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A Case Study of Increasing Vocational High School Teachers Practices in Designing Interdisciplinary Use of Scientific Inquiry in Curriculum Design

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The primary objective of this study was to determine how experience in learning to teach scientific inquiry using a practical approach affected teacher's attitudes, evaluations of use of inquiry and their actual design of inquiry based instruction. The methodology included the use an approach incorporating inquiry methodology combined with a technology-infused and engineering rich approach called "Intelligent Robotics" to help teachers learn and use a new approach to teaching scientific inquiry. The findings showed that these teachers progressively moved from more teacher-centered thinking about teaching to student-centered thinking and actions incorporating scientific inquiry. They also worked together in designing an interdisciplinary inquiry curriculum, providing an effective alternative to traditional rigid standards based curriculum and teacher directed instruction.

Keywords: curriculum design, interdisciplinary, scientific inquiry, vocational high school teacher

BACKGROUND AND PURPOSE

Scientific inquiry as an approach in science teaching

Scientific inquiry has been emphasized in the National Science Education Standards (NSES) as a set of pedagogical methods that represents scientific practices and promotes students' acquisition of content knowledge through the problem solving process (National Research Council [NRC], 2000). Numerous scholars (i.e., Hackling & Garnett, 1995; Lin et al., 2014; Luft, 2001; Staer, Goodrum, & Hackling, 1998;) have indicated that the cultivation of students' inquiry abilities should be at the center of contemporary science education. Therefore, providing students with active opportunities to inquire and receive relevant training during the teaching process has become an essential instructional activity. Through Taiwan's new curriculum standards for senior high-school and vocational education announced in 2006, Taiwan educational leaders hoped to provide innovative curriculum and instruction in every high-school classroom in order to furnish students with a real-world learning environment and cultivate their ability to solve realistic problems. It also aimed to motivate students' curiosity toward advanced technology, encourage them to explore actively and solve problems scientifically, and develop a positive attitude toward scientific learning. Consistent with these NSES standards, the "High Scope Project" funded by the National Science Council [NSC] of Taiwan (NSC, 2007) was initiated to reach the innovative goals of this reform effort, which mainly was intended to design an experimental curriculum with an emphasis of integrating advanced technology into the original high-school curriculum by applying an inquiry

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State of the literature

- Scientific inquiry has been emphasized as a set of pedagogical methods that represents scientific practices and promotes students to acquire content knowledge through a problem solving process..
- Teaching students how to conduct scientific inquiry is an essential reform effort promoted in recent science education. The use of inquiry-based curriculum and instruction is gaining favor in many classrooms since it improves scientific skills through a critical thinking process.
- Teachers may struggle to implement inquiry as a result of lack of inquiry experience; however, teachers' professional development actually practicing scientific inquiry may help them implement the approach and philosophy of "learning by doing".

Contribution of this paper to the literature

- The process (curriculum structure, content design, and instructional design) of vocational high school teachers acquiring scientific inquiry skills and designing interdisciplinary inquiry curriculum has been analyzed in this study.
- The study contributes to the engineering field by showing that teachers could move progressively from more teacher-directed learning to student-centered actions incorporating inquiry.
- Assisted by in-service professional development, vocational high school teachers moved to an inquiry model that incorporated content design, development of inquiry type of activities, and assessment of student performance.

learning approach. Within this project, several "university research teams" and nearby "secondary school teams" worked cooperatively to design and implement the "high scope curriculum" in the targeted high-school. After the original High Scope Project, a second phase of High Scope was initiated. Accordingly, this study was conducted under the second phase of the High Scope Project with duration of three years. The study and project intent was to design an inquiry curriculum with a theme of developing "intelligent robots" in a vocational high-school (VHS) in southern Taiwan.

Technology-infused content for inquiry curriculum design

For several years beginning in 2010, Taiwan has had an "intelligent robot" design competition. "The objective of the competition is to promote the spirit of science and technology to our younger generation. It also serves to bring together skilled researchers and students from different backgrounds to challenge one another in developing better robots for technologies of the future. Robotics is an exciting, multi-disciplinary area that integrates intelligent control, communications, image processing, mechatronics, sensor fusion and many other aspects on one single platform. It is a worthwhile learning experience for all who are involved. Supported by a university team, a professional development (PD) program was developed to equip the VHS teachers with adequate knowledge and ability to work cooperatively to design an inquiry oriented curriculum. Three types of activities, i.e. a 45-hour workshop, weekly meetings involving design and discussion, and monthly reflective exchanges, were implemented within three categories of content: an inquiry-based instructional model [related to mathematics and science education], developing curriculum and designing instruction [related to interdisciplinary issue], and learning advanced technology of intelligent robotics [related to technology education].

Interdisciplinary approach to disenthrall subject-matter boundaries

The original curriculum used in VHS, as in other vocational high-schools, came from common textbooks that were designed based on the official standards approved by the Ministry of Education, Taiwan. Historically, and in recent years, a traditional way of teaching (e.g. lecturing and subject-matter orientated) was employed to implement the curriculum. With this historic approach, students lacked for opportunities to inquire actively, discuss communally, and innovate creatively, as well as learning in a fragmented way within such a "subject-matter oriented" environment. However, as stated in "A Framework for K-12 Science Education" (NRC, 2012),

> *Standards and performance expectations that are aligned to the framework must take into account that students cannot fully understand scientific and engineering ideas without engaging in the practices of inquiry and the discourses by which such ideas are developed and refined. (p. 218)*

Therefore, it is time to disenthrall this predicament and furnish students a better learning environment, which is aligned to the core concept of "Next Generation Science Standards [NGSS]" (NGSS Lead States, 2013). In this study, we provided a qualitative analysis of how the targeted teachers were freed from traditional mindsets to think and act anew during the design process for the "interdisciplinary" inquiry curriculum developed for this High Scope Project. This disenthralling effort focuses on creating an "interdisciplinary" learning environment that addresses the development of knowledge and capability of

"STEM (science, technology, engineering, and mathematics)", which encourages students to apply what they learn in daily life situations and promote the development of creativity. It is also expected that the targeted curriculum and its design process are able to provide positive evidence in support of this innovative reform, which may, in turn, lead to further improvements in all of Taiwan's vocational high-school classrooms.

Purpose of the study

Based in the motives stated above, this study was conducted beneath the High Scope project, which was to assist vocational high-school teachers to design an interdisciplinary and technology-infused curriculum with the inquiry-based instruction through a professional development program. The primary objective of this study was to determine how experience in learning to teach scientific inquiry using a practical approach affected these teacher's attitudes, evaluations of use of inquiry and their actual design of inquiry based instruction.

THEORETICAL FRAMEWORK

Scientific inquiry

Scientific inquiry is essential in enabling students to acquire scientific content knowledge through the problem solving process (NRC, 2000). Based on the NSES (NRC, 1996), scientific inquiry:

> …*refers to the diverse ways in which scientists study the natural world and propose explanations based on the evidence derived from their work. Inquiry also refers to the activities of students in which they develop knowledge and understanding of scientific ideas, as well as an understanding of how scientists study the natural world. (p. 23)*

As a fact, inquiry is a necessary ability of modern people (NRC, 1996, 2012). Research evidence showed that using inquiry-based instructional approach was beneficial to promote students' understandings of the content taught and their learning outcomes in diverse subject areas and various grade levels (Akerson & Hanuscin, 2007; Barak & Shakhman, 2008; Fishman et al., 2003; Lin, et al., 2014; Luft, 2001; Marx, et al. , 2004; Santos-Trigo, 2008). Espinosa-Bueno et al. (2011) confirmed the effects of inquiry-based teaching, and that it enabled students to develop habits of observation and reasoning. They found that students were capable of engaging in critical thinking similar to scientists, and could identify the relationships between theories, practice, and human activities. In addition, students enjoyed the inquiry-based learning experience, where they could connect the problem solving process with the learning task in various disciplines and conduct scientific inquiries similar to scholars. Furthermore, students were more willing to share their experiences after participating in inquiry activities because inquiry-based learning was extremely interesting (Liu, et al., 2009), which was helpful in accelerating the pace of learning and stimulating them in learning science. Banerjee (2010) also found that this method enhanced the self-confidence of 53% of students, and motivated 60% to 70% of students to pursue further education in engineering- or science-related disciplines subsequently.

Besides the fruitful benefits for students, teachers who engaged in designing and implementing an inquiry-based curriculum in practical settings obtained abundant growth in their scientific knowledge, capabilities, and attitudes. With the assistance of appropriate professional development programs, science teachers of various grade levels progressively adopted the inquiry-based approach in science teaching (Akerson & Hanuscin, 2007; Fishman, et al., 2003; Luft, 2001; Marx, et al., 2004; Supovitz & Turner, 2000), where student-centered learning activities were applied to provide more opportunities for students to think and reflect. This transformation was useful for both their inquiry teaching practices and beliefs of using inquiry-based approach to promote students' learning outcomes (Luft, 2001). In addition, empirical evidence also showed that combing "technology-infused" curriculum design with inquiry-based instruction was beneficial to students' science learning (Marx, et al., 2004). In this technology-enriched learning environment, students engaged in investigating the everyday world and developing understating from their inquiries, which were essential for their future science learning and daily applications.

To meet the demands of the inquiry approach, teachers need to be capable of its design and implementation. The main principle in inquiry teaching is that teachers arrange activities with the aim of discovering problems or creating cognitive conflict scenarios. This allows students to discover scientific problems through activities and to construct problem solving solutions (NRC, 2012). The role of the teacher is to provide the motivation and direction for students, themselves, to conduct scientific research, which also helps them develop the capability of critical thinking. The role for each student is that of an enthusiastic thinker, actively participating in the process of questioning, observing, categorizing, explaining, applying, developing, and expressing their own views while accepting those of others, with the final goal of being able to solve a problem and understand the rationale (NRC, 1996, 2000, 2012). Accordingly, teachers need to plan for appropriate scientific experiments throughout the scientific teaching process, allowing students to experience the process through inquiry learning. This approach prompts students to discover problems, understand those problems, and propose and implement various solutions. Finally, the best solution or conclusion is generalized through careful procedures of scientific verification. Throughout the process, students engage in autonomous learning, by means of observation, questioning, investigation, discovery, discussions, reflections, application, cooperation and analysis, which becomes more meaningful, interesting, and beneficial for enhancing their motivation in learning science (Hofstein & Lunetta, 1982; Tobin, 1990).

Inquiry-based instructional approach

Research evidence (Bransford, Brown, & Cocking, 2000; Donovan & Bransford, 2005) has confirmed that a research-based instructional model is truly helpful for students in learning effectively in science and other subject areas. In a meta-analysis of sixty-one studies, Schroeder, Scott, Tolsom, Huang, & Lee (2007) concluded that "inquiry" was one of the three most effective teaching strategies; this might be particularly effective in helping students achieve better in science. This inquiry approach has a lengthy history, since being inspired by Dewey, in 1909, who argued that science teaching didn't provide a learning environment where science was a way of thinking and an attitude of mind (NRC, 2000). Later, Schwab (1960) worked to establish the view that science education could be taught through the sustained use of inquiry, in which students could apply inquiry to learn science effectively by working in the laboratory first before being taught formally about scientific principles and concepts. Based on this perspective, the Biological Sciences Curriculum Study (BSBC) developed the 5E Instructional Model (Bybee, et al., 2006), which was proposed by Bybee (1997); this model integrated several historical models proposed by Herbart and Dewey as well as greater philosophical and psychological thoughts proposed by Atkin and Karplus. This model, grounded in constructivism, assumes that teachers should use various instructional strategies to empower their students to learn actively (Bybee, 1997). For example, teachers should create an inquiry environment where students can explore and explain what they have learned (Orgill, & Thomas, 2007) or discover and solve problems in their own ways (Martin-Hauser, 2002; Windschitl, 2003; Liu, et al., 2009), as well as being assessed authentically. The 5E instructional Model has five phases: engagement, exploration, explanation, elaboration, and evaluation (Bybee, et al., 2006). In this inquiry learning cycle, students are able to gain scientific content knowledge and fundamental abilities through the active inquiry experiences characterized in NSES (NRC, 1996), "Inquiry and the National Science Education Standards" (NRC, 2000), and "Next Generation Science Standards" (NGSS Lead States, 2013). Empirical evidence also exhibited that using 5E model was useful for both promoting secondary students' learning interests and positively enhancing their attitudes toward science (Lin, et al., 2014).

In this study, we used this 5E instructional Model in designing the inquiry learning activities of the targeted curriculum, see figure 1 for an example of the inquiry activity. It aimed to provide students more active and hands-on experimental experiences in learning the main content "Interdisciplinary 'Mechatronics' Intelligent Robot". Further, through the inquiry learning process, it was expected that students could reach the goals of the targeted curriculum and acquire the listed abilities for the future learning.

RESEARCH DESIGN

A case study approach was mainly employed in this study to analyze the design process of the inquiry curriculum. Participants were ten teachers of two departments ("Department of Electrical Engineering [DEE]" and "Department of Mechanical Engineering [DME]") in VHS. There were two main reasons in selecting these teachers: First, as mentioned in the background section, teaching and learning in vocational high-schools needs instant reform efforts to promote students' knowledge and capabilities of scientific inquiry and their understandings and practices of advanced technology. Secondly, "Mechatronics" was chosen as the core concept in order to design an interdisciplinary curriculum with a focus of "intelligent robot". The learning content of two departments was closely related to this topic, where these teachers voluntarily participated in this High Scope project. Data were collected through in-depth interviews (formative and summative, individual and group, use of formal and informal follow-up style), semi-structured observations at all PD events, and field notes and reflection notes in order to obtain the rich and thick data for analyzing this curriculum design process. Based on the theoretical framework of inquiry and indicators of curriculum design and evaluation, the original codes used were centered on two topics for data collection: teachers' conception of inquiry and their plan for curriculum design. Data collected were organized and pre-analyzed using the following steps (Thomas, 2000): preparation of raw data files, closed reading of text, creation of categories, overlapping coding and uncoded text, continuing revision and refinement of category system. Immersion and editing analytic techniques (Crabtree & Miller, 1999) were then employed for further analyses. The editing analytic system, applying the organizing code topics mentioned above, was used to make sure that the analyses focused on the curriculum design process. The immersion analytic system was employed because of the exploratory character of this study,

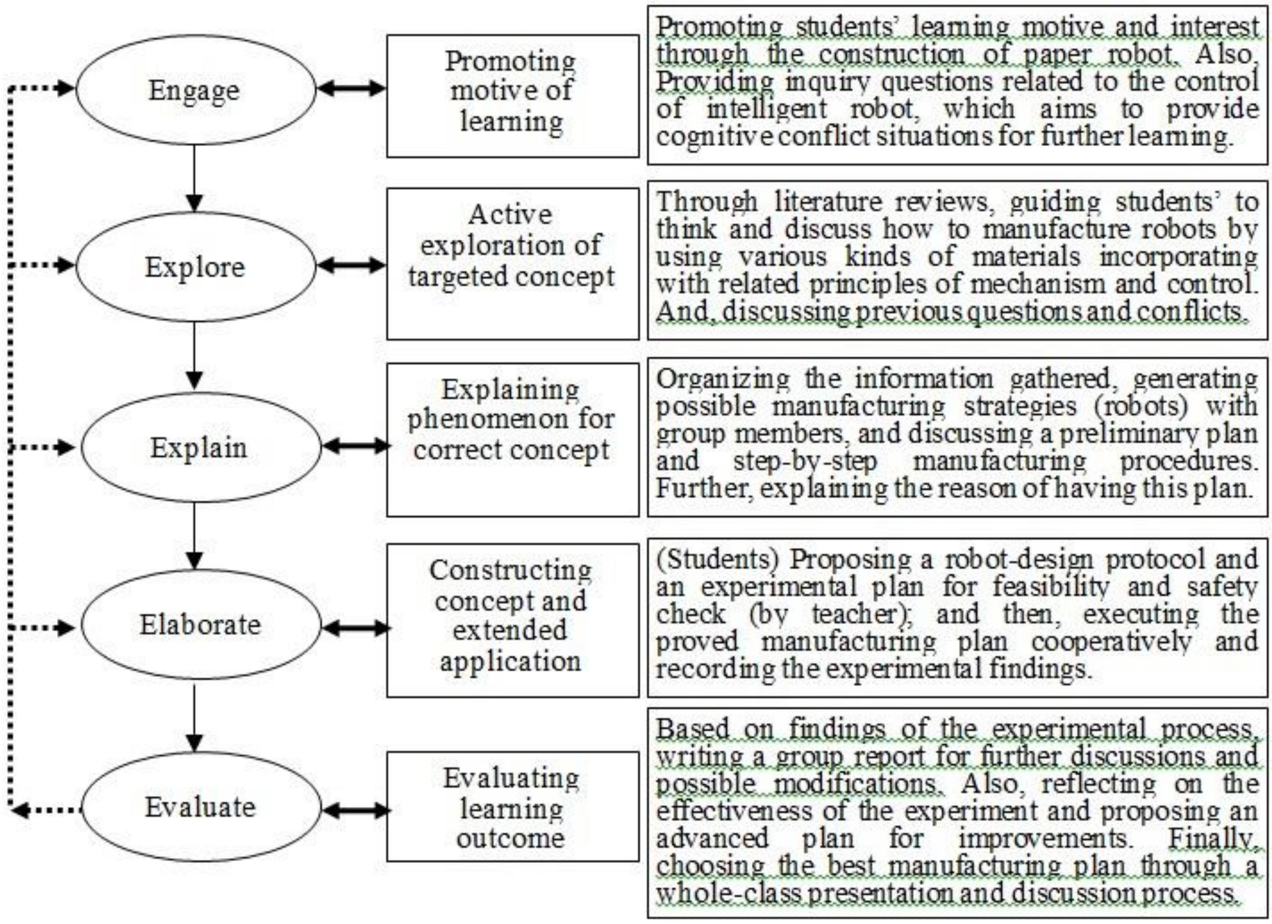

Figure 1. An example of 5E inquiry activity

discovering the possible changes and sources of the changes in the process of targeted teachers' curriculum design. The cycle of immersion was repeated until the reported interpretation was reached (Crabtree & Miller, 1999).

FINDINGS

After teachers participated in the one-year PD program, an analysis of their design process for inquiry curriculum based on intelligent robot development was conducted. According to the data analyses, three themes regarding the curriculum design process were extracted about the progress of their conceptions and actions, where each theme had its own developmental focus: curriculum structure, content design, and instructional design.

Curriculum structure

Curriculum framework—from official subject/department-matter standards to interdisciplinary framework

The focus of the advancing technology used in this study was the design and manufacture of intelligent robots, while "mechatronics" (i.e. the design process that includes a combination of mechanical engineering, electrical engineering, telecommunications engineering, control engineering and computer engineering, etc.) served as an important learning basis for the targeted curriculum. The original curriculum used in VHS came from common textbooks that were designed based on the official standards approved by the Ministry of Education, Taiwan, associated with school-based and department-oriented regulations and needs. Currently, the intelligent robots made by VHS students were mostly developed by using extracurricular time and with teachers' special guidance. Actually, the prerequisite knowledge and ability these students owned and applied in producing robots were actually fragmented and not integrated. Even though the knowledge and ability they learned separately were embedded in the curriculum of two departments (DEE and DME), they still were not able to apply them in practical situations. One DME teacher mentioned that at the beginning of the semester, "we taught based on textbooks, we didn't pay much attention to the content related to manufacture of the robot" (110411-T8). Another DEE teacher also mentioned that, "I am responsible for my teaching tasks; I didn't really think about how my course could be integrated with others" (110111-T6). However, the professional development included in this project prompted these teachers to think closely about the existing curriculum framework. Different from the official subject-matter design, they especially worked on finding possible relationships among all courses in both departments in order to design effectively the interdisciplinary content. As shown in figure 2, based on the core concept of "Mechatronics" and its interdisciplinary nature, the content of this inquiry curriculum is related to science, mathematics, and

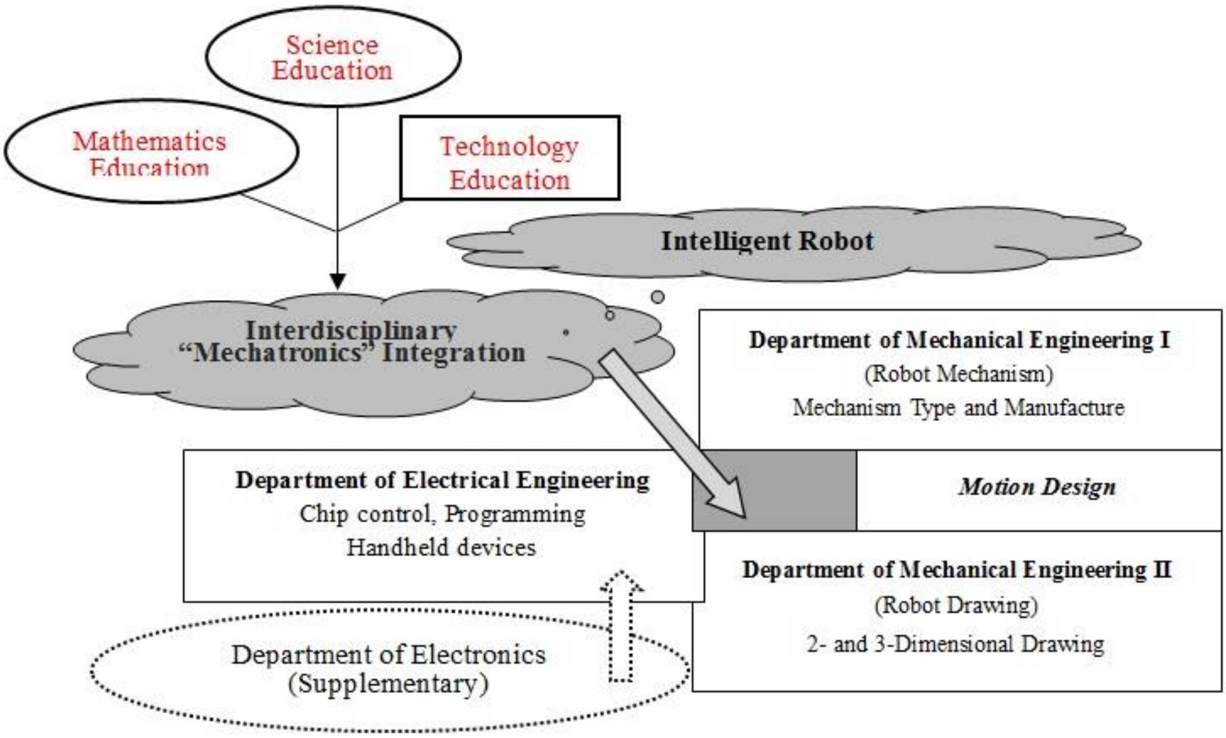

Figure 2. Integrated learning content

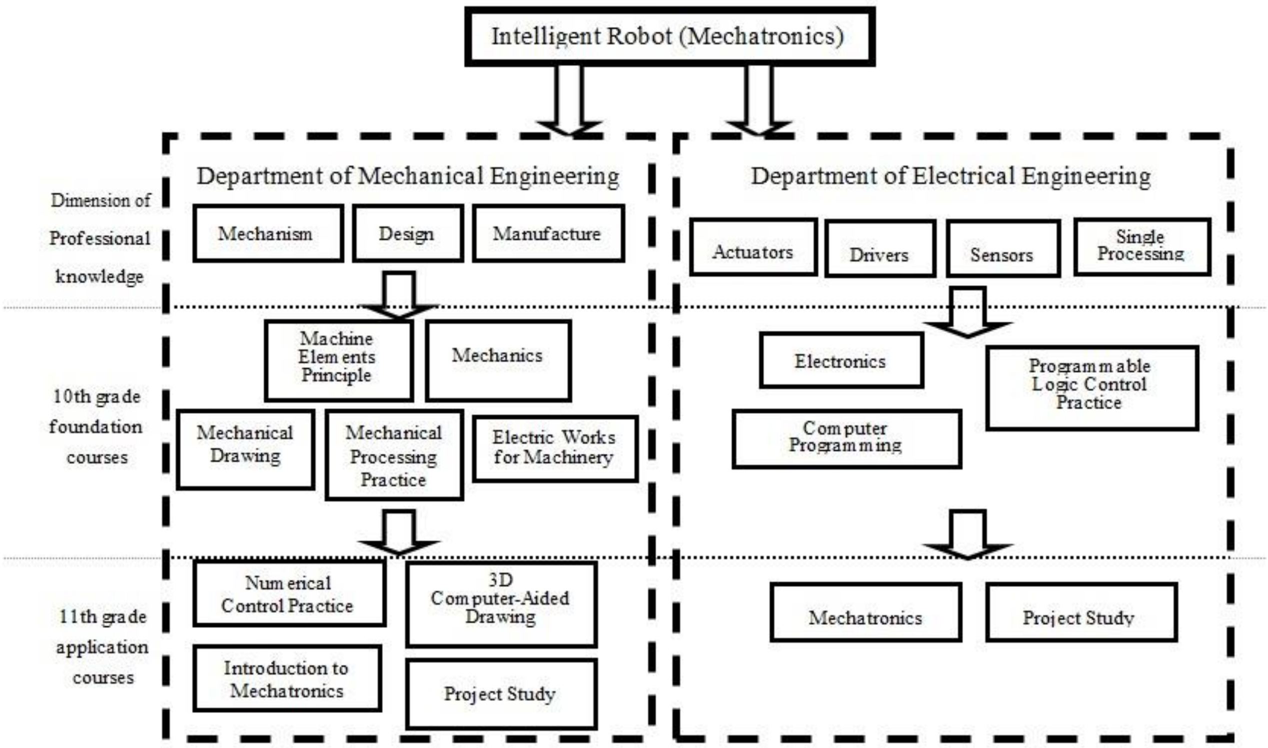

Figure 3. Structure of interdisciplinary inquiry curriculum

technology education. Corresponding courses that teach the targeted content were extracted to design inquiry-based learning activities.

In the design process, most teachers gradually understood how to efficiently integrate the core content of both electrical and mechanical aspects for constructing students' competence in their future designing and manufacturing capabilities of intelligent robots. One DEE teacher elaborated this understanding:

> *We never thought about how to merge those scientific and learning concepts together before. What we are doing now, the interdisciplinary integration, is goal-oriented and conducted based on students' learning needs. We tried to make it more structural and objective-based. Discussions with other teachers exposed me to the attributes of others' experience and knowledge... (050711-T5)*

Actually in the reflective notes, many teachers mentioned that there were too many things that students must learn and master. The traditional curriculum design in vocational high-schools was too segmented, because of the way subject-matter content was organized, to equip students to solve real-life problems by applying what they learned in school. Also, this subject-matter model led to the meaningless learning through rote memorization of the knowledge in textbooks. However, vocational education in the high school level should be problem-based and practical-oriented. We should provide appropriate practical experiences for students to learn problem-solving techniques by using an interdisciplinary curriculum to assist them in grasping core concepts. Teacher T3 mentioned,

> *Our education system was too subject-oriented, but, in fact, various areas of knowledge were interconnected. As I taught the Curvilinear Motion Sliding Table, it was a great teaching aid that could integrate different learning content of several subjects together. It could be seen that its concept was linked to how mechanics worked (Mechanics course), to the design of sliding tables (Mechanical Elements Principle course), to the 2D/3D drawings of tables (Mechanical Drawings course), to the manufacture of tables (Mechanical Processing Practice course), and to the application of Mechatronics concepts in assembling and testing tables (Electric Works for Machinery course). All these efforts were to construct an intelligent robot, which truly required the integration of all prerequisite knowledge. (051511-T3)*

In summary, after participating in this professional development program and going through the curriculum design process, these teachers' conceptions of the curriculum framework transformed the subject-matter model into an interdisciplinary-oriented model. This major change was beneficial to the overall design of the targeted curriculum.

Teachers' view of designing the curriculum—from distinct and diverse to integrated and having agreement

Teachers were from two departments, DEE and DME. Before the curriculum design started, there were no opportunities for them to work collaboratively. At the beginning of the designing process, it was obvious that there were tremendous differences about the initial design conceptions among these teachers of the two fields. DEE teachers thought the integration of "equipment" matched the concept of Mechatronic. On the other hand, DME teachers believed that the movement of a robot must be controlled by the electrical system, so that system was the center of "Mechatronic". This disagreement was finally resolved after a workshop on Mechatronics. As T2 said,

> *About the movement, even though the electric system was not the core concept of Mechatronics, it was one important part of the whole picture. A machine consisted of the mechanism and the electricity, while the electricity included the controller and sensor for the movement". (040612-T2)*

As discussions and collaborative works progressed with the guidance of experts in workshops, an agreement about the core concept was gradually reached amongst them, especially for what kinds of learning experiences they should provide. In order to enhance future competence of inquiry, students were required to have broader views and certain amount of knowledge in related domains, instead of only being good at one domain. Both groups of students could work collaboratively to execute the design and manufacture of intelligent robots, under not only the same structure of the understating of Mechatronics but also the circumstance of understanding each other. Teacher T1 expressed his sentiment,

> *Initially, everyone held subjective viewpoints based upon their own expertise. We didn't have the chance to sit down and discuss before we became involved in this project, and actually I didn't know that there were so much knowledge behind the design and manufacture of robots. After we exposed our perspectives to others, the overall view just came out naturally. We, now, knew which concepts had to be extracted and taught first, and what the next steps were. (080612-T1)*

Additionally, teacher T3 also mentioned how this project brought about a consensus amongst everyone regarding the curriculum design,

> *In the past, we taught routinely based on textbooks, while practical lessons were conducted by asking students to simply follow the stipulated steps. Now, we knew the specific steps in a 5E structure and how to gradually guide students to learn and discover on their own initiative. The majority of us agreed that such a curriculum design could enhance students' capability of inquiry and Mechatronics, so we kept doing it. (083112-T3)*

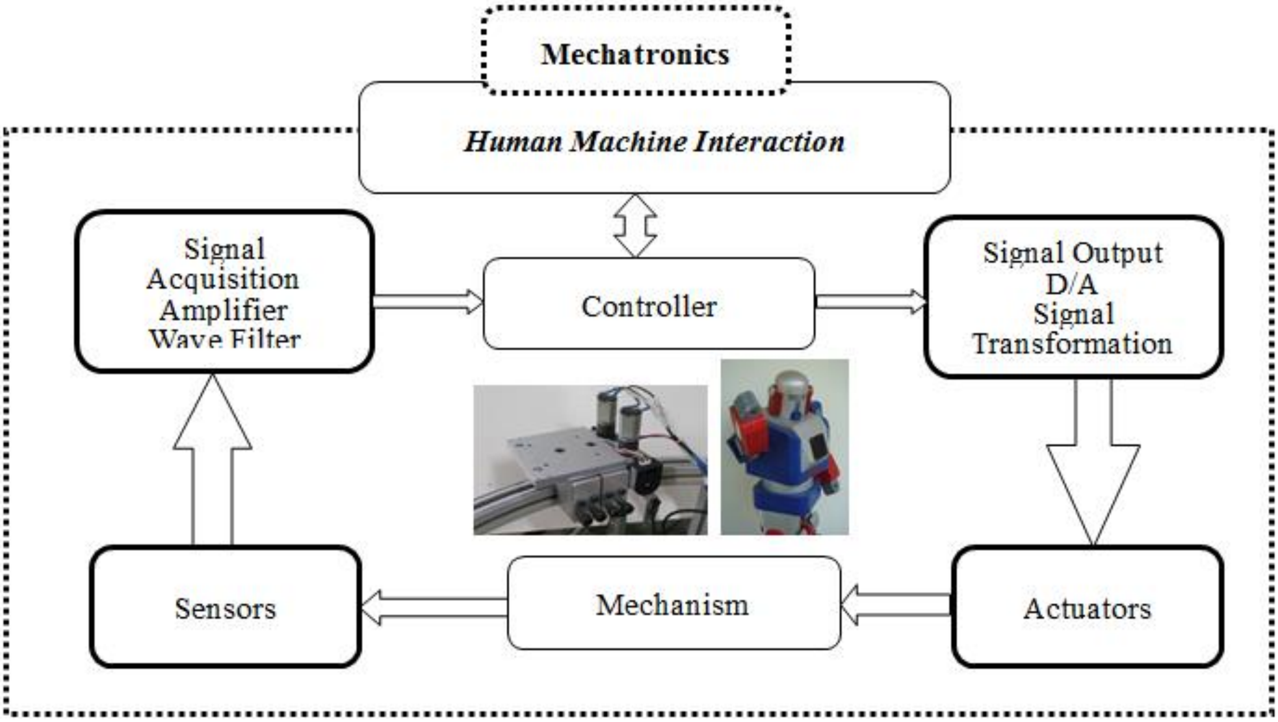

Figure 4. Diagram of Mechatronics

These examples of evidence showed that, in the initial stage, there were many differences and disagreements of the curriculum design among these teachers. However, through the subsequent implementation of the PD, they not only gained professional knowledge but also gradually reached a knowledge-based agreement for the future task (see Figure 4). Unanimously, all teachers agreed that the main goal of the curriculum design was to create "inquiry-based" and "interdisciplinary-oriented" learning whereby their students could acquire the competence for their scientific learning journey.

Content design

Analysis of students' prerequisite and overall competence— from teacher-centered to student-centered

Data from this investigation demonstrated that these teachers' analyses of students' competence was teacher-centered, conservative, and fixed. In the initial stages of the curriculum design, teachers had many doubts about inquiry teaching, mainly because they were not sure of their students' prerequisite knowledge and ability and didn't think their students would fit in this inquiry learning process. For example, some teachers indicated that their students had insufficient background knowledge, and they, therefore, were doubtful about the feasibility of inquiry teaching in their classrooms. As teacher T8 initially mentioned,

> *I think "inquiry" learning for them was too far away from their abilities. Some students did not have good foundational competence (such as mathematical computing) and would require more efforts to achieve higher level work or learn through the inquiry process. You know, mathematical and physical concepts were essential as the key tools of our engineering field. They didn't really have enough tools. (040312-T8)*

Another teacher was also worried about students' fundamental knowledge and self-confidence in learning, which would lead to unsuccessful learning while using the inquiry curriculum. He said,

> *"I was quite worried about their attitude and confidence in inquiry learning, as well as discovering and resolving problems through the cognitive conflict activities we provided" (030912-T5).*

Additionally, they believed that their students were not active learners and required more guidance and assistance from teachers.

In fact, these negative thoughts were based on these teachers' subjective views of their students' capabilities. After a series of PD activities, however, they gradually changed this subjective viewpoint to focus more on authentic needs of their students for the purpose of building their capability of inquiry and interdisciplinary knowledge. For example, teacher T6 said,

> *The professor used the "paper bamboo dragonfly" inquiry teaching activity as an example, which allowed us to participate in the activity as what our students would experience in the future activity we designed. I suddenly realized that, as a learner, what I was required to learn in an inquiry activity; it did not require professional or*

specialized capabilities. The most important thing was the triggering of my curiosity and motivation. (042612-T6)

Gradually, these teachers realized that designing the targeted curriculum required a break from a teacher-centered view and a transition into a student-centered orientation. These changes could be easily found in the interviews of these teachers after the instructional design activities at the later stages of the process; an example is shown below:

R: Why have you changed the title listed in the lesson plan from "teaching objectives" to "learning objectives"?

T2: I thought that I preferred using a student-centered focus instead of a teacher-centered view.

R: Could you compare the difference between the two titles?

T2: The former was used based on my subjective opinion on what my students should learn. The latter was grounded on an analysis of my students' existing knowledge and acknowledgement of their competence. Understanding what my students knew, instead of just focusing on what they didn't know, would help me to design an excellent activity. (082612-T2)

In summary, by holding a subject orient perspective for the analysis of students' competence, these teachers could only discover what students' lacked, and they simply followed the textbooks to teach. However, they progressively altered this teacher-centered view to be more student-centered, which directed them to design an interdisciplinary inquiry curriculum that was intentionally tailored to their students' needs and prerequisites.

The core content—from subject-matter focus to thinking of how to conduct inquiry teaching effectively

At the initial stages, these teachers focused only on the teaching contents and instructional strategies which they were familiar with. In contrast, their knowledge about inquiry teaching was inadequate. Therefore, they would discuss fervently the arrangement of content and some teaching aids, but less satisfactorily on the inquiry teaching part. Teacher T2 indicated at the beginning of the interview,

Content of the curriculum was my expertise, but the inquiry teaching was a brand new method that was so difficult for us, you know, people like us who have taught for a long time! (111211-T2).

At the beginning stages of the PD, it was shown that teachers mainly conducted instruction through narrative lecturing strategies and demonstrating ways to do operational tasks. From the time vocational high-schools focused more on training technical skills and learning the fixed contents of a subject, traditional teaching methods became a better way of reaching the educational goals set up by the official standards. Just as a teacher mentioned,

I believed that this was the case for most teachers [teaching sequential content to standards] in vocational high-schools, as we were trained in this way, so we taught this way; and it somehow worked (041112-T1).

However, such teaching methods were not suited to the inquiry curriculum that they were about to develop. In fact, the main principle of inquiry teaching was that teachers must arrange appropriate activities which allow students to discover problems within a cognitive-conflict scene, and then enable them to search for answers through the process of applying critical thinking skills, instead of teachers just giving answers directly. Fortunately, through intensive discussions within the PD, teachers reoriented themselves into the track of designing inquiry teaching/learning activities. The following evidence was the reflection of a teacher who originally misunderstood the basic principles of the 5E inquiry model:

Initially, I thought that it was just a process. The segmentation of stages was similar to levels of Bloom's taxonomy, where you must complete the lower-level before progressing to the upper-level. Normally, "evaluation" level was the top one, which led us to believe that "explanation" was above "exploration". Now I understood that it was in fact a learning cycle that might repeat if needed, not just a stationary stage or a linear thought. (081112-T1)

Further, they knew that the purpose of inquiry was to allow students to discover problems and place the emphasis on capabilities of actively inquiring and problem-solving. As T5 mentioned,

Inquiry teaching was not about telling students between "right" and "wrong" answers, instead it was to teach students the reason behind those answers they got (081212-T5).

During the PD, these teachers gradually understood the positive impact of inquiry teaching might have to their students. For example, T1 mentioned,

It reminded these vocational high-school students that they needed to have more creativity and innovations instead of just subject-matter knowledge and skills…(041112-T1).

After going through several PD activities and receiving advice from experts, they also began to understand that content of the inquiry curriculum could come from students' daily lives, not necessarily from specific subject-matter knowledge. Said T4,

The professor provided several international inquiry activities in a workshop, such as studying the blossoming of tulips, ingredients ratio in the manufacture of biscuits, etc. These inquiry activities could be found in our daily lives, and didn't consequentially come from abstruse scientific principles (051612-T4).

Finally, it was progressively easier for these teachers to combine subject-matter content with the spirit and model of inquiry teaching in the interdisciplinary curriculum designed. As shown in figure 5 and 6, core concepts that were included in this interdisciplinary inquiry curriculum at the 11th grade were integrated for the instructional design. In the concept maps of the targeted curriculum, the concepts related to "science and mathematics education" fields were exhibited in "ellipse" shapes, while "rectangle" shapes were more relevant to "technology education".

Instructional design

Instructional materials—from existing

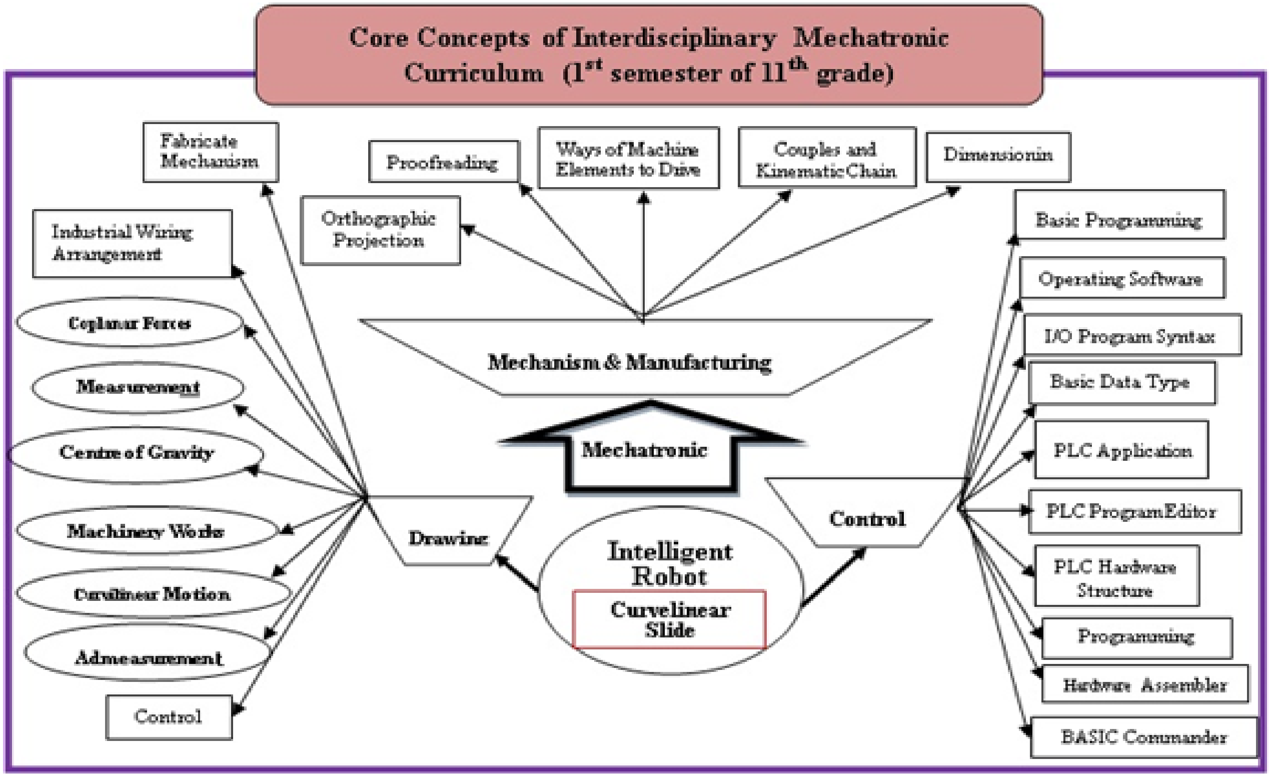

Figure 5. Concept map of interdisciplinary Mechatronics curriculum (1st semester)

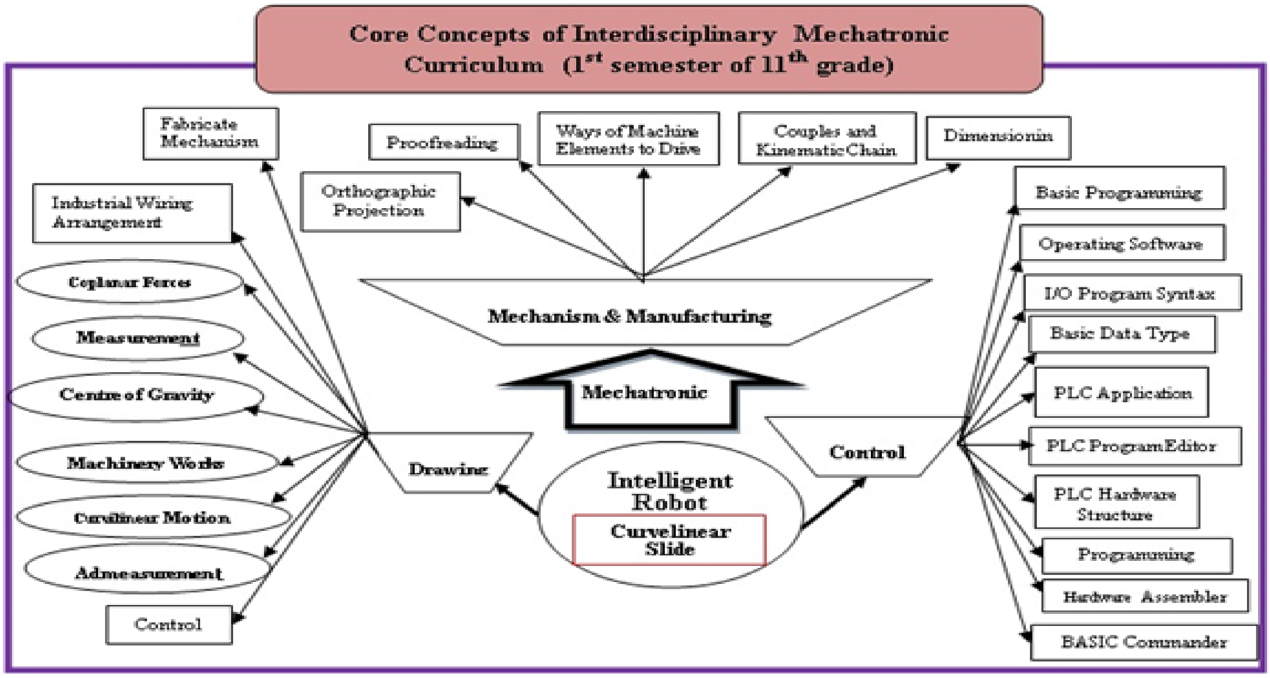

Figure 6. Concept map of interdisciplinary Mechatronics curriculum (2nd semester)

textbooks to newly-developed materials and teaching aids

At the beginning of the instructional design process, teachers were not used to compiling or make up their own teaching materials. For most theoretical courses, instructional content was taught based on official textbooks in conjunction with teacher's manuals. T2 reflected that,

We taught for more than a decade using fixed teaching materials, which was easy for us. But it led to laziness, rigidity, and no improvement, I think (121111-T2).

Most teachers felt that using standardized teaching materials led to stagnancy of both teaching tasks and teachers' professional development. Under this stagnant circumstance, teachers also expressed their frustration since there were no opportunities to work and learn together as a team, even though they psychologically had positive expectations of moving forward. Participation in this project did help to exert appropriate pressure on them to spur professional growth and provide opportunities for interactions and dialogue both academically and affectively.

I believe that this is a good project, which does help us in designing the curriculum and using new teaching methods. Without this project, I would be still teaching according to the standardized guidelines and not creating my own teaching materials; especially, I won't get the chance to discuss and collaborate with others to make new teaching aids. It is indeed better to have some pressure and help. (052112-T4)

Requiring teachers to compile their own teaching materials was the main objective of the project in the first year. However, through close observations, it was found that these teachers' attitudes about compiling their own teaching materials gradually changed from "passive" to "active". One teacher mentioned that after participating in an extensive amount of PD activities,

To be honest, this is necessary! We needed to compile our own materials before teaching in order to better understand what should be taught and what the key contents of Mechatronic were (040612-T2).

Another teacher also said near the end of the first year,

The professor required us to start writing from the rationale of the curriculum design, and then kept going on confirming goals and objectives, compiling teaching content, merging inquiry activities, and finally designing assessment tools and learning sheets. This allowed us to ask ourselves why we were designing this particular content/course, what to focus on, and how to teach later. Therefore, it was a series of connected thoughts and integrated content. (070712-T7)

Moreover, teachers designed their own teaching aids, which was a good way of showing their professional understanding of the subject and a great way of encouraging students to show more enthusiasm. This process also resulted in specific dialogues for the teachers' professional development. For example, a "Curvilinear Motion Sliding Table" (see figure 7) was made mainly by teacher T1 with simple and cheap materials, and it won the praise of other teachers. Eventually, they decided to use this teaching aid as a theme for all teaching content in the first year. T1 confidently stated that, "I spent just three thousand dollars to make this aid, which was better than spending triple amount to buy one" (040612-T1).

In short, though these teachers were initially passive in designing teaching materials and aids, their attitude and behavior gradually transformed to an active approach. Additionally, teachers' use of teaching resources became increasingly diversified, e.g. they created movie clips and pictures relevant to the teaching concept. This change and development deserved to be noticed and appreciated.

Assessment—from summative paper-pencil tests to adding more formative and authentic assessment tools

These teachers mainly used standardized tests as

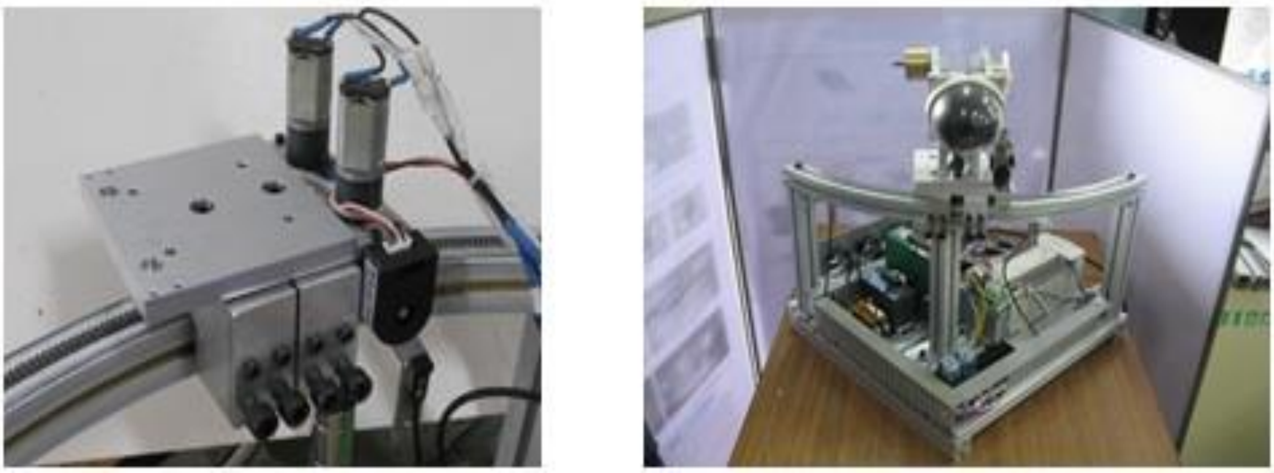

Figure 7. Curvilinear Motion Sliding Table and its application

summative assessments. T8 explained it as follows:

For theoretical courses, we computed scores through tests. Answering a question correctly implied that you understood, and vice-versa; it's fair. For practical training courses, those who performed better would earn better scores, though it would be tested through technical operations. The majority of the grading task was based on the final examination, with little concern of formative performances. Sometimes there is a mid-term. (120711-T8)

Before participating in this project, most teachers would adhere to the school's request and mark students' learning outcomes by giving them final scores. Some teachers believed that, "test results would show whether or not the student had mastered the content" (120711-T8); while some believed that, "giving a score was definitely a symbolic requirement, though it didn't necessarily reflect students' mastery status" (120911-T2). In fact, they knew that one of the purposes of using assessment was to examine students' learning outcomes, even though some of them were skeptical about their earlier approach. Nevertheless, most of them didn't think about another role of the assessment, which was to evaluate the effectiveness of a teacher's instruction. Another aspect of their initial assessment approach was reliance on the use of paper-pencil tests, which focused only on students' cognitive understandings.

As the professional development experience progressed, the dialogue within the team intensified, and they began to understand the importance of evaluating students' thoughts, attitudes, and behavioral change. T1 indicated that, "inquiry is a problem solving process, thus it is important to evaluate students' skills of observation and data collection" (040412-T1). T2 also said, "I tried to connect the theory and the practice, so I provided practice by allowing them to simulate scenarios and write down possible solutions and processes (051112-T2).

Due to the use of inquiry teaching and the integration of mechatronics in targeted courses, teachers were prompted to think about possible changes of instructional designs. They comprehended that multiple assessments were essential for improving both students' learning outcomes and their own teaching performances. They also realized that these assessments must be authentic and dynamic in order to conform to the inquiry teaching design, which allows them to assess students' "true" understandings and capabilities. Within the lesson plans, they tried to employ multiple assessment tools for observing students' inquiry and discussion processes, learning sheets, and oral presentations instead of just using paper-pencil tests. This implied that they didn't emphasize the final result, but the inquiry process. T9 reflected on these changes while evaluating his instructional design activities at the end of the semester,

Previously, I viewed "assessment" as the final stage of teaching, after which there was nothing left to do! Now I realized that assessments needed to be conducted constantly throughout the teaching process, including small tests, learning sheets, and rubrics for practical operations. It allowed me to examine if students have mastered the content and how to design the next class. (081112-T9)

In summary, it was found that these teachers did expand the scope of assessment from only testing students' cognitive understandings to their diverse competencies after participating in the PD program. Both formative and summative assessments were employed in their instructional design to help them to develop better understandings of their students' actual learning situations. Therefore, they could happily say that: "assessments became a helpful tool for promoting students' learning and my own teaching" (081112-T7).

DISCUSSION AND IMPLICATION

Essential aspects and consequences of the learning by doing process in designing inquiry curriculum for vocational high-school teachers

Teaching students how to authentically conduct scientific inquiry is an essential reform effort of recent science education. The use of inquiry-based curriculum and instruction is gaining favor throughout education since it improves scientific skills through the process of critical thinking (Anderson, 2007; Windschitl, 2004). Research also indicates that teachers can struggle to implement inquiry as a result of their own lack of authentic inquiry experience (Windschitl, 2004). As shown in this report, the participating teachers faced similar struggles during the inquiry design process. With the assistances of PD, they progressively moved from more teacher-centered mindsets to student-centered actions incorporating inquiry, including the content of the design, the organization of the activity, and the assessment of the performance. This transformation confirmed the opinions of Loucks-Horsley et al. (2010), which indicated that teachers' professional development within a learning organization helps them to implement the philosophy of "learning by doing". Through intensive discussions, teacher participants in this study engaged in opportunities of "learning by designing" and "learning through interacting", which were truly essential for their professional growth of inquiry. In addition, by employing this "student-centered" inquiry teaching approach, students' competences of scientific inquiry were enhanced (Author, 2014) [Note: This part of results is not included in this paper], which paralleling the findings of related studies (e.g. Lin et al., 2014).

Moreover, the findings of this study is correspondent to previous studies (Akerson & Hanuscin, 2007; Luft, 2001; Supovitz & Turner, 2000), providing proper professional development programs to in-service teachers was so valuable that both their professional growth and belief change helped them develop and implement inquiry-based curriculum and instruction. However, the professional development program employed in previous studies (e.g. Akerson & Hanuscin, 2007; Supovitz & Turner, 2000) were usually in a single format (e.g. workshop) and a shorter or discontinuous period of time (e.g. two weeks, monthly, or 80/160 hours totally). In this study, we provide a "long-term and continuous" (i.e. one year for curriculum design and two years for experimental implementation) and "multiple types" (i.e. workshops, weekly meetings, monthly exchanges, and individual discussions) professional development programs, which were composed of three categories of content. This design is authentically useful in developing the targeted teachers' inquiry teaching practices in real settings. Consequently, this study showed how these teachers adjusted their knowledge and experience of designing proper curriculum and instruction in an inquiry-based framework. Since engineering is a field that is crucial to pursuing the world's challenges and exposure to engineering activities (e.g., robotics)" (NGSS Lead States, 2013) is crucial for attracting youth to this field, this engagement is particularly essential for these vocational high-school teachers who have ordinarily taught science and engineering courses in traditional ways that have had less appeal to students. This perceptional and behavioral change also is beneficial to vocational high-school students in that they can explicitly learn, through robot design practices, to solve real life problems, as well as pursuing "more complex engineering design projects related to major global, national, or local issues" (NRC, 2012, p. 71) by the time they leave the school. This research explicitly studied teacher attitudes and practices, with the assumption that such changes will impact student learning and behavior. The next research steps will be focused on how the teachers implement the designed curriculum within the classrooms and whether their students' inquiry performance actually reaches the designated goals.

Innovation of applying interdisciplinary structure into inquiry learning process for robot design

The teachers in this study benefitted greatly by learning both to appreciate inquiry, participate in inquiry development processes, and design curriculum and instruction based on an inquiry approach to education. In addition to reaping the fruit of inquiry, these teachers, originally from two separate departments, tried to work together in designing an interdisciplinary thematic curriculum leading to success in disenthralling traditional standard-based and subject-matter trammels. For a long time, Taiwanese vocational high-school teachers were enthralled in the standard-based structure, where they taught in a subject-matter manner, used the same textbooks, and assessed their students with standardized tests. They never thought about conducting interdisciplinary tasks for better learning environments. With the contribution of this project, the PD did furnish them with adequate capabilities to rethink how to innovate in designing an interdisciplinary-based curriculum. Indeed, this inquiry curriculum for robot design, initiated by teachers in practical settings, generated the possibility and feasibility of reforming the vocational high-school learning environment. Although traditional instruction often remains the standard in high school science classrooms (Lotter, Harwood, & Bonner, 2007), this disenthralling effort provides a valuable example both in promoting teachers to pursue further professional development and to provide students better opportunities to learn through scientific inquiry processes and interdisciplinary strategies.

However, the professional development program employed in the previous study of Supovitz & Turner (2000) was about "subject-matter" inquiry-based teaching practice, which was aligned to the NSES standards (NSC, 2000). In this study, we employed the newest announced science standards "Next Generation Science Standards (NGSS)" (NGSS Lead States, 2013), which emphasized the "interdisciplinary" conception (e.g. STEM). Similar to Park's (2006) study, we integrated three content areas (i.e. mathematics, science, and technology) in designing the interdisciplinary inquiry curriculum. This integration, i.e. both in this study and Park's study, could serve as empirical evidences of successful innovations on applying interdisciplinary structure into inquiry learning process.

Moreover, the core concept of "Mechatronics" is closely related to the "robot design" in contemporary technology field worldwide. The Obama administration also endeavors to emphasize this robotics issue for future technology development of their children (The White House, 2014), which is also relevant to their future life and jobs. In fact, this "robotics" innovation task can be integrated into the engineering field in vocational high schools. From a global perspective, engineering offers vocational high-school students invaluable opportunities for innovation and creativity (NGSS Lead States, 2013). Likewise, participation in this High Scope project not only helped these teachers understand the crosscutting concepts and disciplinary ideas of science and engineering but also provided a possible future opportunity for VHS students to learn scientific knowledge and engineering design meaningfully and practically. Through this actual doing process, students can be inspired and motivated to recognize that what they learn in the school can relate to their current and future lives and contribute to meeting many of the major challenges that confront society today. Since, "one of the principal goals of science education has been to cultivate students' scientific habits of mind, develop their capability to engage in scientific inquiry, and teach them how to reason in a scientific context" (NRC, 2012), we, as science educators in Taiwan, should endeavor to support our vocational high-school teachers' professional growth in interdisciplinary curriculum design incorporating inquiry, and then prevent from misrepresenting science and marginalizing the importance of engineering. Therefore, further explorations would be useful for identifying whether the PD program of this project might be a reliable model for future innovative plans. These plans may also lead us to a better understanding of how to cultivate our vocational high-school teachers to produce better quality teaching.

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