Journal of Education in Science, Environment and Health

www.jeseh.net

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**ISSN:** 2149-214X

Journal of Education in Science, Environment and Health
Volume 4, Issue 1, 2018 DOI:10.21891/jeseh.389740

# Using Inquiry-Based Strategies for Enhancing Students' STEM Education Learning

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## Article Info

***Article History***

Received:
06 September 2017

Accepted:
30 December 2017

***Keywords***

Higher education
Inquiry-based instruction
Science education
STEM education

## Abstract

The major purpose of this study was to investigate whether or not the inquiry-based method is effective in improving students' learning in STEM (Science, Technology, Engineering, and Mathematics) education. Both quantitative and qualitative methods were used. A total of 73 college students studying Information Technology (IT) were chosen as participants. The instructional strategy used in this study was inquiry-based instruction. Participants were asked to answer a course satisfaction survey which utilized a 5-point Likert-type scale (a grade of 1 for least satisfied and 5 for highly satisfied); data obtained underwent means analysis. In addition, qualitative data including students' learning feedback and instructors' teaching feedback were collected and analyzed. The findings of this study includes: (1) students were highly satisfied on the STEM education learning program used in this study; (2) students' learning feedback also showed that they approved inquiry-based learning; and (3) instructors' teaching feedback showed that they preferred inquiry-based instruction as a teaching method. It can be concluded that the use of inquiry-based instruction can improve college students' STEM education learning.

## Introduction

In recent years, limited higher education resources have made it difficult for Taiwan to keep up with the advancement of the global economy; this in turn, widened the knowledge-action gap in college education and caused disequilibrium in the supply and demand of undergraduates. Relative issues have been explored by many researchers (Chang & Kuo, 2008; Chang & Li, 2014; Chang & Tseng, 2014; Chang & Yuan, 2014; Chen & Lin, 2012; Kuo, 2014; Lai & Sheu, 2016; Lai, Tsai, & Yeh, 2015; Niu, 2014; Wu, 2014). Chen (2014) emphasized that rapid social changes, industrial transformation, and rapid expansion in higher education had created a knowledge-action gap and supply-demand disequilibrium in Taiwan's talents cultivation. This problem needs to be solved immediately.

Taiwan's Ministry of Education strongly advocates the streaming of the curriculum; a system which stresses that a university or college should offer not only academic disciplines but also practical ones. This course system aims to achieve knowledge-action integration in college education (Lai & Sheu, 2016) by closing the knowledge-action gap between academic training and industrial requirements for undergraduates, and reducing retraining that college graduates have to take when they enter the job market. Kuo (2014) pointed out that colleges and universities should strengthen students' international competitiveness and sustainably produce senior talents who can apply what they have learned.

In order to implement the knowledge-action integration initiative in higher education and to improve students' professional knowledge and skills, this study used industry-academy collaboration, which is an inquiry-based teaching model, to explore college students' academic performances in STEM courses.

## Literature Review

### The Development of Higher Education

Zhu (2013) pointed out that, in the era of globalization, the change of vacancies in job markets is accelerated by innovation, rapidly changing industry structure, and the increasingly frequent and complicated mobility of talents. For this reason, colleges and universities must innovate or reform teaching contents and methods in order to enhance students' competitiveness in job markets. He further emphasized that colleges and universities should enhance students' practice-oriented skills to meet enterprises' demands for innovative and professional talents. This may help college students smoothly start their careers upon graduation, reduce the ever-widening knowledge-action gap, and lessen the disconnection between education and industrial demands.

In 2012, the Council for Economic Planning and Development of Taiwan (2012) proposed a special scheme: *Plan for Reducing the Gap between Learning, Training, Examination and Employment* to fill the knowledge-action gap. In addition, Chen (2014) stated that observing overseas educational policies and practices may be helpful in solving this problem. For example, the European Union's human resources development established a program that mainly aims to: (1) urge the European people to have continuing education and to promote the quality of lifelong education; (2) promote the quality of career training and strengthen the multinational cooperation in career training; (3) help European youth develop professional knowledge and skills that the new era needs; (4) integrate academic research and social needs; (5) promote the collaboration between higher education institutes and enterprises.

Several researchers have proposed that colleges and universities should increase industry-academy collaboration, offer practice-oriented courses, and improve teachers' practical ability by enhancing their communication to effectively mend the knowledge-action gap (Chang & Li, 2014; Chen, 2014; Lai & Sheu, 2016; Lai, Tsai, & Yeh, 2015; Lee, 2013; Vinson, Reardon, & Rertoch, 2014; Wang, Huang, & Hsu, 2017; Yang, 2013). Yang (2013) suggested that to assist students' to find a job upon graduation, the design of practice-oriented courses should be based on industrial demands and social expectation, and the content of courses should help students develop their professional quality and innovation capability. In this way, colleges may closely combine schooling and employment and obtain greater educational and economic benefits.

Zhu (2013) held that when offering practice-based courses, an educational institution must first determine what competencies these courses can develop to help students in their chosen career after graduation. After that, various practice models including workplace experience, technical training, research participation and development, or establishment of a business should be used to promote the teaching.

Yu (2013) pointed out that practice-based courses could be taught and researched in the following two ways: (1) actively encourage teachers to observe and intern in enterprises to allow better understanding of their latest equipment, technology, industrial profile, and demands for talents, and closely integrate them to theories and practices; (2) invite industry experts to participate in team teaching. This may help enhance students' understanding of current industry trends which may aid in deciding their future career direction, and promote the benefits of industry-academy integration.

Chiu, Hsu, and Teng (2015) further stressed that higher education institutions should establish an industry-academy alliance with enterprises to provide an environment for practice-oriented courses learning and an opportunity to increase students' project experience and professional practice. Practice-based learning can help cultivate students' various abilities such as problem solving, communication, innovation, and interdisciplinary learning, which can transform learned information to professional knowledge.

In recent years, a growing number of researches have been conducted on the promotion of practice-oriented courses. The results showed that practice-oriented courses could improve college students' professional knowledge and skills (C. C. Chang, 2013; C. F. Chang, 2013; Chiu, Hsu, & Teng, 2015; Lo & Lee, 2014; Wang, 2013; Yu, 2013). Wang (2013) explained that long-term cooperation between academic departments and industry alliance could expand the added value of industry and academy, create new driving force for industry development, and foster an industry-oriented learning environment. This will help students gain industry information, develop technical skills, and improve employment competencies.

In summary, the problems brought by the knowledge-action gap and the supply-demand disequilibrium in the development of higher education in Taiwan require an immediate solution. The above literature review shows that increasing industry-academy collaboration and offering practice-oriented courses, two effective strategies to bridge the knowledge-action gap, are worth further exploration.

**STEM (Science, Technology, Engineering, and Mathematics) Education**

Human resource in science and technology is a fundamental aspect to a country's economic development; college students as future professionals in the field of science and technology are its important source. In recent years, due to the rapid change in the field of science and technology and the rise of interdisciplinary integration, STEM (Science, Technology, Engineering, and Mathematics) education has been in the limelight. Fan & Yu (2016) pointed out that STEM education was not only an issue that has aroused the attention of American educational circles, but also the focus of curriculum reform in many countries. This is because a number of advanced countries like the United States, have fully realized that students' academic performances in science, technology, engineering and mathematics determines a country's economic development and competitiveness.

STEM education is an integrated education that combines scientific inquiry, technology, engineering design, and mathematical analysis into a cohesive learning paradigm, including curriculum content, teaching activities, and educational policy. It aims to cultivate a country's future STEM talents and enhance its competitiveness. In addition, interdisciplinary courses may help increase students' interest in science, technology, engineering, and mathematics and keep students in line with modern science and technology (Chang & Yang, 2014; Duran, Höft, Lawson, Medjahed, & Orady, 2014; Fan & Yu, 2016; Liu, Wu, Hsieh, & Shen, 2013; Lou, Tsai, & Tseng, 2011; Oyana, Garcia, Haegele, Hawthorne, & Morgan, 2015; Reeve, 2015).

Chang and Yang (2014) pointed out that STEM was highly valued in American science education because it is an interdisciplinary approach that integrates science, technology, engineering and mathematics. The curriculum design can be linked to the development of modern science. Classroom discussions and hands-on training in this curriculum allow students to understand conceptual and procedural knowledge, and promote teamwork skills and creativity. Fan and Yu (2016) explained that STEM education emphasizes the cultivation of new abilities in the 21$^{st}$ century, aimed at developing knowledge, attitudes, skills and abilities needed for Taiwan solving real-world problems and for adapting into the ever-changing modern society. Fan and Yu (2016) also summarized five targets of STEM education in the United States: (1) construct integrated STEM literacy; (2) improve American competitiveness in the 21$^{st}$ century; (3) prepare America's STEM labor force (career exploration); (4) foster learning interest and stimulate participation willingness; and (5) develop the ability to connect STEM interdisciplinary knowledge.

Chang and Yang (2014) further noted that the former American president, Barrack Obama, had launched a plan to create the *STEM Master Teaching Corps* which aimed to applaud and award excellent STEM educators in America and improve the teaching of STEM practice. The plan was designed to improve students' performances in science and mathematics, develop their critical thinking, and promote their career competitiveness. In 2014, Obama expanded the plan and put forward a strategy to cultivate STEM talents across the United States.

Fan and Yu (2016) stated that STEM education focuses on guiding students to develop their ability to integrate interdisciplinary knowledge, stimulating their interest in STEM learning, and in helping them develop skills for future employment in STEM jobs as well as STEM literacy a global citizen should have in the 21$^{st}$ century. They further pointed out that STEM programs often have the following essential attributes: (1) using real-world issues or problem situations; (2) designing a project-based, problem-oriented, or inquiry-based learning curriculum; (3) having explicit course objectives, content domains and learning indicators; (4) providing student-centered learning experiences; (5) stressing the connection and integration of STEM knowledge; (6) valuing the cultivation of high-level thinking such as logical thinking, problem solving, and critical thinking; and (7) emphasizing the connection between curriculum and job markets.

In terms of the implementation of STEM as a teaching method, Bybee (2010) suggested that challenging tasks or questions can be utilized to stimulate students to use STEM to find solutions. In addition, the knowledge students acquired in the process of problem inquiry and the abilities they developed in the process of seeking solutions can be measured by common core standards or other national competence standards (i.e. the Technology and Engineering Literacy Assessment developed by the National Assessment of Educational Progress (NAEP)).

With regards to the promotion of STEM teaching activities, scholars suggested that inquiry-based teaching strategy should be used to promote technology exploration, to practice teaching at a higher level, and strengthen the effect of STEM teaching (Barry, 2014; Chang & Yang, 2014; Cheng, Yang, Chang, & Kuo, 2016; Lai & Sheu, 2016).

Chang and Yang (2014) and Barry (2014) unanimously recommended adopting the 6E instructional model to improve the effect of STEM teaching. The model is an inquiry-based teaching strategy whose major teaching procedures include: (1) engaging, (2) exploring, (3) explaining, (4) engineering (elaborating), (5) enriching, and (6) evaluating.

To sum up, the purpose of STEM education lies in helping students improve their learning motivation for STEM courses and enhance STEM literacy, and in understanding how STEM knowledge can be utilized to solve real-life problems. Since human resources in science and technology is the basis of a nation's economic development, students should be encouraged to explore STEM fields and be supported to improve their academic performance in science, technology, engineering, and mathematics to promote economic growth and competitiveness of Taiwan.

## Methods

This study utilized both quantitative and qualitative methods. A total of 73 undergraduates majoring in Information Technology (IT) in an academic institution were chosen as participants. Based on the literature review, the curriculum design and arrangement used emphasized the implication of industry-academy collaboration and practice-oriented courses, and introduced inquiry-based instructional strategy. The holistic course included lectures, game script planning, discussions and interactions with experts in IT, practical exploration and procedural design, and presentation of project results. The entire program was run for two semesters and about 21 instructors participated in this study.

The courses were implemented and measured in three stages: (1) curriculum planning, (2) teaching and learning, and (3) practice and examination. For curriculum planning, the core teaching objectives and content outlines of the courses offered in this study were determined by college instructors who had consulted industry experts. For teaching and learning, the practice-oriented courses were taught through team teaching or seminars coupled with teaching activities conducted by instructors in corresponding departments. Lastly, for practice and examination, learning outcomes were measured jointly by the industrial and educational circles based on students' performances during internship or final presentation.

This study collected and analyzed both quantitative and qualitative data. Based on the evaluation model proposed by Kirkpatrick and Kirkpatrick (2007), a course satisfaction survey was administered (measured using a 5-point Likert-type scale with 1 being the lowest point and 5 being the highest point; Cronbach's α is equivalent to .89) to gather quantitative data and utilized frequency distribution and means to analyze the data. The course satisfaction survey has 8 items and 3 open-ended questions. In addition, students' learning feedback and instructors' teaching feedback were collected for qualitative data analysis. During qualitative data analysis a triangulation and cross-case inductive analysis was conducted to confirm the reliability and consistency of the data analyses and results (Bogdan & Biklen, 1982; Guba & Lincoln, 1999; Patton, 1999; Silverman, 2000).

## Results and Discussion

During the implementation of the IT program, this study integrated cloud computing technology and the implication of the living smart course, and trained students in functional requirement analysis, specification, program development, and software-hardware integration to cultivate their system integration and innovation ability. Competition and practical projects were utilized as a learning outcome measurement. Instructors were asked to plan the teaching content and paradigm for their lectures in advance to help students understand the structure of application systems and the use of function modules. To measure the learning outcome, students were encouraged to design questions by themselves or discuss them with the instructors. This trained students to design function modules on their own or develop new application systems. After they finished their work, they were given an opportunity to learn from each other before the presentation of the final results which were rated by industry experts.

Feedback from students and instructors on practice-oriented courses were collected after the implementation of the holistic course program. All participants respond to the survey and qualitative questions, and the response rate is 100%. The Means and the Standard Deviations of program satisfaction by students and instructors are shown in Table 1. The students' and instructors' satisfaction were rated 4.15 and 4.20 (based on a 5-point Likert-type scale) respectively. The results showed that both students and instructors approved of the IT program.

Table 1. The means and the standard deviations of program satisfaction by students and instructors

| Group | *N* | *Mean* | *SD* |
|---|---|---|---|
| Students | 73 | 4.15 | 0.67 |
| Instructors | 21 | 4.20 | 0.59 |

In addition to the formal curriculum, two industry-academy interaction workshops were held to deepen students' professional practice and inquiry ability. The practical courses taught by industry experts could expand students' various practical abilities, improve their understanding of the application of smart cloud monitoring and the trend of cloud computing industry, and promote their abilities to establish ties with enterprises.

The Means and the Standard Deviations of workshops satisfaction by students are shown in Table 2. The average students' satisfaction rate was 4.35 (based on a 5-point Likert-type scale), which indicates that students were satisfied with the industry-academy interaction workshops. In addition, instructors also showed positive responses to the training method. Instructor Benjamin stated:

> This program not only presented how practical products are developed in the industrial circle, but also provided students with the chance to practice the whole production process of remotely controlled aircraft, and allowed them to finish the trial flight. Further, inviting industry experts as lecturers was conducive in learning practical abilities because their experiences could help students understand work ethics better and adapt to various work pressure.

Table 2. The means and the standard deviations of workshop satisfaction by students

| Group | *N* | *Mean* | *SD* |
|---|---|---|---|
| Students | 73 | 4.35 | 0.72 |

Moreover, the course plan also included a trip to visit the industry. Students were organized to visit an exhibition center. The on-site visit aimed at helping students understand the industrial environment, equipment, and products. The staff on duty was tasked to explain workplace processes which enhanced students' understanding of what occurs in the industry and the developmental trends. During industry visits, students experienced many applications for the Internet of Things in the SIGMU's exhibition center (SIGMU is a security enterprise group in Taiwan) at the Neihu District, Taipei, including smart e-mail, intelligent parking system, earthquake early warning service system, and various interesting devices for smart living.

The Means and the Standard Deviations of field trips satisfaction by students are shown in Table 3. The average students' satisfaction rate on the tour was 4.70 (based on a 5-point Likert-type scale), which indicates that students were highly satisfied with the industry visit. Some of the feedback provided by the students included: "*I now know SIGMU better and the Internet of Things makes life very convenient", "I learned how to use mobile devices and the Internet to manage my life* "; "*I understood the use of the Internet of Things in the market*". In addition, instructor Robert stated, "*The knowledge shared by the industry can enhance students' understanding of enterprises, increase the probability for industry-academy cooperation, and strengthen the communication between the academy and the industry."* It is clear that both the quantitative and qualitative feedback from students and instructors were concurrent; both approved of the above industry visits.

Table 3. The means and the standard deviations of field trips satisfaction by students

| Group | *N* | *Mean* | *SD* |
|---|---|---|---|
| Students | 73 | 4.70 | 0.78 |

An exhibition was held at the end of the term for students to display their achievements in practice-oriented courses and projects. This open method provided an opportunity for them to observe others' results and learn from each other, and helped them improve their learning outcome. A total of 15 groups presented mobile game applications as projects in the exhibit. This hands-on training could help students effectively integrate theory and practice. In addition, both students and instructors showed affirmative and positive responses to the results-sharing training method. Instructor William mentioned:

> The project-oriented achievement exhibition utilized in this study enabled students to learn by through action. They were allowed to design the mid-term and final projects on their own, including the designs and functions of the applications. This shows that through appropriate curriculum articulation and applied design, design and programming can be integrated as one course.

Apart from attending the project achievement exhibition, students also joined and presented their works in the competition held by enterprises and achieved good results. For example, one project entitled *"The Study and Establishment of Pseudo-Hologram System",* won the second prize in the *SYSTEX Cup Apps Creativity Contest*. In addition, another project also achieved second place in the *Wheeled Mobile Robot Tracking-Lego Group A* category in the *2016 Asia Intelligent Robots Competition.* This means the practical training can significantly enhance students' knowledge and skills in Information Technology. One of the students who participated in the intelligent robots competition stated:

> With the injection of project funds, we were able to use the latest Lego Mindstorms to conduct experiments. This helped us improve our practical ability and integrate electro-mechanical knowledge and skills which enabled us to obtained good results in the robot competition.

As can be observed from the above discussion, this curriculum program utilized a practice-oriented and inquiry-based teaching method. After taking practical courses and participating in relevant activities, students were able to create excellent works and achieved good results in a professional competition. The findings are consistent with the findings of Chang & Yang (2014), Cheng, Yang, Chang, & Kuo (2016), Lai & Sheu (2016), and Lo & Lee (2014). The recognition from the industry field indicates that the program could improve not only students' practical ability but their willingness to learn and take responsibility for their own learning. In addition, through industry-academy interaction and industry visits, students could contact the industry in advance and have a chance to communicate with enterprises and learn from them. This experience could help them decide future career development and could stimulate their eagerness to be employed upon graduation. The results showed that the curriculum program provided benefits for students and improved their STEM knowledge and skills.

## Conclusion

The purpose of this study was to explore whether or not the inquiry-based teaching method is effective in improving undergraduates' STEM academic performances. A curriculum program that employed industry-academy collaboration and an inquiry-based teaching method was utilized in this study to help implement knowledge-action integration in higher education and improve students' knowledge and skills in industry-academy practice. The results showed that students had affirmative and positive feedback on the program. Additionally, they were also satisfied with industry-academy interaction workshops and industry visits.

After completing the program, students were able to design a mobile game application which was an indication that students' performances in acquiring knowledge and skills in Information Technology and STEM have enhanced. Furthermore, improvements in practical exploration, and the willingness to learn and take responsibility for their own learning were also observed. Based on the results, this study held that the training in practical exploration was indeed conducive in advancing college students' STEM academic performances. Therefore this study recommended the use of industry-academy collaboration and an inquiry-based teaching method should be further promoted.

## Acknowledgement

This study was funded by the Ministry of Education, Taiwan.

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