A Consistent Numerical Procedure for Integrated Assessment

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Abstract
Due to the outcome-based educational approach, engineering programs must rigorously assess their performance by measuring students' competencies, or outcomes. Two main assessment strategies exist: a holistic assessment based on specific entries and an integrated assessment based on student performance in all courses of a program. For the latter, challenges remain for programs to gather assessment data at the course level and transform them into compact information to measure performance from different perspectives. Current approaches for integrated assessment as practiced by many engineering programs in Malaysia lack standardization and quantitative rigor to provide reliable and meaningful outputs. This work proposes a new assessment model that addresses such issues. It uses matrix mapping and formalizes a consistent mathematical procedure to aggregate data across various levels. Its development, simulation, benefits, and issues are discussed. One advantage of the model is that it allows for a more automated assessment system to be developed.
Keywords: outcome-based education, program assessment, integrated assessment system

Introduction

The Outcome-Based Education (OBE) demands four critical phases an engineering program must undergo: (1) rigorous conception of desired outcomes and curricula;(2) design and facilitation of effective learning environments; (3) collection of evidence on students' attainment of outcomes through assessment, and (4) continuous program improvement based on assessment data. Its actual implementation, however, may vary depending on experiential and cultural interpretations, institutional norms, and national accreditation requirements.

Despite these variations, OBE in itself should be a guiding framework for a program to enhance students' learning experience to develop their competencies. This notion dictates that one measure of success in implementing OBE is in how much a program has transformed its traditional educational practice to adapt to changing learning environments and more integrated curricular activities to produce desired student outcomes. A commendable effort in this direction is that of the CDIO Initiative (Crawley et al., 2007; Worldwide CDIO Initiative, 2014) to reframe the educational goals of an engineering program based on the need for engineers to be able to conceive, design, implement, and operate complex engineering systems.

A demanding aspect of implementing an OBE program, however, is in the assessment process. Indeed, it is one of the main focus of study in engineering education after the introduction of OBE (Wankat, 2004). The main issue on assessment centers on this question: "How do we know whether students have attained desired outcomes and to what degree?"The first part of the question – "how do we know" – requires a program to provide sufficient evidence of outcomes attainment. Where the evidence comes from are subjected to different implementation of OBE. The second part of the question – "to what degree" requires a program to establish a reliable process that provides qualitative/quantitative and direct/indirect measures of outcomes attainment.

One school of thought to address the question above is to realize that not all curricular activities and assessment will provide valid measures of outcomes attainment. Another approach is to use ensemble results on student assessments as a measure of program quality. The latter is the dominant attitude in the accreditation of engineering programs in Malaysia: a program here must put in place a comprehensive assessment system that measures students' attainment of outcomes in all courses, integrates assessment data from all courses and other entries, and provides meaningful directions for improvement. These requirements have lead many programs to meticulously focus on building such a system.

This work presents two different approaches of assessing program outcomes, discusses issues and challenges that undermine the current approach taken by programs in Malaysia, and offers a solution to improve the current system. The solution is designed to create an assessment system that is rigorous numerically based on sound mathematical formulations but not demanding to implement. Furthermore, outputs from the system must be easily interpreted to guide the continuous improvement process. A simulation on a simple but fictitious program is performed to facilitate the mathematical formulation of the model and demonstrate the interpretation of its results.

Background

Two Approaches for Program Assessment

Assessment in engineering education can be interpreted in many ways, depending on the level of its usage. At the course level, assessment is treated as a tool (e.g., an oral or written test, report, thesis, etc) to measure specific student competencies. Outside of courses, assessment can be a number of internal and external methods (e.g., student interviews, standardized exams, etc; see Olds et al. (2005)) used to solicit additional evidence on students' attainment of program educational objectives and outcomes. At the program level, assessment is a system or process used to measure program performance by assessing outcomes attainment from various entries.

One approach to assess a program is to identify entry points that allow holistic evaluation of student

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outcomes. A good choice for holistic assessment is the senior year capstone design courses (McKenzie et al., 2004). In these courses, students are involved as teams in open-ended multidisciplinary projects to design and build complex engineering systems. To complete the projects, students employ wide-ranging engineering skill sets (e.g., designing complex systems, researching literature, working in teams, exercising professional ethics, etc). These realistic multi-objective settings provide ample opportunities for faculty to assess various aspects of student competencies. Junior-level cornerstone projects (Dym et al., 2005) can similarly be used to assess multiple competencies. Exit surveys or interviews offer another set of choices for holistic assessment where graduating seniors self-evaluate their level of competencies. The approach of soliciting opinions, however, may be biased and at best only give indirect measures of outcomes attainment. Nonetheless, they offer independent data to be triangulated with other data to increase assessment reliability. Scales et al. (Scales et al., 1998) explores other assessment options such as alumni/employer surveys and national standardized tests.

Another approach to assess a program is to integrate assessment data from all courses of a program. Rather than selectively choosing specific entries, this "bottom-up" approach views that all assessment activities at the course level are important, and hence must be aggregated to evaluate students' progress. In this program-level assessment strategy, learning objectives of a course must be tangibly linked to program outcomes. This linking provides a route to integrate assessment results at the course level into data at the program level. Subsequent discussion pivots on this integrated assessment strategy.

Using the latter strategy, engineering programs in Malaysia are required in their accreditation exercises to document their assessment process with detailed analysis that maps all assessment data at the course level to outcomes attainment at the program level (EAC, 2012). In addition, it is desired that programs measure attainment on the Bloom's level of competencies and outcomes attainment at various levels (student, course, cohort, and program levels). Inevitably, such demands will pose problems and challenges. This unique experience of seeking for a comprehensive assessment system provides the context to find solutions to those problems.

Current Framework for Integrated Assessment

The current framework of an integrated assessment is the matrix-mapping technique, first proposed by Felder & Brent (2003). Their approach is to use matrix mapping to relate between various elements. One matrix – called the Course Assessment Matrix –maps the learning objectives of a course to the overall outcomes of a program. Another matrix – the Program Outcome Assessment Matrix – shows how the same outcomes are addressed by the courses in the program. Four-level discrete indicators of 0 to 3 are qualitatively assigned in matrix cells to denote degree of emphases: none, slight, moderate, and substantial emphases. Table 1 illustrates examples of these maps.

Table 1: Top: A Course Assessment Matrix to map learning objectives (LOs) of a course to Program Outcomes (POs). Bottom: A Program Outcome Assessment Matrix to map a set of courses to POs

	PO1	PO2	PO3	PO4	PO5	PO6	PO7
LO1	3		2		1		
LO2	1	3					
LO3				3			
LO4					2		3
LO5	3					2	
Course 1	3	2	3	3	3		
Course 2	3	2				1	
Course 3				1	2		3
Course 4			3				
Course 5	3	1				1	

The current approach taken by many programs in Malaysia is to expand upon the original system proposed by Felder and Brent by making the link between the various elements mathematically computable. One possibility is to use course grading weights, credit units and course assessment results to integrate data in all courses. Unfortunately, a few problems arose from an ad-hoc implementation of this strategy.

First, the approach produces non-standard assessment systems across different programs because varying interpretations and techniques are employed to integrate course and program data. It would be difficult, if not impossible, for accreditation officers to benchmark data across various programs: each assessment data is only meaningful when interpreted against the system used to produce it.

Second, some of these systems have been developed in a spreadsheet environment to be distributed to and self-operated by individual faculty members. Any tweaks or upgrades in one version would require instantaneous updates in all copies; failure to do so would reduce their reliability. Tracking coding bugs in a complex spreadsheet environment are also difficult, thus compromising the validity of the results. Such cases inevitably are prone to occur due to the typically elaborate and convoluted cross-linking of formulas between parameters across cells and sheets in these systems.

Third, the data-entry process into a spreadsheet system is demanding for faculty to dutifully partake. In a typical operation, a sizable database of course information, matrix maps, and assessment results for every student must be manually entered into the system. This process can be laboriously tedious, error-prone, time-consuming, and costly. Some programs (including a few at the author's institution) opt to use additional administrative supports to manage the assessment system and other OBE-related tasks (Davis, 2003).

Fourth, the use of discrete values as emphasis indicators are poorly defined to be properly functional when transforming course data into program data. For instance, referring to Table 1, Course 1 places high emphases on five POs while Course 4 places a high emphasis on only one PO. Does this mean that Course 1 is placing more "effort" in teaching and learning compared to Course 4, or that the "value" of emphasis in Course 4 is more than those in Course 1 when considering that their credit units are almost the same (see Table 5)?In other words, should the discrete indicators be used as absolute values or relative measures when subjected to computations? Such ambiguity will pose problems for one to numerically integrate data across courses.

Any assessment systems designed to perform such demanding tasks must therefore overcome three major challenges: to develop relationships between relevant elements at the course and program levels based on consistent mathematical formulations; to compute outputs that measure both the emphasis and the attainment of outcomes at various levels; and to make the data-entry process simple and clear.

An Improved Model for Integrated Assessment

Model Development

Similar to the current system for integrated assessment, the new system maintains that course-level assessment results serve as the core quantitative data for the entire assessment process. These datasets across all courses are then integrated to form a new dataset that measures performance (i.e., outcomes emphasis and attainment) at the program level. We propose the following steps to build the new improved assessment system.

First, we identify and label the key elements used in this integrated assessment system as the program outcomes (PO), the course-level learning objectives (LO), and the assessment tools (AT). These elements are commonly used in a course to measure students' outcomes attainment.

Second, two maps must be established at the onset of designing a course. The first map defines how much a course LO addresses a PO, akin to the Course Assessment Matrix. However, instead of the four-level discrete indices to measure emphasis, this new map uses continuous metrics. The new emphasis metric is a normalized weight W_{LO} such that its cumulative value for each LO, across all POs addressed by the course, is 1. This assignment reflects the weight parameter as a relative measure of emphasis. Here, the use of such continuous metrics to replace the discrete indicators addresses the fourth problem described in the Framework in the previous section.

Table 2 illustrates an example of this map, where W_{LO} is identical to the discrete indices in Table 1, but transformed into the continuous metrics through the formulation

$$W_{LO,ij} = \frac{I_{M,ij}}{\sum_{j=1}^{n_j} I_{M,ij}} \qquad (1)$$

where i and j denotes the row and column indices respectively (i.e. the learning objectives and the program outcomes in reference to Table 2), I_M is the original discrete data in Table 1, and n is the total number of elements in a row or column, depending on the subscript used.

Table 2: Mapping learning objectives to outcomes using emphasis weights W_{LO}

	PO1	PO2	PO3	PO4	PO5	PO6	PO7
LO1	0.5		0.33		0.17		
LO2	0.25	0.75					
LO3				1.0			
LO4					0.4		0.6
LO5	0.6					0.4	

The second map defines the emphasis, labelled as W_{AT}, that an AT allocates to measure an LO. These metrics are similarly presented as relative and normalized weights.

Third, we again use a continuous scale to quantify performance using two normalized parameters (i.e., scaled from 0 to 1): an outcomes emphasis indicator (X) and an outcomes attainment indicator (Y). In a typical running of a course, individual students' performance is assessed through a set of assessment tools (AT). For each AT, a grading weight is allocated to define its emphasis (relative to other ATs) on students' cumulative marks at the end of the course; this weight is the emphasis indicator X_{AT}. The marks for these ATs for individual students are labelled as the attainment indicators Y_{AT}. Table 3 shows an example of a course data containing W_{AT},X_{AT}, and Y_{AT}.

Table 3: Mapping the indicators X_{AT} and Y_{AT} onto X_{LO} and Y_{LO} in Course 1 using the emphasis weights W_{AT}

	X_{AT}	Y_{AT}	W_{AT}				
			LO1	LO2	LO3	LO4	LO5
AT 1	0.40	0.90	0.7	0.2			0.1
AT 2	0.25	0.83		0.7	0.3		
AT 3	0.15	0.40	0.5			0.5	
AT 4	0.10	0.61		0.6			0.4
AT 5	0.05	0.55			1.0		
AT 6	0.05	0.43	0.1			0.9	
X_{LO}			0.360	0.315	0.125	0.120	0.080
Y_{LO}			0.789	0.806	0.718	0.411	0.755

Instead of measuring the outcomes attainment of individual students, the average outcomes attainment of a single course can be measured as well. This is achieved by redefining Y_{AT} as the average marks of all students assessed by an assessment tool. Other types of formulation for Y_{AT} can be used as well to represent a different measure of course performance, e.g., using an RMS-based indicator to measure variations in student performance or a target-based statistical indicator (for example, see Appendix A.4 in (Felder & Brent, 2003)).

Fourth, a set of consistent mathematical procedure shall be developed in this “bottom-up” data transformation. In the next section, we proceed to formulate these formulas to map and integrate assessment data from course-level assessments up to the program-level outcomes attainment.

Detailed Formulation

The following simulation on a fictitious course (labelled as Course 1) illustrates the set of mathematical formulas developed for the data transformation. Course 1 consists of six ATs, five LOs, and seven POs (the computation can be extended to any number of tools, objectives, or outcomes). The course data is shown in Table 3, where each Y_{AT} represents the average mark of all students in the course.

The attainment of the learning objectives at the course level is computed as X_{LO} and Y_{LO} using Equations (2) and (3). X_{LO} is a relative measure of the emphasis given in the course on each learning objective and Y_{LO} quantifies its level of attainment. Table 3 is referred to again in this example to show the computation of X_{LO} and Y_{LO}.

$$X_{LO,j} = \sum_{i=1}^{n_i}\left(W_{AT,ij}X_{AT,i}\right) \quad (2)$$

$$Y_{LO,j} = \frac{1}{X_{LO,j}}\sum_{i=1}^{n_i}\left(W_{AT,ij}X_{AT,i}Y_{AT,i}\right) \quad (3)$$

To simplify the presentations of subsequent formulations, the mapping procedure of Equations (2) and (3) can be written in a compact form as

$$\left(X_{LO}, Y_{LO}\right) = f_M\left(W_{AT}, X_{AT}, Y_{AT}\right) \quad (4)$$

The course’s emphasis and attainment on the learning objectives can then be transformed to determine the course’s emphasis and attainment on the program outcomes (X_{CO} and Y_{CO}) via a matrix mapping using the emphasis weights W_{LO}. With the W_{LO} data in Table 2 and the X_{LO} and Y_{LO} values in Table 3, X_{CO} and Y_{CO} of Course 1 can be obtained from Equation (5) with the results shown in Table 4.

$$\left(X_{CO}, Y_{CO}\right) = f_M\left(W_{LO}, X_{LO}, Y_{LO}\right) \quad (5)$$

The next step is to integrate assessment data from all courses to compute the outcomes emphasis (X_{PO}) and attainment (Y_{PO}) at the program level. Course credit units (T_C) are used to measure the relative importance of one course to another. T_{PO} is a parameter that measures the emphasis of a PO across all courses in the unit identical to that of T_C.

Table 4: The indicators X_{CO} and Y_{CO} of Course 1 computed using X_{LO}, Y_{LO} and W_{LO}

	PO1	PO2	PO3	PO4	PO5	PO6	PO7
X_{CO}	0.307	0.236	0.119	0.125	0.109	0.032	0.072
Y_{CO}	0.788	0.806	0.789	0.718	0.623	0.755	0.411

The procedure to integrate course data follows Equations (6) to (8), written compactly in Equation (9). The *i* (row) and *j* (column) indices are in reference to Table 5, which shows the course-level assessment data (X_{CO} and Y_{CO}) of a fictitious program which consists of four courses.

$$T_{PO,j} = \sum_{i=1}^{n_i}\left(T_{C,i}X_{CO,ij}\right) \quad (6)$$

$$X_{PO,j} = \frac{T_{PO,j}}{\sum_{i=1}^{n_i} T_{C,i}} \quad (7)$$

$$Y_{PO,j} = \frac{1}{T_{PO,j}}\sum_{i=1}^{n_i}\left(T_{C,i}X_{CO,ij}Y_{CO,ij}\right) \quad (8)$$

$$\left(X_{PO}, Y_{PO}\right) = f_A\left(T_C, X_{CO}, Y_{CO}\right) \quad (9)$$

Table 5: The indicators of Courses 1 to 4 mapped through W_{LO} onto the program-level T_{PO}, X_{PO}, and Y_{PO}

	Courses	Credits	PO1	PO2	PO3	PO4	PO5	PO6	PO7
X_{CO}	Course 1	3	0.307	0.236	0.119	0.125	0.109	0.032	0.072
	Course 2	3	0.082	0.796	0.003	0.002	0.117	0.000	0.000
	Course 3	4	0.045	0.070	0.400	0.400	0.085	0.000	0.000
	Course 4	2	0.106	0.153	0.070	0.500	0.080	0.000	0.091
Y_{CO}	Course 1	3	0.788	0.806	0.789	0.718	0.623	0.755	0.411
	Course 2	3	0.646	0.543	0.900	0.900	0.676	0.000	0.000
	Course 3	4	0.550	0.814	0.690	0.930	0.644	0.000	0.000
	Course 4	2	0.567	0.626	0.620	0.793	0.603	0.000	0.568
T_{PO}			1.558	3.682	2.104	2.982	1.179	0.096	0.399
X_{PO}			0.130	0.307	0.175	0.249	0.098	0.008	0.033
Y_{PO}			0.708	0.621	0.703	0.857	0.642	0.755	0.483

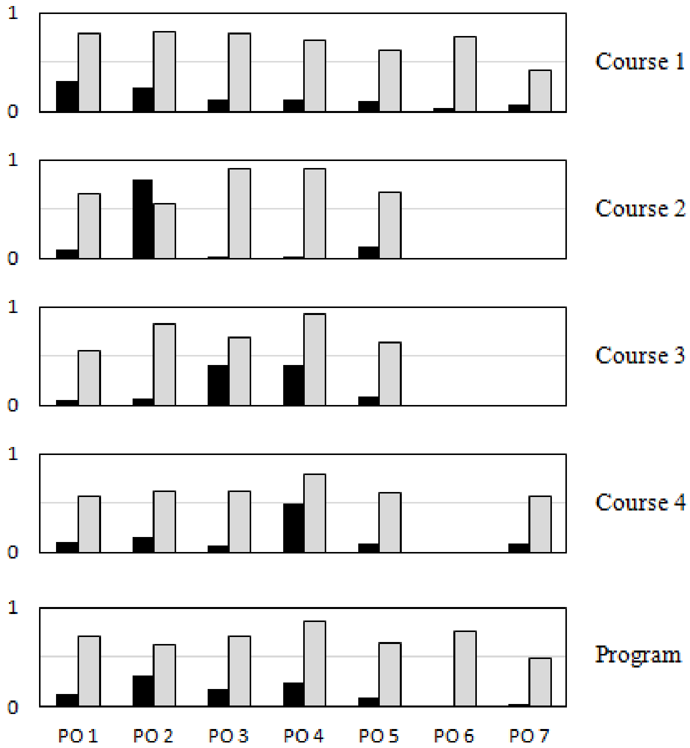

Figure 1: The outcomes emphasis and attainment (black and grey bars, respectively) of the sample program as computed in Table 5

Interpreting the Results

One advantage of this approach is that it offers a simpler way to visualize and interpret assessment results. Figure 1 illustrates the results of Table 5 in a graphical form, which allows one to easily capture how much a PO has been emphasized and attained by each of the courses as well as the program. For instance, Course 1 clearly attempts to have a balance in addressing most of the outcomes. Conversely, Course 2 places a dominant focus on PO2 but with a poor attainment level. Further, virtually all of the courses do not place high emphases on PO6 and PO7.

At the program level, on average, the first five of its outcomes are addressed relatively well; PO 4 achieves a high level of attainment with fine contributions from almost all of the courses. Lower achievement on PO 2 can be traced back to relatively poor attainments in courses 2 and 4.One can also derive from Figure 1 that any remedial efforts on the program should include improving students' performance on PO6 and PO7, which are not emphasized much. In short, from the plots one can easily communicate the essence of program performance and assess clear directions for continuous improvement.

In a real program with a larger number of elements involved (courses, outcomes, objectives, and assessment tools), the tasks of managing data will definitely scale up and the tasks of interpreting the results can be expected to be challenging. Using the new model can ease both tasks through its clear numerical procedure and simplified visuals of the results.

Further Discussions

Extended Applications

The sample case illustrated in previous section is based on an attainment indicator that measures average course performance, i.e., on a Y_{AT} that represents students' average marks. When aggregated across all courses, the result (i.e., Y_{PO}) represents the average performance of an entire program. This system can also be used to analyze program performance from different angles.

For instance, the average performance of a student cohort can be measured by aggregating results from the courses taken by that cohort. Likewise, the performance of a single student can be measured by redefining Y_{AT} based on his or her course assessment marks. Both of these measurements can be further tailored to analyze cohort or student performance in any specific academic year or across all of their completed years of study. As discussed above, Y_{AT} can also be designed to measure variations in student performance and other types of attainment statistics. In short, the robust mathematical formulations allow for easy manipulation of assessment data from various perspectives.

Although the discussion so far is limited to using course-based assessment tools to directly measure program performance, the system is generic enough to be extended for use with other types of assessment tools (e.g., indirect outcomes evaluations via exit interviews and student polls, external data collections from alumni/employer surveys, and non-course-based student projects or portfolios). Two approaches can be taken in processing these assessment data. The first is to combine the course and non-course-based assessment data into an integrated result to measure program performance. To achieve this, some form of weight scales compatible with the credit unit system should be use on the non-course-based data to aggregate them with the course-based data. The second approach is to use them separately thus providing two independent measures of the program performance for triangulation: direct measures of student competencies based on course-based assessments, and indirect data from students' and stakeholders' inputs.

The system can also be used to assess student performance with respect to learning domains, such as the cognitive, affective and psychomotor skills define in the Bloom's Taxonomy (Krathwohl, 2002). In this case, only a single map is needed to link the assessment tools of a course to the learning domains. The computation procedure to obtain course and program-level assessment data is rather straight-forward, analogous to the previous formulations. First, outcomes indicators X_{AT} and Y_{AT} of a course are mapped via a matrix W_{CL} onto the learning domains whose emphasis and attainment indicators are X_{CL} and Y_{CL}. These course data are then integrated across all courses to measure the program-level emphasis (X_{PL}) and attainment (X_{PL}) of the learning domains. Mathematically, this procedure is described by the following two equations:

$$(X_{CL}, Y_{CL}) = f_M(W_{CL}, X_{AT}, Y_{AT}) \quad (10)$$

$$(X_{PL}, Y_{PL}) = f_A(T_C, X_{CL}, Y_{CL}). \quad (11)$$

Remaining Issues

A critical aspect in implementing the new system is the reliability of its results, which is influenced by two factors: the quality of course-based assessment and the validity of the mapping matrices W_{AT} and W_{LO}. The first issue is rather subjective: the quality of faculty assessment can be influenced by their capacity and experience. For instance, the exercise of designing and marking exam papers vary between instructors. Institutional norms and practices can also influence assessment quality. For example, standard guidelines to grade students may differ between institutions. In such cases, techniques to improve student assessment needs to be explored further, e.g., by using rubrics to standardize marking (Trevisan, 1999), establishing clear policies and principles to assess students (Astinand & Antonio, 2012), and promoting good practices based on established standards.

The second issue of mapping accuracy is a new yet unaddressed challenge. A reliable technique to quantify mapping accuracy must be developed. Despite the lack of a framework to build these matrices, mapping should be made as explicit as possible to reduce ambiguity: one approach is to do a one-to-one mapping, where an AT is mapped onto one LO, which in turn addresses one PO (AT 5 meets this criteria in the example of Course 1 above, where it maps solely to LO 3, which in turn addresses only PO 4).

Nonetheless, a number of assessment tools are available (e.g., project reports and presentations, theses, and student portfolios) that measure more than one competency. Building a one-to-one mapping would mean dissecting these tools into smaller parts that measure separate learning objectives. Such a practice should increase mapping accuracy, but at the expense of adding more assessment components to manage and process.

Conclusions

This work has presented a new model of assessing program outcomes. Its key methods are the mapping of assessment data based on students' marks from course-level assessments and the integration of these data from all courses of a program. A mathematical procedure has been developed in this work to standardize the computation process.

The new model is designed to address the challenges faced in preparing detailed analysis of program assessment, particularly in compliance with the accreditation requirements in Malaysia. It extends the basic framework of the current matrix-mapping system by making the assessment data quantifiable across various levels and the connections between parameters more explicit. A simulation of this model on a fictitious program and a set of courses show sits versatility in deriving valuable information.

The model offers a number of advantages. First, it establishes a standard assessment system to be used across different programs. This allows for a more objective comparison or benchmarking between programs. Second, the graphical presentation of output data can be easily communicated and interpreted, allowing faculty to rapidly identify measures for improvement. The visual format also gives a new dimension to see connections between courses through their common outcomes. This clarity helps especially when evaluating the performance of interrelated courses. Third, its mathematical formality permits for a more automated data management system to be built compared to those offered in a spreadsheet environment. Dedicated computer software could be developed to serve this function, or further upgraded into a secure online system to improve access and support data processing from individual courses. This automated system can reduce faculty loads on data input and management.

As mentioned earlier, priorities should be given on developing student outcomes through adoptions of best practices in engineering education. OBE promotes such aims but demands programs to rigorously assess their performance. To comply, some programs have invested considerable efforts and resources to build elaborate assessment systems but lack quantitative rigor to make the process effective and reliable. In doing so, the core priorities become secondary.

The new assessment model proposed here offers to make the assessment process less demanding with meaningful data to inform and guide faculty decisions. With the load on the assessment process reduced, faculty can place more focus rightfully on measures to improve their programs and enhance students' learning experience.

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References

Astinand, A. W. & Antonio, A. L. (2012). *Assessment for excellence: The philosophy and practice of assessment and evaluation in higher education*. Rowman & Littlefield.

Crawley, E. F., Malmqvist, J., Ostlund, S. & Brodeur, D. (2007). Rethinking engineering education: the CDIO approach, Springer.

Davis, M. H. (2003). Outcome-based education. *Journal of Veterinary Medical Education,* 20(3), 227–232.

Dym, C. L., Agongino, A. M., Eris,O., Frey,D. D. & Leifer, L. J. (2005). Engineering Design Thinking, Teaching, and Learning. *Journal of Engineering Education*, 94(1), 103-120.

Engineering Accreditation Council (EAC) (2012). Engineering Programme Accreditation Manual. Board of Engineers Malaysia. http://www.bem.org.my/v3/accreditation_manual.html.
Felder, R. M. & Brent, R. (2003). Designing and teaching courses to satisfy the ABET Engineering Criteria. *Journal of Engineering Education*, 92(1), 7–25.
Krathwohl, D. R. (2002). A revision of Bloom's taxonomy: An overview. *Theory into Practice*, 41(4), 212-218.
McKenzie, L. J., Trevisan, M. S., Davis, D. C. & S. Beyerlein, W. (2004). Capstone design courses and assessment: A national study. In *Proceedings of the 2004 American Society of Engineering Education Annual Conference & Exposition*.
Olds, B. M., Moskal, B. M. & Miller, R. L. (2005). Assessment in engineering education: Evolution, approaches and future collaborations. *Journal of Engineering Education*, 94(1), 13-25.
Scales, K., Owen, C., Shiohare, S. & Leonard, M. (1998). Preparing for program accreditation review under ABET Engineering Criteria 2000: Choosing outcome indicators. *Journal of Engineering Education*, 87(3), 207-210.
Trevisan, M. S., Davis, D. C., Calkins, D. E. & Gentili, K. L. (1999). Designing sound scoring criteria for assessing student performance. *Journal of Engineering Education,* 88(1), 79–85.
Wankat, P. C. (2004). Analysis of the First Ten Years of the Journal of Engineering Education. *Journal of Engineering Education*, 93(1), 13-21.
Worldwide CDIO Initiative: A Framework for the Education of Engineers. http://www.cdio.org. Accessed 23 July 2014.