APPLICATION-ORIENTED TECHNOLOGICAL SKILLS FOR TAIWAN'S SOLID-STATE LIGHTING INDUSTRY

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ABSTRACT

Solid-state lighting is one of Taiwan's major green energy fields. Currently, the country needs more manpower to support industrial development. Engineering programs at technical colleges and universities of technology mainly focus on cultivating graduates' professional skills, which should match the industry's needs; this should be reflected in these programs' curricula. Thus far, a big gap remains between graduates' professional capacities and the industry's requirements. Hence, it is imperative to improve program curricula and academic instruction to promote students' expert abilities. Based on the problem outlined above, this study investigated technology-oriented skills in the solid-state lighting industry to develop new, industry-oriented curricula and enhance academic content. The authors used document analysis, field interviews, meetings with experts, and a questionnaire. The authors employed descriptive statistics such as the frequency, percentage, mean, standard deviation, Kendall's tau rank correlation, and Importance-Performance Analysis (IPA) to collect the data. The authors found that (1) the application-oriented technological skills required for solid-state lighting comprise six categories, and are subdivided into 52 technology-oriented abilities. (2) There are three categories of the importance of solid-state lighting and usage levels in order to sort the data of the rank correlation test, which showed a significant level of $p < .01$ in six classifications. (3) In terms of verifying the basic information of the 52 required skills, they are below the $p <. 05$ level of significance. (4) In terms of the IPA, one competency fell under the area of "urgent investment," 25 related to "maintaining skills," 25 to "deferring investment," and 1 for "over-emphasis." The results can provide an outline of expert abilities in developing or fixing industry-oriented curricula at technical colleges and universities of technology.

Keywords: Importance-performance analysis; professional curriculum; solid-state lighting industry; technological competency.

INTRODUCTION

One of the most important topics in engineering education is how to seamlessly integrate theory and practical applications to develop curricula that are in-line with the requirements of the industrial world, thus cultivating well-trained engineers. Lantada [1] pointed out that "successful engineering professionals need to possess fundamental engineering knowledge, skills, and abilities." Therefore, conducting an in-depth investigation into the skills and abilities required in industrial applications is an important issue in designing engineering curricula or training engineering professionals. The solid-state lighting industry is one of the future's critical engineering fields, where the upstream function includes the epi, chip, and package, the midstream mode includes the module, and downstream refers to lighting/applications.

The advantages of Taiwan's manufacturing growth come from the industrial cluster effect of its semiconductor, panel, and information and communications technology (ICT) businesses

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(and other relevant fields), as well as the economies of scale in production. This has resulted in the accumulation of technology related to LED lighting and optics, which includes manufacturing lighting products, as well as related production and testing facilities. Taiwan's LED lighting sector mostly consists of small and medium enterprises. Their business practices and capacity control are flexible, allowing them to respond rapidly to market demands, since they can customize their products according to their clients' needs. However, from a human resources perspective, Yeh Huey-Ching, former Director-General of the Bureau of Energy at the Ministry of Economic Affairs, pointed out that there are currently around 10,000 to 20,000 workers in Taiwan's green energy field. Scholars have estimated that by 2015, if Taiwan can become a "trillion dollar industry," then it would have around 110,000 professionals, including lower, middle, and upper class employees. The room for growth is around 10 times that of the current number of workers; hence, growth should be prioritized on vocational training centers and educational institutions [2].

In the early days, Taiwan's economic model focused on labor-intensive fields, which progressively moved to technology-based and capital-intensive businesses, and then to knowledge-intensive industries. The development of technical and vocational education was always in line with the unique requirements of these areas, playing the important role of human resource suppliers. In the face of challenges brought about by 21st century globalization, and to guarantee Taiwan's competitive advantage, technical and vocational instruction should fulfill at least three major tasks: (1) Develop and teach world-class human resources professionals; (2) Prevent a human resource shortage in the industry; and (3) Increase the industry's competitiveness. In other words, technical and vocational education should guarantee: (1) The necessary fundamental knowledge and expert skills to be competitive in the global market; (2) Proof of ability that is widely recognized and accepted in the industry; (3) The required competencies for employment and development in present and future job markets; and (4) The knowledge and capacity required for life-long learning [3].

Talent is fundamental to the expansion of high-tech industries. Therefore, cultivating an adequate number of the right people to effectively meet the needs of these fields is an important issue. This is especially applicable to the country's high-tech businesses, which are growing rapidly; the speed of their growth is much greater than that of universities offering related courses, resulting in a severe shortage of engineers and technically competent workers. Furthermore, not all graduates from these schools fit the needs of high-tech companies, especially due to the academicization of technical and vocational education, causing a schism among the industry's technically talented personnel. This leads to competency deficiencies or a skills gap [4, 5, 6].

Based on the background and problems discussed above, this study focuses on the application-oriented part of the solid-state lighting industry. In addition, the study explores the required university-level skills, which will be used as a reference to improve courses and teaching methods in the hope of developing the practical capacities needed by the application end of the solid-state lighting industry. This study answers the following questions: (1) What are the abilities needed by the application sector of Taiwan's solid-state lighting industry? (2) In terms of these competencies, what are the views of Taiwan's application-end businesses in the solid-state lighting industry?

LITERATURE REVIEW

Competency analysis

"Competency" refers to the abilities required for the work or tasks of a specific profession, and mostly consists of knowledge, skills, and affection. According to Walther and Radcliffe [8], developing competencies involves learning activities, other curricular elements, the student's disposition, extracurricular factors, and meta influences. In addition, Zhuang Tsian Pen [9] believed that the theoretical basis of competency analysis is mainly based on these three points: (1) The theory of the practitioner's personal views; (2) The theory on the goals of technical and vocational instruction; and (3) The theory of decentralization.

Competency analysis can use an employee's work or position to establish competency standards so as to enable: (1) Curriculum development; (2) Confirmation of training needs; (3) Career plan development; (4) Workplace safety; (5) Selecting personnel; (6) A write-up of the job description; and (7) Work evaluations [10]. The most common methods for gathering data include observations, interviews, a questionnaire, and document analysis. The first two techniques are generally suitable for exploratory research, while the last two are appropriate for exploratory or empirical research. The authors of this study employed the methods mentioned above simultaneously according to the practical job requirements. In this context, the interview procedures to collect information on skills are mostly based on the interview subject, and are limited to analyzing staff positions and/or their direct supervisors. Interviews mainly involve understanding the interviewee's job description, work activities, work responsibilities, and clarifying the relationships among the job responsibilities and the necessary skills for each task. After interviewing all subjects, the authors organized job functions into 8-12 fields and labeled them [11].

Importance-performance analysis

The business community often uses Importance-Performance Analysis (IPA) to analyze the importance and performance of a product or service, and to show its relative strengths and weaknesses to find areas for improvement or the key elements to success [12, 13]. The use of IPA can be visualized on the X-Y coordinate plane, where X represents importance (the farther to the right, the higher the importance), and Y represents performance (the farther above, the higher the performance). On this coordinate plane, the origin is the mean value of importance and performance, while the meaning of each quadrant is shown in Figure 1. If the result of the analysis falls inside the first quadrant, it means that importance is low but performance is high; thus, the priority of the analyzed item is relatively low, so people should invest less in the future. The second quadrant represents high importance and high performance; thus, the current results of the analyzed item should be maintained. The third quadrant represents low importance and low performance; hence, the analyzed item is not performing well, so there is no need to continue investing in the future. The fourth quadrant represents high importance and low performance; therefore, the analyzed item needs further improvement [13].

Lewis [14] introduced IPA to an engineering journal, and offered an actual mechanics course to perform the analysis and investigation, then proceeded to show the strengths and weaknesses of the aforementioned method. More importantly, he was able to help reform engineering education through the course. This study also used IPA to analyze the skills discussed in the previous section, and to discover the vital technological abilities needed to cultivate more well-trained engineers.

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Performance

Quadrant I Over-emphasis (Low Importance, High Performance)	Quadrant II Maintaining skills (High Importance, High Performance)
Quadrant III Deferring investment (Low Importance, Low Performance)	Quadrant IV Urgent investment (High Importance, Low Performance)

Importance

Fig. 1. IPA Analytical Connotations [12]

METHODOLOGY

Research process

In order to explore the technological skills required in the application end of Taiwan's solid-state lighting industry, and to understand the views of business owners regarding the technological capacities mentioned above, the authors primarily used competency interviews, discussions with experts, and a questionnaire. The discussion below focuses on these three procedures. In the competency interviews, the researchers first gathered the latest documentation, both local and international, related to the solid-state lighting industry, and conducted document analysis to interpret and collate the results. These were then integrated with the study's related dimensions and electronic data to develop the "Required Technological Competencies in Taiwan's Solid-State Lighting Industry" (the first draft), to be used as reference materials for conducting competency interviews. The next step was to choose solid-state lighting businesses in the northern part of the country as study samples. The authors chose twelve companies based on their nature, size, and products, followed by semi-structured competency interviews to gather the opinions and suggestions of personnel and supervisors from engineering and related technical departments. The results were then collated into "Required Technological Competencies for the Application End of Taiwan's Solid-State Lighting Industry" (the second draft).

As for the discussions with experts, in order to confirm the required technological abilities for human resources in the application end of the solid-state lighting industry, the researchers invited seven experts from related fields, and proceeded to have detailed conversations with them. In terms of the questionnaire, to understand the opinions of solid-state lighting businesses regarding the technological skills mentioned above, this study designed a questionnaire titled "Required Technological Competencies of Talent in the Application End of the Solid-State Lighting Industry" and applied purposive sampling to investigate 160 solid-state lighting enterprises (mostly from the Taiwan Lighting Fixture Export Association: http://www.lighting.org.tw, the Taiwan LED Lighting Industry Association: http://www.taiwanled. org.tw, and the Taiwan Electronic and Electrical Manufacturers' Association: http://www.teema.org.tw). The questionnaires were distributed to the technical departments or human resources department. The companies were contacted by telephone to inquire if they were willing to assist in the research. Then, one copy of the survey was sent to each company; 104 completed questionnaires were returned, with an effective recovery rate of 65%.

Instrument

The main instrument used by this study was the questionnaire: "Required Technological Competencies in the Application End of the Solid-State Lighting Industry." The content included: (1) Background data on the company (5 questions), and (2) "Required Technological Skills in the Application End of the Solid-State Lighting Industry" (11 categories and 52 questions). The questionnaire was scored using a 3-point scale, and respondents had to focus on importance and frequency when answering. The questionnaire began to develop with the results gathered from the document analysis, as found in "Required Technological Competencies in Taiwan's Solid-State Lighting Industry" (first draft). The authors used competency analysis and discussions with experts to confirm the first draft; afterward, two expert scholars were invited to review the first draft of the questionnaire to guarantee the effectiveness of the content. Lastly, 50 companies were chosen to conduct a questionnaire pre-test. The 42 completed questionnaires that the researchers received were used to check for internal consistency. Based on the results, the questionnaire achieved an internal consistency reliability higher than 0.80; in terms of importance, the overall reliability was 0.968, and the usage was 0.970 (as shown in Table 1). This means there was a good internal consistency reliability [15].

Table 1. Questionnaire to Measure Internal Consistency Analysis

Category (Competency Details)	Importance	Frequency	Category (Competency Details)	Importance	Frequency
1. Applying circuit principles（10）	.873	.842	2. Usage of technical parameters（7）	.895	.904
3. Designing driver circuits（10）	.901	.911	4. Usage of instruments and equipment（11）	.953	.939
5. Usage of software tools（7）	.847	.881	6. Creating new lighting products（7）	.910	.917

Data analysis

Using the data from the questionnaire, the authors performed: (1) Mean and standard deviation to analyze each technological skill; (2) Kendall's tau rank correlation test to compare the correlations of the technological abilities in each category; and (3) IPA to examine the technological competencies in each category, and divide them into four types: over-emphasis, maintaining skills, deferring investment, and urgent investment.

RESULTS

Analysis of the Importance and Frequency of Technological Competencies

Table 2 presents the results of the data on the importance and usage of technological abilities in Taiwan's solid-state lighting industry from the perspective of businesses. There were 15 competencies that had "high" mean values for importance (2.50-3.00), 36 with "moderately high" importance (2.00-2.49), and one with "moderately low" importance (1.50-1.99). Among these, "A-10" had a relatively lower importance than the other technological capacities. Based on frequency, there were 13 technological competencies with "high" mean values for usage (2.50-3.00), 31 with "moderately high" usage (2.00-2.49), and 8 with "moderately low" usage (1.50-1.99). Among them, "A-9, A-10, B-2, D-2, D-7, D-8, D-10 and E-5" had relatively lower usage than the other technological skills.

Based on the analysis of the importance and frequency of technological competencies, we discovered that A-10 (i.e., principles of using a transmission interface circuit) had low importance and usage. Therefore, when training solid-state lighting industry professionals in the future, we can consider removing this technological skill from the list. As for the seven capacities with lower frequency, since they have low frequency in the applications of the solid-state lighting industry, we can consider removing them or invest fewer resources in teaching them.

Table 2. Analysis of the Importance and Frequency of the "Required Technological Competencies of Solid-State Lighting Industry Applications"

Required Technological Competencies	Importance Mean Value	Importance Standard Deviation	Rank	Frequency Mean Value	Frequency Standard Deviation	Rank	IPA Quadrant
A. Applying Circuit Principles							
A-1 Principles of using a direct current circuit	2.65	.517	1	2.65	.539	1	II
A-2 Principles of using alternating current circuits	2.46	.652	5	2.27	.718	6	II
A-3 Principles of using a variety of switching circuits	2.41	.691	6	2.36	.634	4	II
A-4 Principles of using a variety of amplifier circuits	2.13	.777	8	2.14	.749	7	III
A-5 Principles of constant current (voltage) circuits	2.62	.596	2	2.52	.580	2	II
A-6 Principles of using power factor circuits	2.48	.607	4	2.34	.630	5	II
A-7 Principles of using AC-DC Converter Circuits	2.49	.683	3	2.39	.686	3	II
A-8 Principles of using AC-DC variable flow circuits	2.24	.757	7	2.04	.767	8	III
A-9 Principles of using LED PWM gray-scale/color circuits	2.13	.698	8	1.94	.708	9	III
A-10 Principles of using transmission interface (e.g., RS232, RS485) circuits	1.96	.800	10	1.82	.781	10	III
Kendall's tau-b correlation coefficient				.854** (p < .01)			
B. Usage of Technical Parameters							
B-1 Usage of light measurement (such as luminous intensity or	2.61	.660	1	2.63	.684	1	II

total luminous flux)							
B-2 Usage of radiation measurements (such as radiation intensity and radiation flux)	2.04	.787	7	1.98	.833	7	III
B-3 Usage of color measurements (such as color purity, color temperature, and color rendering index)	2.05	.682	4	2.50	.696	3	I
B-4 Usage of electrical parameters (such as forward current voltage, time switching, and capacitor)	2.44	.680	5	2.40	.718	5	II
B-5 Usage of thermal parameters (such as junction temperature, luminous efficiency, and thermal resistance)	2.55	.605	3	2.53	.615	2	II
B-6 Usage of LED color specifications for X, Y, Z values	2.36	.667	6	2.25	.681	6	III
B-7 Usage of LED international standards (such as CIE Standard and IEC Standards)	2.56	.605	2	2.46	.648	4	II
Kendall's tau-b correlation coefficient				.619 ($p > .01$)			
C. Designing Driver Circuits							
C-1 Usage of LED specifications	2.59	.601	1	2.55	.647	1	II
C-2 Usage of LED light emitting principles	2.40	.661	5	2.35	.649	3	II
C-3 Design of LED light emitting circuits	2.46	.667	2	2.34	.693	5	II
C-4 Design of PWM Circuits	2.43	.665	3	2.35	.725	3	II
C-5 Design of analog dimmer circuits	2.21	.649	9	2.17	.643	7	III
C-6 Design of digital dimmer circuits	2.25	.635	7	2.13	.653	8	III
C-7 Usage of micro-controllers	2.22	.696	8	2.10	.688	9	III
C-8 Usage of IC interface	2.15	.721	10	2.07	.757	10	III
C-9 Design of power supply circuits	2.38	.658	6	2.31	.685	6	II
C-10 Usage of EMI/EMC specifications	2.42	.634	4	2.36	.667	2	II
Kendall's tau-b correlation coefficient				.719** ($p < .01$)			
D. Usage of Instruments and Equipment							
D-1 Usage of color spectrum	2.22	.800	5	2.05	.826	6	III
D-2 Usage of ellipsometer	2.01	.770	11	1.82	.795	11	III

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D-3 Usage of luminance meters	2.28	.743	4	2.22	.743	2	III
D-4 Usage of lux meters	2.51	.668	1	2.48	.725	1	II
D-5 Usage of LED light intensity distribution meter	2.34	.771	2	2.12	.861	4	III
D-6 Usage of integrating sphere	2.34	.796	2	2.14	.890	3	III
D-7 Usage of thermoelectric performance analyzer	2.18	.747	7	1.94	.779	8	III
D-8 Usage of light, color, and electrical integrated testing of a machine	2.06	.708	9	1.89	.766	10	III
D-9 Usage of LED aging test machine	2.16	.790	8	2.01	.747	7	III
D-10 Usage of LED MTBF prediction tester	2.06	.774	9	1.91	.796	9	III
D-11 Usage of power analyzer	2.19	.789	6	2.08	.804	5	III
Kendall's tau-b correlation coefficient				.833** ($p < .01$)			
E. Usage of Software Tools							
E-1 Usage of PCB software (such as Turbo PCB)	2.25	.693	4	2.24	.707	3	III
E-2 Usage of technical drawing software (such as 3D Solid Works)	2.43	.665	2	2.40	.672	2	II
E-3 Usage of computer-aided design software (such as AutoCAD)	2.54	.573	1	2.52	.598	1	II
E-4 Usage of optical simulation software (such as OSLO)	2.17	.717	5	2.05	.759	6	III
E-5 Usage of photonic crystal simulation software (such as OptiFDTD)	2.19	.708	7	1.80	.734	7	III
E-6 Usage of optical simulation software (such as TracePro)	2.16	.739	6	2.10	.788	5	III
E-7 Usage of lighting design software (such as lighttools, photopia)	2.26	.800	3	2.15	.821	4	III
Kendall's tau-b correlation coefficient				.619 ($p > .01$)			
F. Creating New Lighting Products							
F-1 Collect market information	2.82	.435	4	2.64	.564	3	II
F-2 Analyze product requirements	2.84	.421	1	2.68	.552	2	II
F-3 Conduct sample testing and functional testing	2.84	.421	1	2.69	.549	1	II
F-4 Propose product	2.84	.464	1	2.57	.611	5	II

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development plans							
F-5 Perform product design and test	2.75	.517	6	2.62	.603	4	II
F-6 Confirm product quality (conforms to safety specifications)	2.78	.502	5	2.56	.612	6	II
F-7 Propose a patent application,	2.56	.636	7	2.24	.736	7	IV
Kendall's tau-b correlation coefficient				.617 (p > .01)			

Note 1: IPA quadrants: I represents "Over-emphasis," II represents "Maintaining skills," III represents "Deferring investment," while IV represents "Urgent investment."
Note 2: If the correlation coefficient of Kendall's tau-b reached significance (**p<.01), this means that the correlations of the industry experts' ranking between the importance and frequency of the technological competencies achieved a level of significance.

Rank Correlation Test of the Importance and Frequency of Technological Competencies

To see if the rankings between the importance and frequency of technological competencies in Taiwan's solid-state lighting industry were consistent, Table 2 focused on six dimensions. The authors performed Kendall's tau-b rank correlation test, which included the six dimensions: circuit application principles, usage of technical parameters, designing driver circuits, use of instruments and equipment, usage of software tools, and creating new lighting products. Based on the statistical analysis of the results in Table 2, three dimensions – application circuit principles, designing driver circuits, and the usage of instruments and equipment – achieved statistical significance in the rank test of technological competencies for importance and use. As for the other three dimensions, although they did not achieve statistical significance, their Kendall tau-b correlation values were greater than 0.60, which shows that there was a certain level of correlation between their importance and frequency. As for why the other three elements did not lead to statistical significance, researchers believe it may be related to the fact that they had fewer items; each one only had seven skills. The outcome is easily affected by slight differences, which caused the dimensions to be statistically insignificant [16].

IPA of Technological Competencies

Figure 2 shows the results of the IPA performed on the technological competencies, whereby the first quadrant (over-emphasis) contains one technological ability, the second quadrant (maintaining skills) contains 25 technological abilities, the third quadrant (deferring investment) contains 25 competencies, and the fourth quadrant (urgent investment) contains one technological skill. Based on the IPA results, we know that among the 52 capacities designed in this study, 25 deserve continued attention, and the technological competency F-7 (to propose a patent application) deserves to be given a high priority when developing technical resources for the solid-state lighting industry. On the other hand, although half of technological skills deserve to be given priority, researchers discovered that 25 of them were not important for practicing professionals; these abilities did not have a high frequency. In other words, when cultivating technical personnel in the future for the solid-state lighting industry, these technological competencies should be reassessed to understand their relevance, in order for schools to cultivate a greater number of well-trained professionals based on the industry's requirements [1].

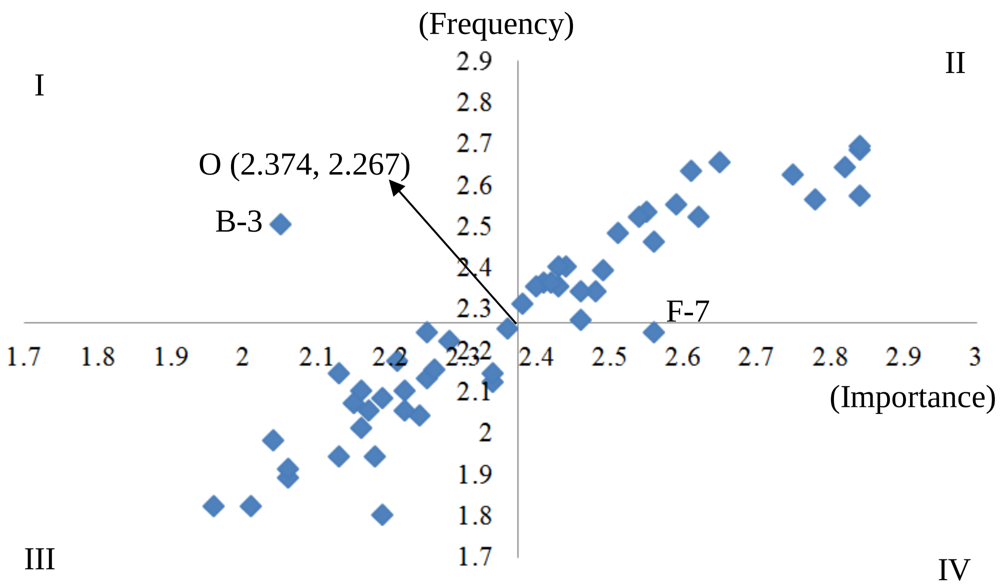

Fig. 2. An IPA Diagram of the "Technological Competencies Required by Application-end Businesses in the Solid-State Lighting Industry"

CONCLUSIONS

Our goal is to effectively increase the quality and quantity of the necessary personnel in order to fill the gap between Taiwan's solid-state lighting industry and educational system. To explore the technological abilities required at the application end of the solid-state lighting industry, this study used document analysis, competency interviews, discussions with experts, a questionnaire, and IPA. The study yielded 6 categories and 52 types of technological skills, as well as an analysis and grouping of their importance and frequency. The main conclusions are: (1) Regarding the importance and frequency of the required technological competencies in their industrial applications, the views of the businesses at the application end of the solid-state lighting industry were consistent. (2) The views of solid-state lighting industry businesses regarding the importance and frequency of the required technological skills had mean values that mostly fell between "moderately high" (2.00-2.49) and "high" (2.50-3.00). (3) Based on the perspectives of solid-state lighting industry enterprises relating to the importance and frequency of the required technological abilities, three of the six categories of technological skills had a high correlation between importance and frequency. (4) Based on the IPA of the required technological capacities, 1 fell under the category of "over-emphasis" and 25 under the classification of "maintaining skills." Another 25 competencies fell under "deferring investment," and 1 fell under "urgent investments."

Based on the aforementioned conclusions, this study proposes the following important insights: (1) Engineering or technical/vocational instruction should be more closely linked with the industry's requirements. Therefore, university engineering and related courses can use the results of this study as a reference. Firstly, the courses have to focus on personnel (such as professionals) that they need to train and develop, establish academic and training goals, and select the required categories and technological skills. Hence, one could suggest that: students are "required" to learn "low importance, high frequency" skills in category I; "should" learn "high importance, high frequency" abilities in category II; "high importance, low performance" capacities in category III; and "can" learn "high importance, low usage" skills in category IV, followed by the design of required course modules (units) and teaching

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materials (containing experiments and practice). (2) The authors applied IPA when categorizing technological competencies, whereby the original reference indicators were importance and performance. However, for this study, the authors changed them to importance and frequency. Since applying this concept in the initial stage, the research community can take it further by focusing on the theoretical fundamentals of in-depth research, or conduct further applications of IPA when examining technological competency. (3) Since engineering or technical/vocational instruction needs to be aligned with the country's economic policies and requirements for industrial development, related entities such as the Department of Education and the Department of Economic Affairs should have a more positive view of engineering course development. In addition, universities can provide sufficient funding for the required software and hardware expenses needed by students of engineering and related disciplines, thus ensuring that both industry and education will emerge as winners, and graduates will have greater career prospects ahead.

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