Introducing scientific inquiry into the core capability indices of project-learning courses

Chin-Wen Liao, Ta-Chun Chang, Ming-Shang Su & Yao-Tsung Chiang

National Changhua University of Education
Changhua, Taiwan

ABSTRACT: This study introduced inquiry-based learning into project-learning courses for students majoring in electrical and electronic engineering in vocational high schools and constructed core capability indices (CCIs) for these courses. Initially, after compiling the dimensions and implications of each capability through a literature review, this study conducted a 3-round Delphi process to establish a CCI framework by administering a questionnaire survey to 19 experts. Subsequently, this study designed a 9-point scale and applied the analytic hierarchy process to the responses of the 19 experts, performing paired comparisons among the indices, testing consistency, and obtaining the weight of each index. Afterwards, on the basis of the constructed CCIs, a questionnaire survey was administered to 225 students. An importance-performance analysis was performed to determine the importance levels expected by the experts and the students' satisfaction toward their actual performance.

INTRODUCTION

In five years, Taiwan could experience a negative population growth. The most recent population projection by the National Development Council indicated that if Taiwan experienced zero population growth during the three to four years preceding 2019, the country's population growth would become negative after 2019. If this trend remains unchanged, Taiwan's population may decline to 16.6 million by 2061 (70% of the current population), with the number of older people escalating and affecting the nation [1]. According to its government, Taiwan is encountering a rapidly aging population and is estimated to become an aged society by 2018 (> 14% of the population ≥ 65 years old) and a hyper-aged society by 2025 (> 20% of the population ≥ 65 years old). These circumstances will considerably affect national competitiveness and productivity in Taiwan and create further strain on social problems, such as the care of older people and resource allocation.

If a school desires to cultivate students' diverse abilities in the context of globalisation and to develop their strengths to meet future challenges, the most fundamental practice is to develop and enhance its courses. The theory of multiple intelligences indicates that human intelligence is formed from the following abilities: verbal-linguistic, logical-mathematical, musical, bodily-kinaesthetic, visual-spatial, interpersonal, intrapersonal and naturalistic [2]. Strengthening these abilities through a single subject is difficult. The goals of subject education in high schools can be divided into the cognitive, psychomotor and affective domains. Educators of each subject dedicate their long-term efforts and attention to achieving all of these goals through instructional design, implementation and evaluation.

The spirit of inquiry is crucial to contemporary science education. According to the *White Paper on Science Education* issued by the Taiwan Ministry of Education, science education is characterised by the cultivation of scientific literacy, and the implications of science education reside in scientific inquiries, which enable students to obtain relevant knowledge and skills, develop the habit of scientific thinking, investigate and argue using scientific methods, and apply scientific knowledge and skills to problem-solving for further recognising the nature of science and engendering the scientific spirit [3]. The spirit of inquiry, according to the *National Science Education Standards*, denotes a type of multifaceted activity that involves observing; raising questions; referring books and other sources of information to learn things already known; conducting research plans and reviewing the already-known things through evidence; using tools to collect, analyse and interpret data; proposing answers, interpretations and predictions; and sharing conclusions with others [4].

As early as 1998, the Department of Science at the Hong Kong Institute of Education and the Education Bureau of Hong Kong jointly organised science project competitions. The idea of organising such activities is derived from the teaching and learning of general studies. Using project design as a learning activity not only can enhance students' knowledge of the topics involved, but can also develop their abilities of expression, observation, thinking and judgment. Concurrently, students can discover how to collaborate effectively with peers to complete the activities [5].

The Taiwan Ministry of Education is currently preparing a technology-based high school syllabus that is expected to be published in 2016 and fully implemented in 2018. Preparing such a syllabus entails the following principles [6]: a) emphasise pragmatism; b) implement a coherent curriculum; c) enhance basic functions; and d) fulfil different demands. In addition, schools will be granted greater flexibility in developing feature courses of their own. One of this study's research motivations is to examine the question of how schools can take advantage of favourable school conditions, such as existing teachers, equipment, student competence and educational performance, to propose innovative curricula and adopt project-learning courses that will guide students in developing the research abilities required for actively exploring dynamic emerging technologies, enhance their learning outcomes and develop them into talent for pioneering technology. The other research motivation of this study focuses on the question of how schools can cultivate a spirit of scientific inquiry in students and encourage them to value enthusiasm for active inquiry and learning through a series of science and technology course plans, emphasise the development of experimental and practical abilities, as well as courses involving research and innovation, incorporate actual industry demands and university assistance and guidance, make full use of university research resources, and finally, enable students to complete projects collaboratively to achieve the goals of strengthening basic technology education and developing a technology elite consistently from vocational high schools to universities of science and technology.

RESEARCH OBJECTIVES

This study has the following objectives:

1. Construct inquiry-based learning and introduce it into the core capability indices (CCIs) and criteria of project learning for vocational high school students majoring in electrical and electronic engineering (EEE).
2. Investigate the importance (expectation) of project-learning CCIs for students and their performance (actual perceptions) regarding project-learning CCIs and determine the distribution of these CCIs in four quadrants: keep up the good work, concentrate here, low priority and possible overkill.

LITERATURE REVIEW

The 21st Century marks an era of information explosion, high-tech development, rapid social change and increasingly close international relations. The Nine-Year Joint Curriculum is aimed at cultivating sound citizens who can integrate cultural and technological knowledge and skills, actively explore and solve problems, employ information and language, and engage in lifelong learning [7].

The National Research Council of the United States considers inquiry the cornerstone of science learning [4]. When engaged in an inquiry, students describe objects or incidents, raise questions, establish explanations according to existing scientific knowledge, test their explanations and express their ideas. To identify the hypotheses proposed, students must apply logic and critical thinking, and consider alternative explanations; students actively develop their understanding of science through connecting their scientific knowledge with reasoning and thinking skills.

In addition to lectures by teachers, inquiry-based teaching facilitates student participation in thinking, doing and discussion with varying frequency. Teachers view learners from an integral perspective in this student-centred teaching mode; they are more concerned with students' cognitive and creative growth, and their teaching aims to develop further students' multiple abilities. Teachers must create a learning environment that initiates interaction among and active construction by learners. Through the process of inquiry, students practise the scientific method, acquire familiarity with the scientific knowledge system and cultivate appropriate scientific attitudes.

Implementation of Inquiry-Based Teaching

During an inquiry, students observe and explain events according to their prior knowledge and perceive possible differences between their own ideas and scientific concepts. Inquiry-based teaching should offer examples pertaining to students' daily experience and encourage students to reflect upon their prior knowledge, pose questions and hypotheses, and connect their prior experiences with new knowledge. Consequently, acquiring an understanding of the model, process and particulars of inquiry-based teaching facilitates its implementation. Industry-related departments at vocational schools aim to develop students into high-quality basic personnel for the industrial sector. In addition, students should fully understand the current conditions and implications of scientific-inquiry-based industries to be qualified for production work when entering the job market. However, current curricula in vocational high schools do not offer courses that involve scientific inquiry, which is a tremendous limitation for students who desire to join a production company or undertake further study at a university of science and technology.

Studies on Scientific Inquiry

Many relevant studies have adopted qualitative research methods. For example, Demir and Şahin explored question formation and resolution through an open-inquiry activity involving high school students [8]. The study indicated that most of the students' questions were derived from their learning and life experience. Although the scientific activities undertaken by the students differed from those of scientists, their experiences with scientific inquiry were meaningful.

Ramnarain investigated a teacher's beliefs towards questions raised by students in an inquiry activity and identified difficulties regarding encouraging students to exercise the spirit of inquiry and raise questions in class [9]. The aforementioned studies have discussed problems regarding inquiry, which facilitates clarifying some questions posed by this present study.

Scientific Inquiry in Project Learning

Wang et al proposed three types of inquiry learning: a) in structured inquiry, teachers guide the inquiry, and students follow the instructions to reach specific outcomes; b) in guided inquiry, teachers assist students with designing and undertaking the inquiry by selecting questions regarding the inquiry, discussing with students how to undertake such an inquiry and teaching them the required skills; and c) in open or full inquiry, the course is student-centred; students raise questions, design and undertake the inquiry [10]. In addition, Bodzin and Catesargued have stated that inquiry-based learning involves different levels of management, ranging from being directed by learning materials to being directed by students, and that the degree of student autonomy is inversely proportional to the level of supervision by teachers or through learning materials [11].

Different inquiry models require different abilities of teachers and students. In project-learning activities, students frequently face poorly structured information processing, decision making and even poorly structured problems that involve numerous difficulties and lack solutions. However, the gap between theory and practice in the traditional teaching model hampers the flexible application of knowledge and prevents students from acquiring the experience of actually solving a poorly structured problem. In such situations, students typically pay a substantial price whilst striving to attempt these poorly structured problems. Project-learning courses are suitable for providing scenarios through which students develop the ability to solve structured, semi-structured and poorly structured problems.

RESULTS AND DISCUSSION

- Construct inquiry-based learning and introduce it into the core capability indices of project learning for vocational high school students majoring in electrical and electronic engineering:

This study invited 19 experts to form a Delphi team to conduct a Delphi questionnaire survey. Consequently, the study aimed to introduce inquiry-based learning into the CCI items of project learning for vocational EEE students. The experts were divided into two teams as follows:

1. Experts: the authors selected nine participants from among Taiwan college and university teachers.
2. Vocational high school teachers: the authors selected ten participants from among Taiwan vocational school teachers who had experience in being advisors to students attending project competitions.

The research instrument used in this study was a questionnaire on introducing inquiry-based learning into the core capability indices of project learning for EEE students in vocational high schools. By analysing the literature, this study compiled a preliminary list of capabilities and implications. After these results were submitted to the experts for review, a questionnaire with expert validity was constructed. In a subsequent Delphi process, this questionnaire underwent three rounds of revisions, merges, additions and deletions according to the opinions and suggestions of the Delphi experts, until all of the experts reached a consensus. Finally, the capability indices were compiled and developed (Figure 1).

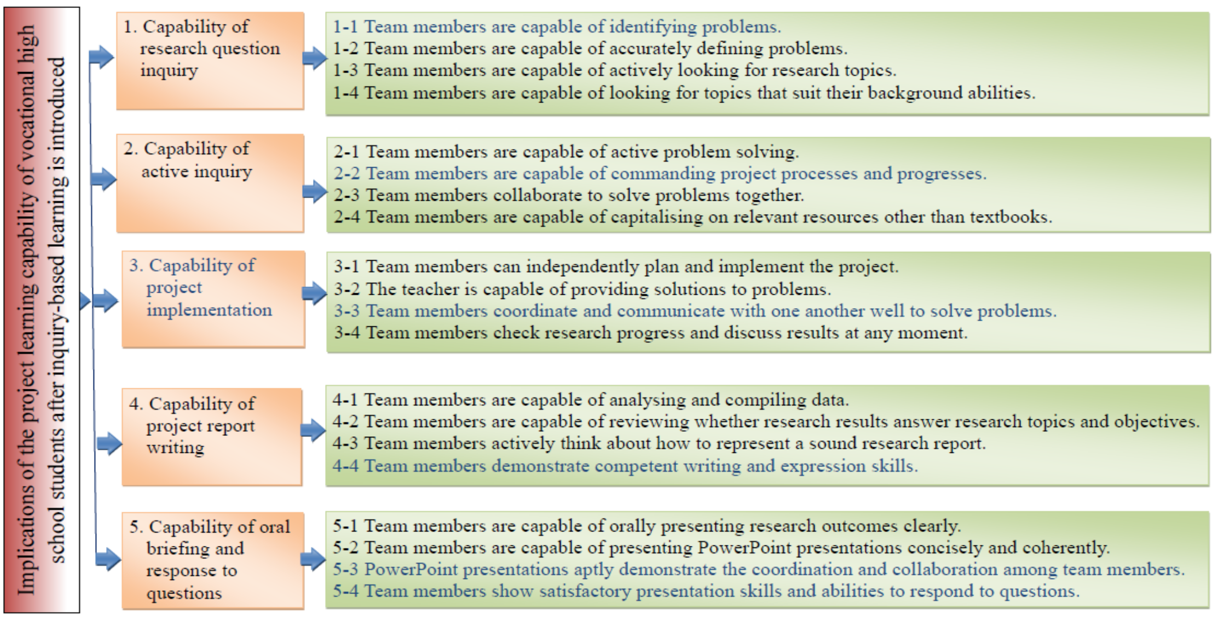

Figure 1: CCI framework.

The CCIs entailed five dimensions (i.e., capabilities of research question inquiry, active inquiry, project implementation, project report writing, and oral briefing and response to questions), 20 index implications and 79 index particulars.

- Confirm the expert-assessed criteria for the importance levels of core capability indices:

The analytic hierarchy process (AHP) was applied to determine the weight of each CCI item. Hence, this study designed questions for the third round of the Delphi questionnaire survey by which the experts could provide their opinions regarding the weight of each CCI item.

In the questionnaire survey, a paired comparison of the CCI items was conducted using a 9-point scale to evaluate the importance of the indices, resulting in the following CCI weights [12]:

1. In the first tier of index dimensions, the capability of project implementation was the factor most emphasised by the experts (Figure 2).

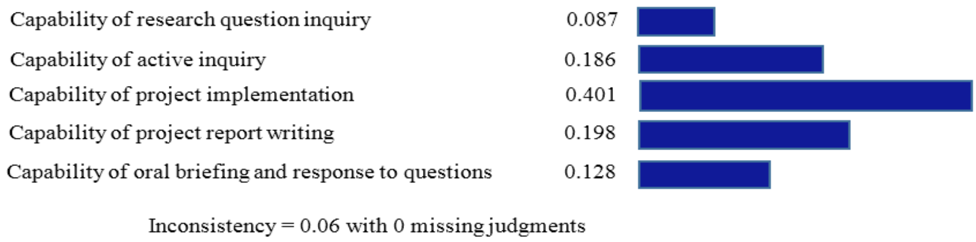

Figure 2: AHP results of the first tier of index dimensions.

2. The AHP results of the second tier of index dimensions were as follows:

The results of the factor weight analyses on the capability dimensions of research question inquiry and active inquiry (Figure 3 and Figure 4)

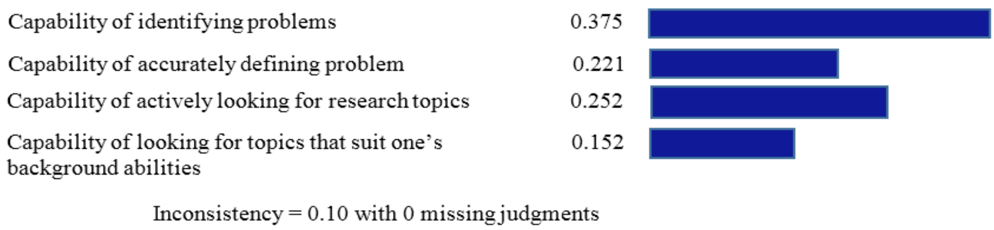

Figure 3: Analytical results of the dimension of research question inquiry.

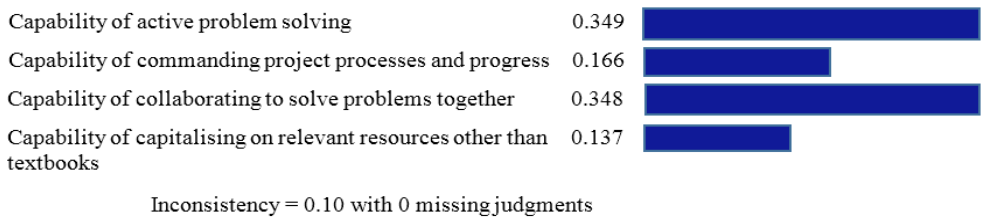

Figure 4: Analytical results of the dimension of active inquiry.

Results of the factor weight analyses on the capability dimensions of project implementation and project report writing (Figure 5 and Figure 6).

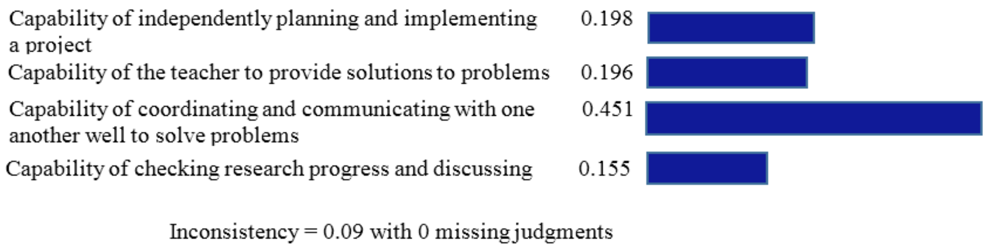

Figure 5: Analytical results of the dimension of project implementation.

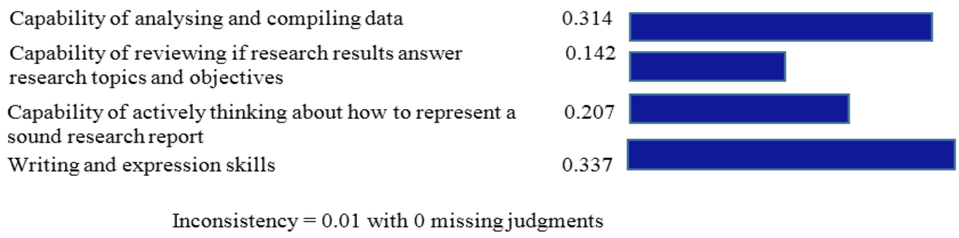

Figure 6: Analytical results of the dimension of project report writing.

Results of the factor weight analyses on the capability dimensions of oral briefing and response to questions (Figure 7).

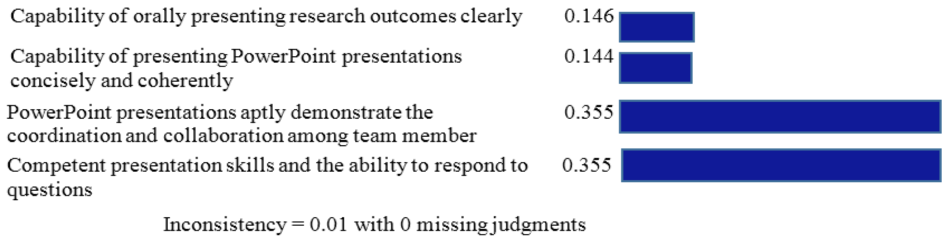

Figure 7: Analytical results of the dimension of oral briefing and response to questions.

- Analyse the importance (expectation) levels of the project-learning activities for students majoring in electrical and electronic engineering, as well as their performance (actual perceptions) levels in such activities:

The population of this study was vocational EEE students from vocational high schools, vocational schools affiliated to high schools and comprehensive high schools across Taiwan. After performing a cluster sampling, 255 students who had attended EEE project-learning courses were recruited, to investigate the importance (expectation) levels of project-learning course activities for students and their performance (actual perception) levels regarding such activities. Methods, such as means, standard deviations, paired-samples *t* tests, and analysis variance were performed to verify and analyse the data.

- Understand the distribution of the core capability indices among the quadrants of *keep up the good work, concentrate here, low priority* and *possible overkill.*

Importance-performance analysis (IPA; expectation-actual perception) was a simple framework first proposed by Martilla and James [13]. The study drew a two-dimensional matrix, with performance as the x axis and importance as the y axis, on the basis of the mean scores of importance and performance.

According to Sampson and Showalter, IPA is mainly used to investigate importance and performance, with the importance and performance levels of each attribute being assessed according to the scores of the attribute [14]. The assessed levels of each attribute are, then, plotted in a two-dimensional coordinate plane, with importance as the y axis and performance as the x axis. By using level midpoints, O'Sullivan divided the plane into four quadrants: keep up the good work (Quadrant 1), concentrate here (Quadrant 2), low priority (Quadrant 3), and possible overkill (Quadrant 4; Figure 8) [15]. The factors included the following capabilities: research question inquiry, active inquiry, project implementation, project report writing, and oral briefing and response to questions.

Quadrant 2 Concentrate here	Quadrant 1 Keep up the good work
Quadrant 3 Low priority	Quadrant 4 Possible overkill

Figure 8: IPA chart [15].

This study conducted an IPA to investigate the five dimensions of introducing inquiry-based learning into the CCIs of project learning among vocational high students from the perspectives of experts and students. The five dimensions were the capabilities of research question inquiry, active inquiry, project implementation, project report writing, and oral briefing and response to questions.

Because of limited article length, this study focused only on the *project implementation* dimension and investigated the following groups of students individually: 1) students who had attended and won a project competition; and 2) students who had not attended a competition or students who had attended one, but had not won the competition.

- Importance–performance analysis of the capability dimension of project implementation among students who had won a project competition:

In this dimension (Figure 9), the items in Quadrant 1 (keep up the good work) included: *3-2 The teacher is capable of providing solutions to questions*, *3-3 Team members coordinate and communicate with one another well to solve problems*, *3-1-3 Team members try to find possible causes when mistakes are found in experiments*, *3-1-4 Team members find causal relations according to the changes occurring in experiments*, *3-3-1 Team members effectively divide the labour and responsibility* and *3-4-4 Team members make use of research operations and records to find answers and to reflect on and revise their learning directions*. These results indicated that the students attached great importance to these index items and demonstrated high performance as well. Therefore, these conditions should be retained and may be regarded as advantages to introducing inquiry-based learning into the CCIs of project learning among EEE students in vocational high schools.

The items in Quadrant 2 (concentrate here) involved: *3-1 Team members can independently plan and implement the project*, *3-1-1 Team members can understand the relationships between research steps and topics*, *3-1-6 Team members can conduct experimental observations or obtain data measurements for reference*, *3-2-4 New ideas can be inspired during teacher–student discussions*, *3-3-3 Team members are willing to cooperate and learn* and *3-3-4 Team members are willing to accept others' opinions that are superior to those proposed by themselves during communication*. These results showed that the students attached great importance to these index items, although their performance did not meet their expectations. Therefore, educators should give priority to improving the problems encountered by students, as indicated by these index items, when introducing inquiry-based learning into the CCIs of project learning among EEE students in vocational high schools.

The items in Quadrant 3 (low priority) consisted of: *3-1-5 Team members spontaneously learn the techniques required for completing the project*, *3-2-2 Team members follow the steps and methods proposed by their teacher in conducting an experiment*, *3-4-1 Team members record research processes and results in detail* and *3-4-2 Team members use tables and pictures to record research progresses and processes in detail*. These results indicated that the participants attached low importance to these index items and that their performance was poor as well. Therefore, these index items may be regarded as the secondary problems to be improved when inquiry-based learning is introduced into the CCIs of project learning among vocational high school EEE students.

The items in Quadrant 4 (possible overkill) were: *3-4 Team members check research progress and discuss results at any moment*, *3-1-2 Team members revise their experimental methods and continue to try other methods when encountering difficulties in an experiment*, *3-2-1 Team members compare and contrast their problem-solving methods with the experimental steps suggested by their teacher*, *3-2-3 Team members fully capitalise on the necessary resources and operational skills provided by their teacher*, *3-3-2 Team members share resources and discuss questions together*, *3-4-3 Team members require themselves to complete an experiment within a predetermined period*. These results showed that the participants attached low importance to these index items, although their performance exceeded their expectations. Therefore, these index items may be regarded as the parts requiring less effort from students when inquiry-based learning is introduced into the CCIs of project learning among EEE students in vocational high schools. The authors suggest that teachers and students save time and effort by focusing instead on the items in Quadrant 2 that require improvement.

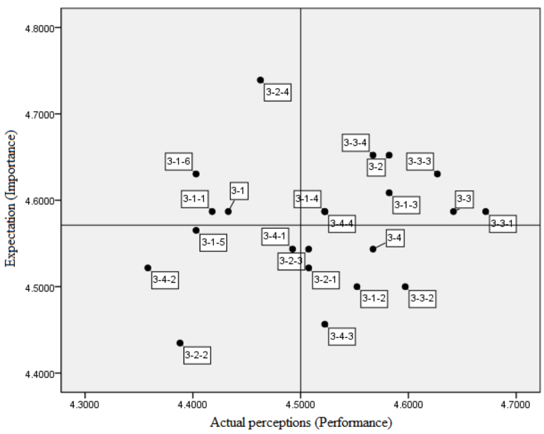

Figure 9: IPA of students who have won a project competition.

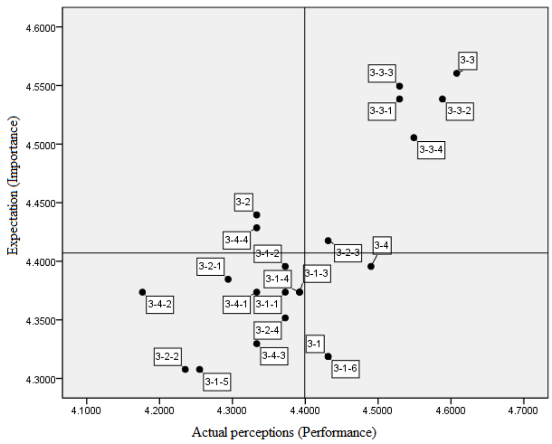

Figure 10: IPA of students who have not won a project competition.

- Importance-performance analysis of the capability dimension of project implementation among students who had not won a project competition:

The experts' total average score of expectation for the CCI index and dimension of project implementation was 4.537 (x axis), and the students' total average score of performance satisfaction was 4.452 (y axis). The two points were used to divide the x and y axes into four quadrants (Figure 10).

In this construct, the items in Quadrant 1 (keep up the good work) were: *3-3 Team members coordinate and communicate with one another well to solve problems*, *3-2-3 Team members fully capitalise on the necessary resources and operational skills provided by their teacher*, *3-3-1 Team members effectively divide the labour and responsibility*, *3-3-2 Team members share resources and discuss questions together*, *3-3-3 Team members are willing to cooperate and learn* and *3-3-4 Team members are willing to accept others*. These results indicated that the students attached great importance to these index items and demonstrated high performance as well. Therefore, these conditions should be retained and may be regarded as advantages to introducing inquiry-based learning into the CCIs of projection learning among EEE students in vocational high schools.

The items in Quadrant 2 (concentrate here) involved: *3-2 The teacher is capable of providing solutions to questions* and *3-4-4 Team members make use of research operations and records to find answers and to reflect on and revise their learning directions*. These results indicated that the students attached great importance to these index items, although their performance did not meet their expectations. Therefore, educators should focus on improving the problems encountered by students, as indicated by these index items, when introducing inquiry-based learning into the CCIs of project learning among EEE students in vocational high schools.

The items in Quadrant 3 (low priority) included: *3-1-1 Team members can understand the relationships between research steps and topics*, *3-1-2 Team members revise their experimental methods and continue to try other methods when encountering difficulties in an experiment*, *3-1-5 Team members spontaneously learn the techniques required for completing the project, 3-1-4 Team members find causal relations according to the changes occurring in experiments, 3-1-3 Team members try to find possible causes when mistakes are found in experiments*, *3-2-1 Team members compare and contrast their problem-solving methods with the experimental steps suggested by their teacher, 3-2-2 Team members follow the steps and methods proposed by their teacher in conducting an experiment, 3-2-4 New ideas can be inspired during teacher–student discussions*, *3-4-1 Team members record research processes and results in detail*, *3-4-2 Team members use tables and pictures to record research progresses and processes in detail* and *3-4-3 Team members require themselves to complete an experiment within a predetermined period*. These results showed that the students attached low importance to these index items and that their performance was poor as well. Therefore, these index items may be regarded as the secondary problems to be improved when inquiry-based learning is introduced into the CCIs of project learning among EEE students in vocational high schools.

The items in Quadrant 4 (possible overkill) were: *3-1 Team members can independently plan and implement the project*, *3-4 Team members check research progress and discuss results at any moment* and *3-1-6 Team members can conduct experimental observations or obtain data measurements for reference*. The results indicated that the students attached low importance to these index items, although their performance exceeded their expectations. Therefore, these index items may be regarded as the parts requiring less effort from students when inquiry-based learning is introduced into the CCIs of project learning among EEE students in vocational high schools. The authors suggest that teachers and students save time and effort by focusing instead on the items in Quadrant 2 that require improvement.

CONCLUSIONS

According to the presented outline, research questions, purpose and discussion, the following generalised conclusions can be drawn:

1. The CCIs entailed five dimensions (i.e. capabilities of research question inquiry, active inquiry, project implementation, project report writing, and oral briefing and response to questions), 20 index implications and 79 index particulars. In the AHP, the capability of project implementation was the factor most emphasised by the experts.

2. Importance-performance analysis of won and not won-players, in the items in Quadrant 1 included *3-3 Team members coordinate and communicate with one another well to solve problems*, *3-3-1 Team members effectively divide the labour and responsibility, 3-3-3 Team members are willing to cooperate and learn* and *3-3-4 Team members are willing to accept others*. These four items were of high importance to the students and should be emphasised in inquiry-based learning.

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