the nanotechnology courses to be very good or excellent. Less than 4% of the students did not yield a satisfactory result, due to their lack of previous engineering learning. On the other hand, a set of graded scores for assessing the project findings of students are organized and displayed according to the frequency of occurrence of specific values. The students were asked to rate the criteria for the frequency distribution of scores on a 0–100% scale. The frequency distribution of scores is shown using a histogram in Fig. 5(b). Histograms display the percentage of students, dispersion, and grading tendency of the distribution of a population of data. About 70% of the students accounted for the first three grades in all seven criteria indicators, showing that the laboratory activities in the introduction to nanotechnology courses were found to be positive. Clearly, the results of the laboratory



(a) (b)

Fig. 5. Percentages of students' pedagogical assessment scores (a) according to Table 3 and the students' score distribution, (b) for assessing learning in nanotechnology courses with laboratory activities.

activity are much better, clearly showing that the students taking the nanotechnology courses were highly motivated.

In sum, the students indicated that they had personal gains because they developed problem solving skills during this project. Also, the students expressed that their creativity, critical thinking and learning motivation were enhanced considerably in the process. Furthermore, students revealed that their activities and task accomplishments made them feel more self-confident than before. Moreover, many of them implied that having developed these skills they revised their project plans and decided to work as an engineer in the future.

5. Limitations and future research

Although the results of this study were satisfactory, they could not be proved due to several limitations. First of all, the sample size was small, and a control group was not considered. Second, the study was conducted as a laboratory activity, and several important laboratory facilities were not readily available. Third, this study contained many issues in nanotechnology courses by laboratory activities. Future research in this activity should consider contributing to the nanotechnology production skills of students to create and try out effective education activities for their future classrooms. The students associated their existing knowledge with laboratory activities that enhanced their skills and abilities in the nanotechnology courses. The findings of this study were presented to the related projects and research teams. This project, through its research involvement, offered the students more guided, formal and comprehensive training on physical vapor deposition, SEM, XPS and AFM tests, and some of the undergraduate students involved in this research experience became capable of running these instruments in their own research projects. This project may offer hands-on experience to explore nanotechnology by integrating laboratory activities for the students and can improve upon these results by considering the limitations. The project development during this study provided a foundation for future studies to develop and build upon the effective learning of nanotechnology courses.

6. Conclusions

This study addressed the development of a physical vapor deposition, for use in zirconium nitride modules in laboratory activities in nanotechnology courses. The project is also introduced to engineering laboratory curricula by incorporating nanotechnology courses in labs, mentoring undergraduate students in nanotechnology research and offering a laboratory activity course about how the laboratory-based project enhanced their nanotechnology skills. Through the analysis of the students' interviews, it was found that the students believed the implementation of this project was appropriate for the course because they could apply both their knowledge of nanotechnology science and the hands-on skills they learned from the laboratory activity class when they carried out the project. They found that the project could help them become aware of their own laboratory activity abilities and provide the nanotechnology experience of actually creating skills in real-life contexts. They also suggested future implementations of the disciplinary-based project in the nanotechnology course. Based on the evaluation results and responses to the questionnaires, it was found that this nanotechnology exploration project was successful. The students and experts rated the nanotechnology laboratory activity highly, with mean values of 4.093 and 4.263 for both groups, respectively. In addition, the Cronbach's alpha coefficient of the laboratory activity questionnaire results for the satisfaction of the experts and the students in this study were 0.953 and 0.947, respectively, displaying excellent reliability in the survey's internal consistency. Furthermore, more than 78.34% of the students scored over 80, suggesting that they found the laboratory activity in the nanotechnology exploration project to be very good or excellent. In other words, the students obtained very good academic results.

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