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Design and Development of a Tool for Measuring Learning Outcomes in a Manufacturing Engineering Program Based on Outcome-Based Education

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Abstract. Curriculum certification is the evaluation of a curriculum's quality. There are numerous accreditation systems in the world, such as the Accreditation Board for Engineering and Technology (ABET) and the Asean University Network Quality Assurance (AUN-QA). The results of program learning outcomes (PLOs) have been displayed for each accreditation system. Curriculum management should be designed to ensure that students' PLOs are met by the time they graduate. All subjects in the curriculum assist students in achieving their PLOs. Each subject in the curriculum contributes to the attainment of each PLO. On the other hand, each subject must complete a number of PLOs successfully. All student assessments of course learning outcomes (CLOs) were included to reflect the PLOs. To assess the CLOs, activities are allotted to each subject in order to meet the CLO requirement. To assess learning outcomes, it is necessary to compile all lecturer and student task data. However, managing this process requires considerable time. In contemplation of outcome-based education, this study designs and develops a tool to evaluate manufacturing engineering program learning outcomes. The "AAD-MfE program" was developed as a systemic tool to resolve the complexity of PLOs' data quality assessment. This program displays reliable information because all instructors simultaneously input task scores, subject grades, and CLO measurements. The PLOs of students have been monitored in real-time so that they can be improved while students are studying. The AAD-MfE program is a tool for demonstrating curriculum outcomes that are professional and appropriate for certification.

Keywords. Outcome-based education, engineering program, outcome measurement

Introduction

Engineering curriculums are being developed globally, and high-quality programs are frequently accredited by standard third-party organizations such as Accreditation Board for Engineering and Technology (ABET) [1] or ASEAN University Network-Quality Assurance (AUN-QA) [2]. The ABET accredits engineering programs worldwide,

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wheraes the AUN-QA accredits programs developed in ASEAN universities. Typically, these accreditations ensure that the programs adhere to an outcome-based education (OBE). Learning outcomes are a crucial component of OBE curricula, as they are the driving force behind efficient curriculum administration to ensure student success.

In engineering education, OBE has acquired popularity as a strategy for improving the quality of engineering programs by aligning curriculum and teaching methods with desired learning outcomes. There have been several research studies conducted on the implementation of OBE in engineering education. Karami et al. [3] reported that the implementation of OBE in an engineering curriculum improved student learning outcomes, particularly in the areas of critical thinking and problem-solving. According to a study conducted by Ghani et al. [4], the implementation of OBE in an engineering program increased students' engagement, motivation, and participation in class. A study by Tariq et al. [5] found that the implementation of OBE in an engineering program enhanced program effectiveness by better aligning the curriculum with the learning outcomes and by allowing faculty to identify and address areas where students were struggling. However, measuring curriculum learning outcomes can be challenging due to various factors, such as curriculum subjects, tasks, and activities, as well as the large number of students and lecturers involved in the evaluation process.

Typically, the achievement of student program learning outcomes (PLOs) is evaluated upon graduation and is a crucial factor in curriculum management. The PLOs measurement method (see Figure 1) is processed by course learning outcomes (CLOs) results from the first year to the fourth year of the study. For 25 sub-PLOs of the manufacturing engineering (MfE) program, the department has provided supurb curriculum management. Each MfE subject must contribute to multiple PLOs and be designed to assist students achieve each PLO. To fulfill the requirements of the CLOs, each subject's CLOs are assessed through activities. The PLOs of each student are reflected in all CLO assessments. Course design, also known as course specification, consists of the following components: time, subject plan, knowledge, activity, assignment, assessment method, teaching technique, and a total score for each task and CLO. Each subject's lecturers report CLO measurement data, which is then summarized and monitored by the curriculum management team in order to enhance student PLOs.

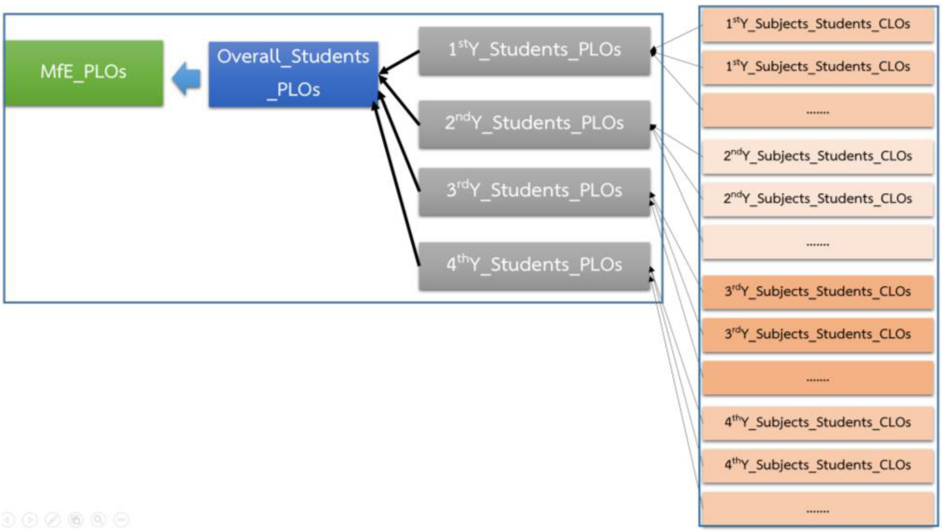

Figure 1. The MfE PLOs measurement method.

The measurement method collects a large amount of data from numerous tasks, subjects, and instructors, which is subsequently utilized to calculate and monitor student PLOs. It is extremely time-consuming. Therefore, it is necessary to develop a program that can accurately measure and monitor PLO results in a more efficient manner while ensuring their credibility and accuracy. Consequently, the objective of this study is to create and implement a tool for measuring learning outcomes in a manufacturing engineering program. By offering a reliable measurement method for PLOs, such a program could potentially be accredited or certified.

1. Conceptual Background

On a global scope and at various levels, OBE methods have been incorporated into educational systems [6]. The OBE approach seeks to establish a well-designed educational system that provides students with clear learning outcomes at the completion of their learning [7]. This enables students to comprehend what is expected of them and supports teachers in determining what they're supposed to teach. Implementing OBE necessitates consistency in intended educational outcomes, teaching and learning activities, and assessment procedures and practices [8]. The desired outcomes should be based on skills that students will use in the real world, such as lifestyle, professional and vocational, intellectual, interpersonal, and personal. The operating principle of OBE-based program design is a downward progression from the program's culminating outcomes to the course outcomes that are measured by specified learning tasks. In addition, the course- and program-level outcomes should be fundamentally linked to the ultimate educational outcomes.

The Conceiving-Designing-Implementing-Operating (CDIO) framework is an innovative educational framework that has been adopted by many universities [9] for producing engineers of the 21st century. The framework places an emphasis on engineering fundamentals in the context of conceiving, designing, implementing, and operating actual systems and products [10]. Active learning is emphasized by CDIO to encourage students to take an active role in their own education. Development of a program is dependent upon delineating four expectations: technical, personal, interpersonal, and CDIO. To develop complex engineering systems with added value, students must comprehend the fundamentals of pertinent technical knowledge and reasoning. Interpersonal skills, including collaboration and communication, are honed to prepare students for team-based environments of the twenty-first century. To effectively create and operate products and systems, students must comprehend the concepts of conceiving, designing, implementing, and operating systems.

Accreditation by ABET ensures that a university's engineering program meets internationally recognized quality standards [11]. This is due to the fact that graduates of accredited programs possess unique experiences in personal, interpersonal, and system-building skills, which distinguish them in actual engineering teams and allow them to develop new products and systems. According to the ABET accreditation system, all approved baccalaureate-level programs must meet eight criteria. These include the student criterion, the program educational objectives criterion, the student outcomes criterion, the continuous improvement criterion, the curriculum criterion, the faculty criterion, the facilities criterion, and the institutional support criterion [1]. For the curriculum's fifth criterion, the requirements specify engineering-related subject areas. In addition, the program curriculum must devote sufficient attention and time to each component, in accordance with the program's and institution's outcomes and goals. The professional component must consist of college-level mathematics and fundamental sciences pertinent to the student's field of study, as well as engineering topics pertinent to engineering sciences and engineering design. With the implementation of ABET accreditation for manufacturing engineering programs, the program should prepare graduates to be proficient in the following five areas: materials and manufacturing processes; process, assembly, and product engineering; manufacturing competitiveness; manufacturing systems design; and manufacturing laboratory or field experience. Students are consequently equipped for manufacturing engineering practice that adheres to engineering standards and multiple realistic constraints. As of 2023, ABET accreditation had been granted to 4,564 programs at 895 colleges and universities in 40 countries.

The AUN-QA aims to harmonize educational standards and encourage the continuous improvement of academic quality among ASEAN universities. Additionally, AUN-QA conducts institutional assessments, which examine the institution as a whole as opposed to examining specific programs. At the program level, the AUN-QA paradigm examines three distinct curriculum or program components: input, process, and output [12]. PLOs represent the characteristics and skills that students are expected to acquire after completing a program, and they are developed with the requirements of stakeholders in mind. Therefore, the program subjects have been designed to contribute to the PLOs. Then, the CLOs were created to supplement the PLOs.

2. The Existing Program

Accreditation by ABET requires that program educational objectives (PEOs) align with the requirements of stakeholders, including employers, alumni, and faculty. These PEOs serve as the program's long-term objectives and guide curriculum development, assessment, and continuous improvement efforts. The ABET accreditation process also includes a comprehensive evaluation of program outcomes, including the evaluation of student performance on aligned PLOs. AUN-QA is a system of quality assurance that requires to improve the quality of higher education programs in the ASEAN region [1]. The primary focuses of AUN-QA standards are program management, teaching and learning, and support services. The system requires programs to define intended learning outcomes (ILOs) that align with the mission and stakeholder requirements of the program. These ILOs serve as a guide for curriculum development, teaching and learning activities, and evaluation. AUN-QA also accentuates the significance of continuous improvement, requiring programs to assess and evaluate their ILOs on a regular basis and make any necessary adjustments to enhance program quality. Work-integrated learning (WIL) is a method of education that combines theoretical knowledge with practical work experiences. Through authentic work experiences, WIL aims to develop students' professional skills, industry knowledge, and employability. WIL activities may include apprenticeships, cooperative education, capstone projects, and partnerships with the business community. WIL offers students opportunities to employ classroom knowledge in real-world contexts, acquire practical skills, and build professional networks. Through the incorporation of WIL into the curriculum, students are better prepared for the demands of the workforce and graduate with the relevant skills and knowledge.

The manufacturing engineering program at Prince of Songkla Univesity (PSU) has been designed following the OBE methodology, incorporating the CDIO framework, ABET and AUN-QA accreditation systems, and the WIL approach [12]. The program has identified ten major PLOs (see Table 1.) and twenty-five sub-PLOs. The PLOs consist of both generic and subject specific outcomes. The design of a curriculum for PLO achievement necessitates that all courses contribute to each PLO. Figure 2 depicts an example of the mapping between the PLOs and the subjects. The black circles and white circles in Figure 2 represent the primary and secondary course contribution to PLO achievement, repectively.

Table 1. Generic and subject specific outcomes of PLOs for the manufacturing engineering program.

Program Learning Outcomes (PLOs)	Generic	Specific
PLO1: An ability to identify, formulate and solve complex engineering problems in Thailand, especially in the southern region, by applying principles of engineering, science, and mathematics		✓
PLO2: An ability to apply modern engineering principles to develop innovations in collaboration with other disciplines		✓
PLO3: An ability to develop and conduct appropriate experimentation, analyze, and interpret data, and use engineering judgment to draw conclusion		✓
PLO4 An ability to exploit digital technologies to design, test, inspect, control, and manage manufacturing systems		✓
PLO5 An ability to design manufacturing engineering innovations that can be commercialized or eligible for patenting		✓
PLO6 An ability to acquire new knowledge to empower lifelong self-development	✓	
PLO7 An ability to demonstrate empathy, social contribution, and prioritization on benefit of mankind	✓	
PLO8 An ability to recognize ethical and professional responsibilities in manufacturing engineering situations	✓	
PLO9 An ability to communicate using different modes of delivery such as writing reports, oral presenting, and elaborating effectively and understandably for international audiences	✓	
PLO10 An ability to function effectively on a team whose members together provide leadership, create a collaborative and inclusive environment, establish goals, plan tasks, and meet objectives	✓	

Courses	credits	Curriculum program learning outcomes (PLOs)																											
		PLO1			PLO2		PLO3			PLO4				PLO5	PLO6		PLO7		PLO8		PLO9					PLO10			
		1.1	1.2	1.3	2.1	2.2	3.1	3.2	3.3	4.1	4.2	4.3	4.4		6.1	6.2	7.1	7.2	8.1	8.2	9.1	9.2	9.3	9.4	9.5	10.1	10.2	10.3	10.4
200-112 Fundamental Mathematics for Engineer	3((3)-0-6)			●	●	●										○			○										
200-113 Fundamental Physics for Engineer	3((3)-0-6)			●	●	●										○			○										
200-114 Fundamental Chemistry for Engineer	2((2)-0-4)			●	●	●										○			○										
226-102 Mathematics for Computer Aided Design	3((3)-0-6)			●	●	●				○						○			○	○									
226-104 Fundamental Chemistry Laboratory	1(0-3-0)			●	●	●	●	●	●							○			○		●			○			○		
226-202 Mathematics for Control Systems and Engineering Analysis	3((3)-0-6)			●	●	●				○	○	○				○			●	●						●	●	●	●
200-111 Into Engineering World	2((2)-0-4)			●															●	●						●	●	●	●
200-116 Basic Engineering Programming	3((2)-2-5)			●						●	○	○	○						○	○									
200-117 Basic Engineering Drawing	2((2)-0-4)			●	●					●									○										

Figure 2. The mapping between MfE PLOs and subjects.

There are numerous courses to complete each PLO achievement. For instance, 200-112, 200-113, and 200-114 were created to attain PLO 1.3 (see Figure 2). Each course was intended to accomplish multiple PLOs; for example, 226-202 was intended to achieve PLOs 1.3, 2.1, 2.2, 8.1, 8.2, 10.1, 10.2, 10.3, and 10.4 (see Figure 2). In every course, therefore, instructors have designed CLOs to contribute their own PLOs. Numerous tasks, such as in-class activities, homework, projects, and exams, are designed to help students attain all CLOs. For the purpose of determining student CLOs, each developed task is evaluated using various criteria. In addition, instructors have evaluated all developed assignments in order to assess the CLOs of each student. Then, the instructors have recorded these CLOs' data.

Four educational years remain until MfE students graduate. A large amount of CLOs data from these courses has been compiled and measured for the student PLOs. Administrators of the curriculum have determined all PLOs from each CLO and are also monitoring the PLO achievement to enhance student learning outcomes. For the MfE program, it takes all instructors and administrators a significant amount of time to administer these PLO monitoring data. The AAD-MfE program has been developed as a systemic tool to address the complexity of assessing PLOs in order to reduce the amount of time required.

3. Methodology

One of the fundamental tenets of OBE is that a curriculum is designed from the ultimate outcomes, or PLOs, downwards. To ensure the intended level of achievement, it is necessary to conduct explicit assessments of students' PLO accomplishments as they progress toward graduation. In response to the requirement, the "AAD-MfE program" website (see Figure 3) was created to assist MfE instructors with student assessment and MfE program administrators with determining and monitoring PLOs. The program process entails the input of course activities and CLO assessment results, as well as the determination of students' and the MfE program's PLOs.

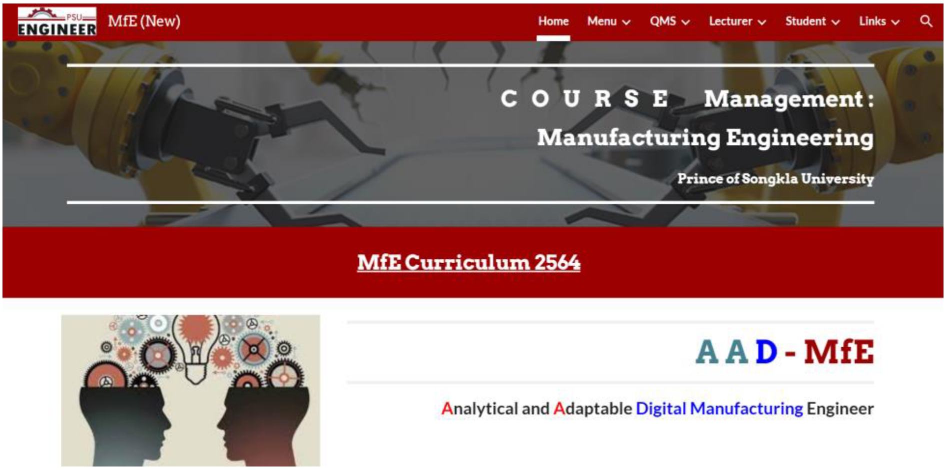

Figure 3. the AAD-MfE program website.

Specifically, the MS Excel-based AAD-MfE program is divided into two levels: curriculum level and instructor level. At the curriculum level, primary data preparation must be completed prior to entering all data into the program. The basic information is created for data entry at the curriculum level. Because the data for each course must be identical, curriculum administrators must compile the data. There are two subsections within the curriculum data section: core data and the CLO matrix. The program's core data includes a list of course instructors, the course group's name, the learning level, the assessment method, a list of program learning outcomes, etc. The matrix is used as a diagram of the relationship between PLOs and CLOs in a subsequent subsection called the CLO matrix. After initial data entry has been completed, the AAD-MfE program will be utilized by instructors to collect data for each course.

The program's second level is intended for each course's instructor evaluation. It is divided into three modules: course design (see Figure 4), score entry, and CLOs and grading report (see Figure 5).

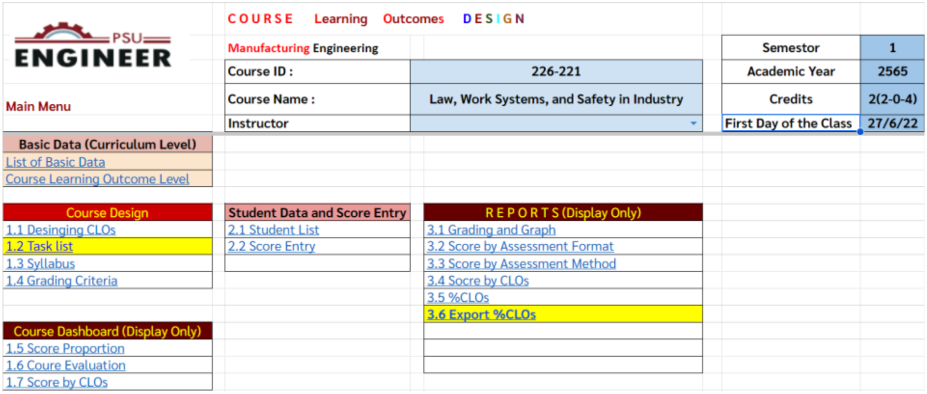

Figure 4. Course design part of the AAD-MfE Program.

3.5 Score by CLOs

ID	226-221			Menu						
Name	Law, Work Systems, and Safety in Industry				%CLOs					
		Max		90.8	100.0	95.0	100.0	87.5	100.0	100.0
		Min		65.2	0.0	0.0	0.0	0.0	0.0	0.0
		Average		77.2	96.9	61.7	91.2	74.8	82.4	84.9
		SD		6.6	15.7	16.0	15.6	12.7	15.9	17.1
No.	Student ID	Student Name	Grade	Total Score	CLO-01 (รอง) เข้าใจความต้องการเชิงเทคนิคและข้อจำกัดของปัญหาที่เกี่ยวข้องกับกฎหมาย	CLO-04 (หลัก) สามารถออกแบบงานที่เกี่ยวข้องกับกฎหมาย ระบบงาน	CLO-14 (รอง) สามารถค้นคว้าและเลือกแหล่งความรู้ทางวิชาการที่	CLO-15 (รอง) สามารถนำเสนอหรืออธิบายหลักการ กฎหมาย ระบบงาน	CLO-17 (หลัก) นำหลักจรรยาบรรณทางวิศวกรรมการผลิต ร่วมกับความรู้ใน	CLO-18 (หลัก) นำปัจจัยที่เกี่ยวข้องกับด้าน กฎหมาย ระบบงาน
1	6410110034		B+	75.1	100	59	87	75	83	75
2	6410110061		B	70.5	100	52	87	75	80	75
3	6410110084		A	86.6	100	79	100	75	85	100
4	6410110103		B	70.2	98	54	87	75	80	75
5	6410110119		C+	65.7	100	40	87	75	80	75

Figure 5. CLOs and grading report part of the AAD-MfE Program.

In the course design module, it is used for entering course design and information. It has four subsections, which are as follows: 1) the design of the specific CLO utilized in this course; 2) a task list for course evaluation; 3) a teaching plan; and 4) grading standards. List of students and score input are the two subsections that comprise the score entry module. The list of students can be imported with ease from the student information system (SIS) of the university. In the subsections for score entry, the list of students will be displayed in a row, and a task list with CLOs will be displayed in a column. This method of data entry has been found to be practical for instructors who input data because it is similar to the standard method. It is used in the CLOs and grading report module for display and reporting. It can be presented in six distinct ways: 1) grade with a histogram; 2) score according to the format of the assessment. 3) score based on the assessment method; 4) score based on CLOs; 5) score computed as a percentage of CLOs; and 6) percentage of CLOs for exporting.

The percentage of a CLO for a course is calculated by dividing the student's total score on the same CLO by the CLO's total score. The percentage of a PLO is derived from the CLO results by adding all CLOs (the course weight allocated by its credit multiplied by its CLO percentage). After courses have completed data entry, the AAD-MfE program will calculate student PLOs (see Figure 6). The cell color for each PLO indicates the student's status. For instance, the red color indicates a failure. The curriculum administrators have monitored the results of the PLOs and informed the instructors involved in order to enhance student learning.

%CLOs					PLO 1.1	PLO 1.2	PLO 1.3	PLO 2.1	PLO 2.2	PLO 3.1	PLO 3.2	PLO 3.3	PLO 4.1	PLO 4.2	PLO 4.3	PLO 4.4	PLO 5	PLO 6.1	PLO 6.2	PLO 7	PLO 8.1	PLO 8.2	PLO 9.1	PLO 9.2	PLO 9.3	PLO 10.1	PLO 10.2	PLO 10.3	PLO 10.4	Average
No.	Student ID	Student Name	Total Subjects	Total Credits	CLO-01	CLO-02	CLO-03	CLO-04	CLO-05	CLO-06	CLO-07	CLO-08	CLO-09	CLO-10	CLO-11	CLO-12	CLO-13	CLO-14	CLO-15	CLO-16	CLO-17	CLO-18	CLO-19	CLO-20	CLO-21	CLO-22	CLO-23	CLO-24	CLO-25	
1	6410110034		4	10	73	40	55	56	17									84	75	72	79	90		60		88	79	100	100	71
2	6410110061		4	10	80	57	57	63	28									88	75	87	78	84		0		85	65	100	92	69
3	6410110084		4	10	79	50	83	66	50									92	75	88	89	100		0		85	87	100	100	76
4	6410110103		4	10	70	36	45	45	14									80	75	57	72	84		0		80	45	100	100	60
5	6410110115		3	8	58	40	40	46	16									80	75	65	69	100		0						54

Figure 6. PLOs monitoring part of the AAD-MfE Program.

4. Results

For the second semester of the academic year 2022, numerous course instructors have entered course information into the AAD-MfE program. The program receives a great deal of information, but the CLOs and PLOs values are determined very quickly. Due to program calculation, there is precise determination. In determining, no human error can occur. In addition, the values of CLOs and PLOs are known in real-time, allowing students with outcome learning issues to take corrective action. Nevertheless, the AAD-MfE program should be enhanced due to its large data set and user-friendly interface.

5. Conclusion

Measurement of student learning outcomes is essential for accreditation. Since a large amount of data is used to determine the results, they must be valid and reliable. In this instance, a powerful tool, such as the AAD-MfE program, is used to ensure the curriculum's quality. The curriculum has been implemented the AAD-MfE program for the second semester of the 2022 academic year as part of the manufacturing engineering program. The AAD-MfE program can rapidly determine the CLO and PLO values from a large quantity of input data. The process of determining and assuring the quality of the MfE curriculum is devoid of human error. In addition, CLO and PLO scores are accessible in real-time, allowing students with any learning issue to take corrective action.

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