A Performance-Based Evaluation Model for Engineering Education Programmes

Hsi-Chi Hsiao

Graduate Institute of Business and Administration, Cheng Shiu University
840, Chengcing Road, Niaosong, Kaohsiung 833, Taiwan

In the article, the author proposes an evaluation model as the basis for setting up evaluation indicators for engineering education programmes. This model is based upon the social system model as one dimension, which treats the educational procedure as an open system of *input → process → output → feedback*; furthermore, the common evaluation model is used to analyse the past few decades via the method of induction. In this way, the author generalises three performance elements of the school as the other dimension. This includes the educational achievement performance, external competition performance and resources utilisation performance. The author further constructs the Evaluation Indicators Matrix (EIM) by these two dimensions. Finally, by means of deduction, the evaluation indicators of QQA engineering programme and ABET are applied into this EIM, which function as a kind of comparison, and the findings are discussed in order to elaborate on the use of this evaluation model.

INTRODUCTION

Since the 1980s, higher education has been transformed from being *elite* education to *public* education in many countries [1]. Thus, people regard higher education as an important public service. Therefore, apart from its traditional functions of instruction and research, higher education should gradually strengthen its level of service to society [2]. Since the quality of national policies is under the evaluation and supervision of the people, the quality of higher education that offered to the public is certainly under public supervision as well. Besides, higher education should also comply with the demands of the stakeholders of education.

The prevalence of higher education implies the advent of a new era of *market-oriented* education. Higher education institutions undertake the responsibility to assure the quality of educational performance offered to the public. They have to pay attention to how higher education contributes to the demands of the country, society and the economy.

In the past few decades, education quality, education quality assurance and education accountability have been considered as the top main international issues of higher education. Due to such demands, educational evaluation has become an important means for governments to access educational quality and efficiency since the 1960s [3]. At the eighth round of GATT negotiations in Uruguay, higher education has been included within the service industry sector. The World Trade Organization (WTO) has helped facilitate turning the role of higher education from being an academic manufacturer to a service provider.

The opening up of the higher education market implies the start of educational competition – no matter if the force is from national or international schools. Higher education institutions should start to respond to the public with respect to how higher education complies with the demands of the market. They should also note how higher education complies with the demands of the nation, society and the economy. In addition, when facing the main stakeholders of higher education (ie students), higher education institutions should treat them as the clients or customers who receive their service, and offer educational quality and service that are equal to the same monetary value in order to meet the demands of stakeholders.

Stakeholders should supervise and recognise the achievements and improvements of the quality of education, and the accountability of higher education institutions. Educational quality should also be assured

by activities in educational evaluation. In the 21st Century, the era of the knowledge-based economy, the assurance of educational quality and higher education accountability has become an irresistible trend. The evaluation system of higher education should adjust and improve its contents in order to fit with this move.

Engineering education is a component of higher education and one of the representative programmes of each school for a long period of time. The quality of engineering education tends to be the assurance of the level of educational quality at universities. The advent of the information technology era will directly affect the culture and method of engineering education. Indeed, the quality of engineering education faces an unprecedented challenge. Therefore, developing an evaluation model that is suitable for engineering education at universities is considerably important.

According to Kells' classification, with respect to an international evaluation system of higher education of the 20th Century, evaluation system of the American region tend to focus upon the active improvement of the quality of the educational institutions' internal operations [4]. European countries, on the other hand, stress the assurance of quality. The evaluation of higher education in the UK, in particular, emphasises the orientation of governmental leadership and funding support.

Among the approaches utilised for educational evaluation, researchers such as Tayler, Stufflebeam, Scriven and Stake have pointed out evaluation models with different dimensions [5]. Among them, the decision-facilitation evaluation model proposed by Stufflebeam is widely accepted worldwide. However, engineering incorporates the type of activities and profession that involves the following:

- Utilises knowledge and the sciences in order to transform natural resources into useful tools or architecture;
- Contributes to the economic and social development of human beings;
- Further improves the life quality of humankind.

Since the dawn of civilisation, engineering has been an ancient and important activity of humankind. The accumulation and passing on of engineering knowledge and experience depend upon the execution of engineering education. Engineering education has to recognise the demand of human beings' society in order to proceed with the necessary reformation and design of the curriculum [6]. This also involves the further passing on of useful engineering knowledge and experience, as well as the cultivation of engineering talents.

In facing this era of the development of the knowledge-based economy and the rapid changes in the required engineering skills, researchers need to re-examine whether previous evaluation models are suitable and whether the purpose of the evaluation is quality-oriented or improvement-oriented. Therefore, from the perspective of social systems theory, this author intends to elaborate on the role and responsibility of engineering education in modern society from different points of view, and to further construct an evaluation model that is suitable for engineering education programmes in higher education. Educational institutions can follow this evaluation model and establish self-evaluation indicators that comply with the profession of engineering education in order to allow its educational production to meet the demands of society regarding the quality of education.

LITERATURE REVIEW

Open system theory

General system theory was initially proposed by Bertalanffy in the 1950s. He believed that a *system* is a kind of compound formed by the interaction of the elements of an organisation [7]. However, the survival of the system has to rely on the production after the operation and the exchanged resources of external circumstances. Based upon two essential concepts of the system *boundary* and *purpose*, Berrien pointed out that a *system* is a kind of interaction among various elements, and is constructed by the boundary between input and output [8].

Whether a system is categorised as an *open system* or *closed system* depends upon the *penetration* of the boundary. If a system can import resources into its boundary from external circumstances via the function of *input*, and generate the production out of the boundary through the function of *output*, the said system would be regarded as an open system. In other words, the operation and production of the open system are actually affected by the input resources offered by external circumstances outside of the boundary of the system.

According to open systems theory, the operation of an organisation would be affected by, and reply to, external circumstances. Through the procedure of competition, the organisation obtains the *input* resources from external circumstances. The obtained resources experience the procedure of *processing* within the boundary of the system in order to generate valuable *output*. The products of the organisation return to and affect the external circumstance. At the

same time, the external circumstances would respond to the products of the organisation. These responses return to the system again through the procedure of *feedback*. The function of *feedback*, which allows external circumstances to recognise the operation of the system, can stimulate the system to adjust itself based upon responses from the external circumstances [8]. The internal operation of the organisation and the regular cycle of receiving feedback from external circumstances strengthen the consistent interaction between the organisation and circumstance.

For the social system in which human beings are the main factors, the application of general system theory is affected by a lot of variables. Getzels et al point out that one has to elaborate the actual inter-action among social organisations on the basis of society system theory [9]. Generally speaking, society system theory explores the interaction of members of a society via the structure of an open system. Since school is the product of social organisation, it is usually regarded as an open system and sub-system of the social system [10]. Thus, one school has to win over the personnel, materials and money of the social system with the sub-system of other schools, and involves these resources within the procedure of educational dealings. Finally, the school is able to offer society remarkable graduates and other forms of educational performance. Educational production would return to the social system as an advantage to fight for the resources of the social system. Mean-while, society would evaluate the quality of the products of the schools and offer feedback to the said schools to stimulate any necessary adjustments in educational policy.

From the perspective of general system theory, a system is usually comprised of various sub-systems. Each sub-system can be treated as an individually operated open system. In addition, open system theory regards a system as a competitive organism. Each sub-system has to compete with others in order to obtain useful resources of the system as the basis to maintain the survival and operation of the system.

Based upon the boundary concept of open system theory, the school sub-system is regarded as an individually operated social system. The quality of the products of this system affects the performance of the system of the school. Thus, in order to maintain the regular operation of the school and products with exquisite quality, the system of the school, within its boundary, has to set up a diagnosis mechanism so that it can judge and maintain the standards of various internal operations.

Barnard believes that in the open system of an organisation, and in order to maintain the existence of the organisation permanently, *effectiveness* and *efficiency* are the most important products of the system [11][12]. Therefore, the social system outside of a school would demand and expect the effective-ness and quality of that school. Furthermore, the school itself has to maintain its advantage within the social system. In order to accomplish these purposes, the school has to gather the appropriate resources and make the production via the process of transformation, and further return the educational products to the social system. Likewise, internal members of the school system demand and expect the effectiveness and quality of the school. Since the school is the enacting unit of education, it has to set up its standard of goals on the basis of external and internal demands, as well as gathering appropriate educational resources and policies that deal with the process of reform so that the school can make educational products that fit in with this standard.

Since education is the mechanism for cultivating human resources in society, the result and process of education should achieve certain standards of quality, which should also be oriented to customers' demands. The culture of educational quality should include the concept and means of quality control and quality assurance. Its evaluation standard should rely on students' achievements with respect to educational objectives. In this way, education can undertake the responsiblity for effectiveness.

Education is usually treated as an operated proce-dure of *imput → process → output* within the open system of education [10][13]. As such, the establish-ment of all the educational objectives and involvement of education resources have to comply with the demands and expectations of all the stakeholders. That is to say, the school needs to recognise the culture of external demand in order to set up positive educa-tional objectives and further obtain better products. It can also adjust its resources and procedures for dealing with the system according to stakeholders' feedback. Thus, the evaluation with respect to educa-tional quality not only proceeds when accomplishing education, but also deals with the process of edcuation. In this way, one can remedy any insufficiency of educational policies in a timely manner.

Evaluation Model Review and the Tasks of Higher Education

Nutall pointed out that evaluation indicators should allow stakeholders to profoundly observe the operation and effectiveness of the educational system and offer background materials with respect to policy decisions [14]. Therefore, the current research focuses on

analysing previous main evaluation theories and on exploring the perspectives and assessed elements of each evaluation theory. From these perspectives and assessed elements, the author further generalises the tasks and effectiveness of educational institutions.

Popham divided common patterns of educational evaluation into the following four categories:

- Goal attainment models, eg Tyler's objectives-based studies;
- Decision-facilitation models, eg Stufflebeam's decision-oriented studies;
- Judgemental models that emphasise outputs, eg Scriven's consumer-oriented studies and Stake's client-centred studies;
- Naturalistic models, eg Stake's client-centred studies [5][15].

These four evaluation models are explored below, along with a further analysis of the educational tasks of schools according to the key points of each evaluation models.

A Comparison of the Objectives of Each Evaluation Model

A comparison of Tayler's objectives-based studies and Stufflebeam's decision-oriented studies indicates that Tayler's model mainly evaluates the differences between the objective and the result of the professional service. However, this model focuses upon an evaluation of the result and neglects the process. On the other hand, Stufflebeam's decision-oriented model pays emphasis to assessing the process, which complements the disadvantage of Tayler's model. The spirit of these two models is to evaluate the objectives of the organisation, execution of various policies, differences between the results and the objectives, and the decision for improvement. From the educational perspective, the evaluations of these two models are to internally diagnose educational objectives and processes in order to improve the performance of the school.

A comparison of Stufflebeam's decision-oriented studies and Stake's client-centred studies reveals that Stufflebeam's model mainly focuses on the procedure of the plan (input → process → output), and an evaluation of the labour input and materials. On the other hand, the stakeholders under Stake's model can evaluate the advantages and disavantages of the operation of the resources in a particular setting using different perspectives. Thus, one has to pay attention to how the school obtains personnel, materials resources and funds while operating various educational

policies, as well as how it evaluates the plan and results of the distribution and operation. Additionally, the evaluation of the operation of educational resources allows the persons involved (ie the providers, operators and users of educational resources) to understand the school's operation of educational resources. In addition, since the efficiency and effectiveness of various educational operations affect the educational performance of schools, one has to review and improve educational performance. The review and improvement rely on definite policies and the participation of stakeholders so that the outcomes are revealed. Therefore, these two evaluation models signify the impact of educatonal performance and educational resources upon the efficiency of educational institutions.

A comparison of Scriven's consumer-oriented studies and Stake's client-centred studies shows that Scriven's model mainly takes the perspective of those stakeholders who receive professional service in its assessment of the advantages of professional services. On the other hand, Stake's model focuses on a particular setting. Given these different perspectives, stakeholders can evaluate the advantages and disadvantages of the professional services. In terms of the nature of educational service, these two evaluation models stress how the school's performance meets the demands of stakeholders and how external parties (eg society and industry) regard the performance of the educational service provided.

Generalisation of the Main Educational Tasks of the School from the Above Analysis

Regarding *educational achievement performance*, the school has to clearly define its educational objectives and compare its educational results and educational objectives in order to evaluate the efficiency of its educational performance and reveal the outcomes of the said performance.

Concerning *resources utilisation performance*, education involves the procedure of input → process → output. Within this process, one would execute various educational policies and activities to accomplish the function of educational tranformation. The opertaion of these plans and activities rely on the support of various resources. The efficiency of the school's operation of these resources affects the works of educational policies and activities.

With regard to *external competition performance*, schools offer various products to the external social system. The most important of these products is the school's graduates. Since the quality of graduates directly affects their capacity of obtaining an occupation and contributing to the production force of

society, stakeholders like parents, enterprisers, education supporters and community members would naturally demand a high level of quality of school products. With better educational products, a school would certainly obtain a better reputation from stakeholders and further strengthen its competitiveness within the overall educational circumstances to allow it to obtain more resources on the execution of various educational policies and activities, thereby further generating better educational performance.

Summary

Although the above four evaluation models have their own advantages, they are not capable of meeting the rapid changes taking place in the external circumstances of education. For example, even though Tayler's objective-based studies imply the spirit of accountability, the efficiency result merely reveals the educational outcomes. The model cannot identify the problems that faculty encounter during the process of executing education. Although Scriven's consumer-oriented studies focus on the demands of external customers, its process resembles the means of market research that only offers customers one-way findings and cannot generate interaction with consumers. Stake's client-centred studies evaluate educational problems through action research. However, since the external reliability of this model is insufficient, the result of the evaluation may be easily influced by certain people, which would affect the integrity of the evalution [5].

Common education evalutions usually utilise Stufflebeam's decision-oriented studies (CIPP model), which is an evaluation model that contains more complete scales and processes. However, the procedure of the structure is hardly understood. Usually, one can only utilise the whole execution of the CIPP model (context → input → process → output). A one-unit evaluation procedure (such as context evalution or output evaluation) is often neglected.

RESEARCH METHODOLOGY

A new evaluation model for higher education was targeted in order to overcome the disadvantages of the main education evaluation models. The establishment of the model was based upon the method of induction, which reviewed and analysed the documents, and further generated an evaluation model. A subsequent effective test via deduction was also undertaken. The elaboration of the evaluation model established by the research is presented in Figure 1.

Induction is the principle to find out the generalisation of an individual phenomenon. That is to say, from a series of particular observations, one discovers a pattern that explains the order of all the particular incidents. On the other hand, deduction involves finding out the uniqueness of an overall phenomenon, which covers testing the actuality and applicability of the model on the basis of the logically or theoretically predictable model [16].

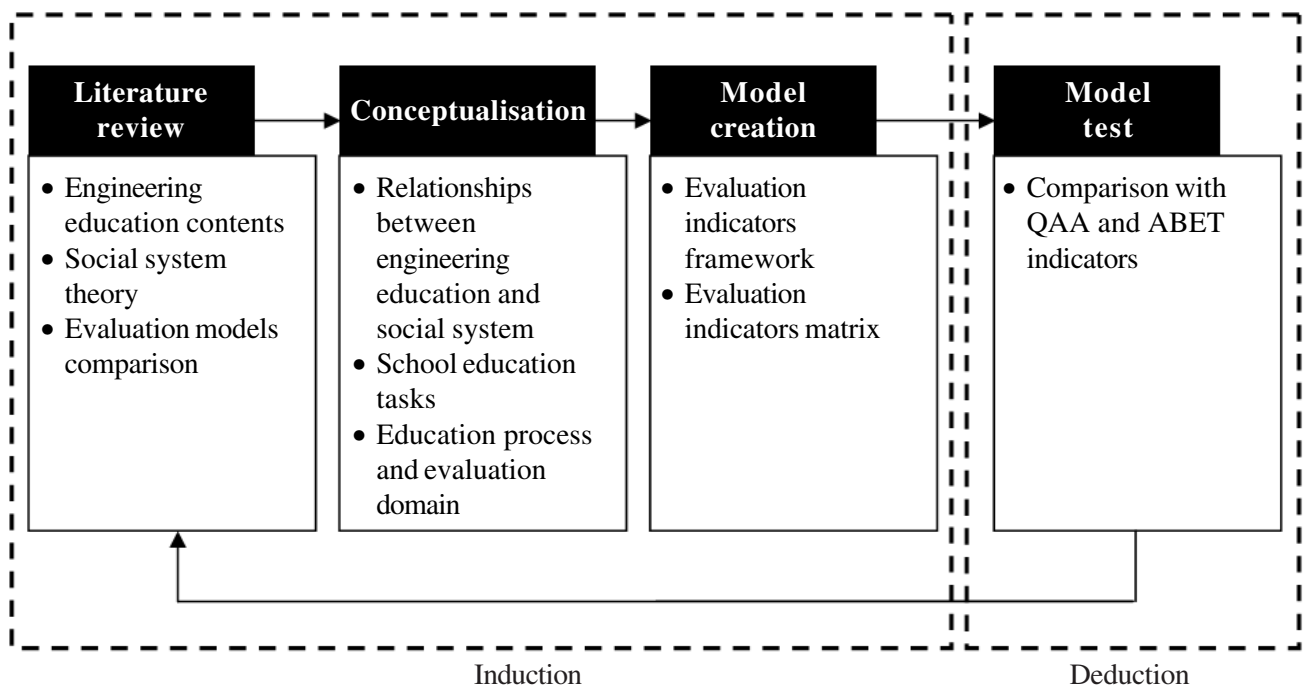An analysis was undertaken of engineering education, social system theory and a comparison of

Figure 1: The research method (redrawn from Babbie [16]).

previous common evaluation models. This involved looking at the educational procedure implemented by the school and the school's educational tasks with respect to the social system. This would help in constructing the main elements of education evaluation and further proposing a new education evaluation model. The current research employed the standard of engineering education from the Quality Assurance Agency for Higher Education (QAA) of the UK and the Accreditation Board for Engineering and Technology (ABET) of the USA so as to examine its applicability via deduction.

RESULTS

Evaluation Model

According to the previous exploration with respect to systematisation, the procedure of education can be regarded as an open system model of *input* → *process* → *output* → *feedback*. The educational system mainly comprises the three tasks of *educational achievement performance*, *external competition performance* and *resources utilisation performance*. The purpose of education evaluation should be to assess the school's performance when it proceeds with the above tasks.

Based upon this concept, a two-dimensional evaluation model was established as part of the research presented in this paper (Figure 2). Within this system of coordinates, the x-coordinate represents the performance elements of the school, the y-coordinate represents the procedure of education system and the domain where x-coordinate and y-coordinate meet are the evaluation indicator cells. Each evaluation indicator cells contains several evaluation indicators. The evaluation designers can design appropriate evaluation indicators according to this system of indicator coordinates. The elaboration of each part of the system of coordinates is are detailed below.

Education Procedure

Input entails the procedure when the school selects appropriate resources with regard to educational policies in order to achieve the following:

- Accomplish each educational plan;
- Accomplish the operation of the institutions;
- Maintain the competitiveness within the social system;
- Achieve the goals of education.

Translation covers the procedure in which the school executes a series of instruction, learning, administration and management based upon the inputted educational resources.

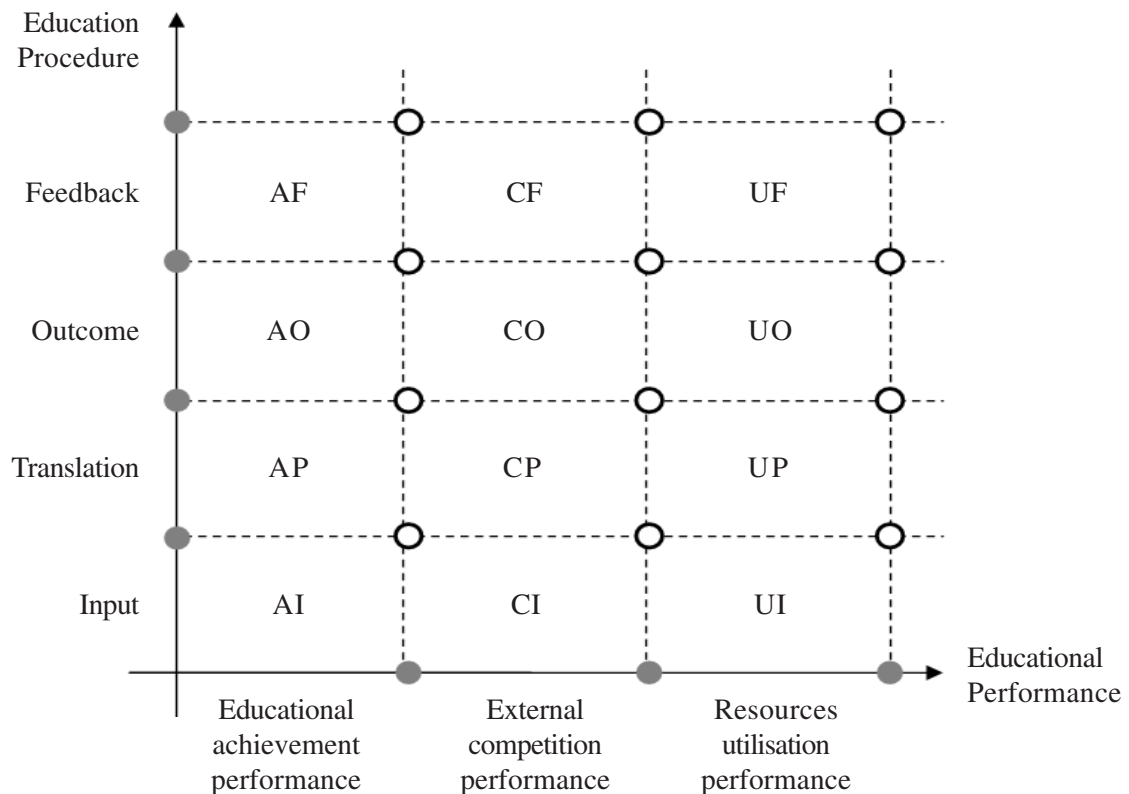Outcome is the production procedure in which the

Figure 2: The evaluation indicators framework.

school transforms the educational resources it has obtained via a series of stages.

Feedback involves the procedure in which the school compares the outcomes of education with the originally established objectives or standards, and further reviews the difference and operates the related adjustment.

Educational Performance

Educational achievement performance is the school's performance with respect to educational objectives, vision, courses, instruction, learning and study assistance, as well as students' achievements, in order to maintain the operation of the school system and prove that the school's educational outcomes comply with the relevant standard.

External competition performance refers to performance with respect to recruitment, research, industry service, continuing education, the quality of graduates, alumni achievements, as well as teachers' accomplishments and reputation, in order to strengthen the school's competitiveness in the social system and meet the demands of external shareholders.

Resources utilisation performance covers the performance of the transformation in terms of funds, personnel, equipment, research, educational setting and administrative support in order to maintain the operation and competitiveness of the school system and meet external demands.

Evaluation Indicator Matrix (EIM)

As shown in Table 1, the corresponding domain where the x-coordinate and y-coordinate meets within the coordinates system of the evaluation indicator framework comprises the cells of educational evaluation indicators. The cell might include several evaluation indicators. Faculties can set up a proper evaluation indicator on the basis of the principle of this coordinates system and consider the aspects of the time, geography, humane culture, politics and economics of the school. One can combine the form and principle of the coordinates system of an evaluation indicator, thus generating a matrix of evaluation indicators. Faculties can clearly recognise the relationship of each indicator from this matrix (Table 1).

Comparison

The evaluation indicators of the QAA and ABET's accreditation indicators were imported into the evaluation indicator matrix [17][18]. From this, one finds that the evaluation indicators of these two institutions

focus on *resources utilisation performance* and *educational achievement performance*. Only a few indicators appear within the *external competition performance*. Since the QAA evaluates higher education courses mainly upon the concept of quality assurance, its objective is the outcome of the products of these courses. On the other hand, ABET pays attention to the accreditation of the courses and aims to stimulate the improvement of the courses. Therefore, in terms of the outcomes of the products, the QAA is more students' achievements-oriented (such as the pass rates and progress rates), while the orientation of ABET tends to focus on the students' capacity provided by the courses (such as the capacity of knowledge and ability to operate equipment). In addition, from the culture of the indicators of these two institutions, one finds that they both focus on courses of educational achievement performance and the utilisation of the input resources that are focused on improving courses. Instead of stressing the external performance of educational institutions, they improve the efficiency of the courses via external stakeholders' participation in the establishment and course modifications.

Since the QAA and ABET particularly emphasise the procedure of the self-evaluation of educational institutions, the pattern of evaluation indicators mainly focus on the objectives and their achievements with regard to the bottom line. Furthermore, within the same indicator cell, the statement usually implies a synthetic concept. The accreditation standard of ABET of the *faculty professional development* of the UP indicator cell (as shown in Table 1) and the *sufficient number and competences to cover all curricular areas* of the AO indicator cell, for example, both literally refer to the faculty's capacity and achievements with respect to research or industry service, and how the achievements of the staff affect the course's design or process of instruction. In terms of the indicator content of the EIM proposed here in this research, these two indicators should be settled to the cells of external competitive indicators (CP and CO). However, ABET assesses the efficiency of these two indicators from the standpoint of the efficiency of the courses. Thus, the research still places it within the course indicator cells of educational performance.

The evaluation indicators of current evaluation institutions were used in order to deduce and analyse the accountability of the proposed evaluation model. Based upon the results of importing the evaluation indicators of the QAA and ABET, each indicator of the QAA and ABET can clearly mark its position within the evaluation matrix and points out its function. This indicates that the evaluation model proposed here

Table 1: The evaluation indicators matrix.

Education Process \ Educational Performance	Educational Achievement Performance	External Competition Performance	Resources Utilisation Performance
Input	**AI** The contents, goals and standards of educational objectives, visions for development, curriculum, teaching, learning, assisting and student achievements of the schools based on the resources possessed during the operation.	**CI** The current status or resources of student enrolments, research, inventions, industry services continuing education, graduates' quality, alumni achievements based on possessed resources and the foundation of educational performances of the school.	**UI** The current status and amount of used resources, eg appropriate funds, human resources, facilities, libraries, environments and administrative support by the school based on reflections from the social environment outside the school.
Translation	**AP** Actions done regarding educational objectives, curriculum and teaching, eg curriculum design, teaching activities, approaches and plans, the design of students' learning activities, student counselling units, evaluations of student achievements and all sorts of related meetings.	**CP** Actions and activities such as planning, execution, management and services regarding student enrolments, research, inventions, industry services, continuing education, graduates' quality, alumni achievements, teaching staff's achievements and reputation.	**UP** Actions or activities held during the process of job assignments, management, planning and decision-making regarding resource investments.
Outcome	**AO** Obtained outcomes in matters like educational objectives, curriculum and teaching after a series of transforming actions, with the main focus on students' learning results. For instance, number of students passing, number of students suspended, evaluation results of teaching and learning, as well as the learning effects of the curriculum.	**CO** Effects obtained through a series of transforming actions like student enrolments, research, inventions, industry services, continuing education, graduates' quality, alumni achievements, teaching staff's achievements and reputation. For instance, acquired study funds, number of theses, number of patents, performance of product services and social services, students' competition results, ratio of further studies and ratio of graduates' employment, graduates' ratio of entering the market, alumni achievements and social status of the school.	**UO** The obtained outcomes of invested resources after a series of transforming actions, eg amount of resources obtained by unit staff number, the status of resource usage by staff members, the influences of educational quality brought by each of the resources.
Feedback	**AF** Plans or actions after processes, corrections and consolidations regarding the effects of the outcomes produced by education.	**CF** Plans or actions after processes, corrections and consolidations regarding outcomes produced outside of educational institutes.	**UF** Plans or actions after processes, corrections and modifications done based on outcomes produced from the operation.

retains certain efficiency and applicability in terms of setting up and generalising different evaluation indicators.

CONCLUSION

The research presented in this article mainly focuses on the process of the execution of engineering education and how an engineering department proposes a new evaluation model with respect to the operation of its internal resources, educational performance and obtaining external resources. Although the outcomes of the courses are the core value of educational performance, the evaluation model does not assess the efficiency of the whole educational institution merely from the standpoint of the outcomes of the courses. This point might be different from the perspectives of the current educational evaluation and accreditation paradigms of the QAA and ABET. However, the products of engineering education are closely connected with the demands of society and they are not merely to meet course demands. Therefore, the model presented here not only includes all the evaluation indicators and standards of the two evaluation institutions (QAA and ABET), but also reveals the results of the external competition between educational institutions. Thus, one can recognise that this model possesses sufficient applicability and generality.

In the research presented here, the author reviews previous common and effective evaluation models (such as CIPP) and generalises a new evaluation model. However, this is not meant to undermine the value and efficiency of those evaluation models. That is to say, under the influence of changing international educational circumstances, engineering education should closely meet the demands of society, particularly with respect to the influence of human society and the quality of life. Through an efficient evaluation model that complies with current knowledge and social demands, engineering education should thus be able to examine the quality of its educational products and their contribution to society.

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BIOGRAPHY

Professor Hsi-Chi Hsiao received his MS degree from the University of Wisconsin in 1983 and his PhD from Indiana State University in 1987. He was head of the Department of Industrial Education at the National Changhua University of Education and the President of the National Penghu Institute of Technology. He has also served as a government consultant in the field of curriculum and instruction, vocational and technological education, and research in applied science education for many years. He is now a chair professor at the Graduate Institute of Business and Administration, Cheng Shiu University, and Reviewer-in-Chief for Research in Applied Science Education, Division of Science Education, National Science Council, Taiwan. His research interests have been focused on curriculum development, skills testing and creativity for technological and engineering education.