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An Engineering Education Capability Maturity Model

Abstract
With the stress of producing a Global Engineer and the creation of International Registry of Engineers, the importance of international recognition of Engineering degrees through accreditation is increasing. Many countries and whole regions are lagging behind adopting an engineering program accreditation system, and have found the expense of undergoing ABET or CEAB Substantial Equivalency prohibitive. At the Organization of American States's Engineering for the Americas Symposium, the Latin American and Caribbean Consortium of Engineering Institutions (LACCEI) proposed an assessment model that provides a five-level evaluation that could lead to accreditation. This paper describes the model, which applies a multi-level, model-based process improvement model widely used in the software systems engineering, called the Capability Maturity Model (CMM), to Engineering Education. Model-based process improvement uses a model to guide the improvement of an organization's processes and aims to increase the capability of work processes. Process capability is the inherent ability of a process to produce planned results. This paper presents an overview of the CMM and proposes three CMM-based models for improving the process capability of the engineering institution, the engineering faculty and the engineering student. Feedback is sought refining this multi-level engineering program assessment instrument to move engineering programs in regions lacking an engineering accreditation system toward program accreditation or substantial equivalence.

Introduction

In order to compete in the world economy, nations need to produce Global Engineers, who can practice across boundaries. The European Union has strengthened the economy of its member nations by achieving agreement and unity in standardizing monies, trade and education. China is fast improving its economy and competitiveness in the world market, again through unity. If the Americas are to remain competitive, Latin America, the Caribbean, the U.S.A. and Canada must join their education efforts and form a recognized standard for engineering and technology programs. Having such a standard would allow engineering institutions to form a consortium to offer or accept courses originating from recognized institutions, and create Dual Degree Masters that address the needs of the area and give it a competitive edge. The Americas need a standard to permit an engineer to practice across national frontiers, and strengthen the economy of the Americas. A first step toward achieving unity in the Americas for recognizing engineers, is moving towards a mechanism for assessment and recognition of engineering institutions.

The Accreditation Board for Engineering and Technology, Inc[1] (ABET) is the recognized accreditor for college and university programs in engineering, technology, computing and applied science in the United States. ABET is a federation of 31 professional and technical societies from these fields. About 2,500 programs in over 550 colleges and universities in the United States are accredited. ABET also offers educational credentials evaluation to those educated outside the U.S. and provides certification of equivalence to ABET accredited programs to international institutions of higher education. This evaluation results in accreditation or no accreditation, with comments on commendations, deficiencies, weaknesses, and concerns.

To become a licensed Professional Engineer in the United States is a four step process.

1. Graduate from an approved four-year engineering program (ABET accredited if the institution is in the United States).
2. Register with the state's Board of Examiners for Professional Engineers and Land Surveyors to take and pass the Fundamental in Engineering Exam (FE), which is administered in April and October each year[2].
3. Complete four years of additional engineering experience.
4. Pass the Principles and Practices of Engineering Examinamination (PE) that is administered through the National Council of Examiners for Engineers and Surveying (NCEES)[2].

To become a certified *Engineer-in-Training* or an *Engineer Intern*, a person must complete the first two steps. To become certified as a *Professional Engineer* and thus become licensed to practice in a state in the USA, the individual must complete all four steps.

Thus, the first step for attaining engineering licensure in the USA is graduating from an approved (ABET accredited or equivalent) engineering program. The Canadian Engineering Accreditation Board (CEAB)[3] was first created based on ABET and these two organizations mutually recognize degrees they accredit. In Latin America and the Caribbean the approval of Professional Engineers is often done through the Ministries of Education and standards and requirements vary. There is a need to move towards a standard of recognizing the level of quality of an engineering or technology program in Latin America and the Caribbean. Once that standard is developed, a recognized standard across the Americas can be attained.

In 2002, the International Register of Professional Engineers (IRoPE)[4] was formed, which is governed by the Engineer's Mobility Forum and Engineering Technologists' Mobility Forum, consisting of national engineering organizations of Australia, Canada, Hong Kong, Ireland, Japan, Korea, Malaysia, New Zealand, South Africa, United Kingdom and United States of America. This register is open to engineers who:

1. are licensed for independent practice within their own economy,
2. have an academic qualification equivalent to an accredited degree,
3. have seven years post-graduation experience,
4. have spent at least two years in significant engineering practice
5. are maintaining relevant continuing professional development at a satisfactory level

The second requirement greatly limits Latin American and Caribbean engineers from being players globally and decrease their mobility and opportunities.

Having an accredited or international recognized engineering degree is critical for engineers and engineering institutions in order to compete in today´s global economy. This paper outlines the progress made, particular the Americas, and proposes an alternative model for the region.

Motivation

Table 1 lists national accrediting bodies for engineering programs. The Latin American and Caribbean Consortium of Engineering Institutions (LACCEI)[5] noted that there were no internationally recognized accrediting bodies in their region on this list, thus requiring their universities to seek substantial accreditation for their engineering programs. Mexico does have the Consejo de Acreditación de la Enseñanza de Ingenieria (CACEI) which is translated Accreditation Council for Engineering Programs, which has accredited 285 undergraduate engineering and science programs and 32 technical programs in México.

Table 1. Recognized National Accrediting Bodies for Engineering Programs

Australia	The Institution of Engineers, Australia *Signatory to Washington & Sydney Accords, APEC Engineers Register and Engineers Mobility Forum (International Register of Professional Engineers)*
Bangladesh	Institution of Engineers Bangladesh *Provisional signatory to Engineers Mobility Forum (International Register of Professional Engineers)*
Canada	The Canadian Council of Professional Engineers *Signatory to Washington Accord, APEC Engineers Register and Engineers Mobility Forum (International Register of Professional Engineers).* The Canadian Council of Technicians and Technologists *Signatory to Sydney Accord. Contains links to Provincial member organizations.*
France	Conseil National des Ingenieurs et des Scientifiques de France *French professional engineers organisation* Commission des Titres D'Ingenieur *French engineering courses accreditation body*
Germany	Accreditation Agency for Study Programs in Engineering, Informatics, Natural Sciences, and Mathematics (ASIIN) *Provisional signatory to Washington Accord* Verein Deutscher Ingenieure (VDI) *The Association of Engineers* Verband der Elektrotechnik Elektronik Informationstechnik (VDE) *The Association for Electrical, Electronic & Information Technologies*
Hong Kong-China	The Hong Kong Institution of Engineers *Signatory to Washington & Sydney Accords, APEC Engineers Register and Engineers Mobility Forum (International Register of Professional Engineers)*
India	National Board of Accreditation *Indian technical subjects accreditation body* Institution of Engineers of India *Provisional signatory [with Engineering Council India) to Engineers Mobility Forum (International Register of Professional Engineers)*
Indonesia	The Institution of Engineers, Indonesia *Signatory to APEC Engineers Register*
Ireland	The Institution of Engineers of Ireland *Signatory to Washington, Sydney & Dublin Accords, and Engineers Mobility Forum (International Register of Professional Engineers); member of FEANI*
Italy	Consiglio Nazionale Ingegneri *Member of FEANI*
Japan	Japan Accreditation Board for Engineering Education *Provisional signatory to Washington Accord* Institution of Professional Engineers Japan *Signatory to APEC Engineers Register and Engineers Mobility Forum (International Register of Professional Engineers)*
Korea	Korean Professional Engineers Association *Signatory to APEC Engineers Register and Engineers Mobility Forum (International Register of Professional Engineers)*

Malaysia	Board of Engineers Malaysia *Provisional signatory to Washington Accord* Institution of Engineers Malaysia *Professional engineering institution*
New Zealand	The Institution of Professional Engineers, New Zealand *Signatory to Washington & Sydney Accords, APEC Engineers Register and Engineers Mobility Forum (International Register of Professional Engineers)*
Pakistan	Pakistan Engineering Council
Russia	Russian Association for Engineering Education Accreditation Board
Singapore	Institution of Engineers Singapore *Provisional signatory to Washington Accord* Professional Engineers Board *Professional Engineers registration body*
South Africa	The Engineering Council of South Africa *Signatory to Washington, Sydney & Dublin Accords, and Engineers Mobility Forum (International Register of Professional Engineers)*
Sri Lanka	Institution of Engineers Sri Lanka
Thailand	Thai Professional Engineering Board *Signatory to APEC Engineers Register*
United Kingdom	Engineering Council of the United Kingdom (ECUK) *Signatory of the Washington Accord and Sydney Accord*
USA	The Accreditation Board for Engineering & Technology *Signatory to Washington Accord* National Council of Examiners for Engineering and Surveying *Contains details of Licensure Examinations and links to all State Licensing Boards* United States Council for International Engineering Practice *Signatory to APEC Engineers Register and Engineers Mobility Forum (International Register of Professional Engineers)*
Other Engineering Federation Organizations	
Europe	FEANI *Pan-European Federation of National Engineering Associations, with links to and contact details of its 25 national member bodies* EurEta *The European Higher Engineering and Technical Professionals Association* SEFI *European Society for Engineering Education*
Outside Europe	APEC *Asia Pacific Economic Cooperation* CEC *Commonwealth Engineers Council* Washington Accord *International mutual recognition agreement of accredited professional engineering programmes* WFEO *World Federation of Engineering Organisations*

If there are accrediting agencies that will grant substantial equivalencies to programs in regions that do not have engineering accrediting agencies, why is a new model needed for these regions? As can be seen in Table 2 and 3, not many institutions in Latin American and Caribbean countries have attained accreditation from either ABET nor CEAB.

Table 2. ABET Substantially Equivalent Latin American and Caribbean Engineering Programs
[year of accreditation]

Chile	**Pontificia Universidad Católica de Chile**, Santiago, Chile Chemical Engineering [2003] Civil Engineering [2003] Computer Engineering [2003] Electrical Engineering [2003] Mechanical Engineering [2003]
México	**Instituto Tecnológico y de Estudios Superiores de Monterrey (ITESM)** **ITESM – Campus Monterrey,** Monterrey, México Chemical & Industrial Engineering [1992] Chemical & Systems Engineering [1992] Civil Engineering [1992] Computer Systems Engineering [2001] Electronics & Communications Engineering [1992] Industrial & Systems Engineering [1992] Mechanical & Electrical Engineering [1992] Mechanical & Industrial Engineering [1992] **ITESM – Campus Ciudad México,** México D.F., México Electronics & Communications Engineering [2003] Industrial & Systems Engineering [2003] Mechanical Engineering [2003] **ITESM – Campus Estado de M éxico,** México D.F., México Electronics & Communications Engineering [2002] Electronics & Computer Engineering [2002] Industrial & Systems Engineering [2002] Mechanical Engineering [2002] **ITESM – Campus Querétaro,** Querétaro, México Computer Systems Engineering [1993] Electronic Systems Engineering [1993] Electronics & Communications Engineering [1993] Industrial & Systems Engineering [1993] Mechanical & Industrial Engineering [1993] **ITESM – Campus San Luís Potosí,** San Luís Potosí, México Industrial and Systems Engineering [2004] **Universidad Autónoma de Nuevo León**, San Nicolás de los Garza, México Civil Engineering [2004]
Puerto Rico	**Universidad de Puerto Rico – Mayagüez**, Mayagüez, Puerto Rico Chemical Engineering [1970] Civil Engineering [1960] Computer Engineering [1994] Electrical Engineering [1960] Industrial Engineering [1970] Mechanical Engineering [1960]

Puerto Rico (cont.)	**Universidad del Turabo**, Gurabo, Puerto Rico Mechanical Engineering [2005] **Universidad Politécnica de Puerto Rico**, San Juan, Puerto Rico Civil Engineering [1996] Electrical Engineering [1996] Environmental Engineering [2002] Industrial Engineering [1996] Mechanical Engineering [1996]

Table 3. CEAB Substantial Equivalent Latin American and Caribbean Engineering Programs [year of accreditation]

Costa Rica	**Universidad de Costa Rica** – San José Ingeniería Civil [1999] Ingenieria Industrial [2000] Ingeniería Eléctrica [2000] **Instituto Tecnológico de Costa Rica -** Cartago Ingeniería de Construcción [2001] Ingeniería Electronica [2004] Ingeniería de Industrial de Mantenimiento [2001] Ingeniería Industrial de Producción [2004]

Background

This paper described a model proposed by LACCEI at the Organization of American States's (OAS) Engineering for the Americas Symposium[6] last year. It is a model for assessment and incremental improvement of engineering and technology education in regions where there is no engineering program accredition system. The proposed model is called the Engineering Education Capability Maturity Model (EECMM). The model, an extension of the Capability Maturity Model (CMM) in Software Systems Engineering, classifies an engineering educational program into one of five levels, one being the lowest capability and 5 the highest. Achieving Level 5 would indicate that the program is ready to undergo ABET accreditation or substantial equivalency evaluation. The Caribbean countries at the OAS Symposium have agreed to adopting a model for Caribbean Engineering Program Accreditation at the LACCEI Conference in Puerto Rico in June 2006. The EECMM is being considered, and other models will be considered. Feedback is sought to improve the model before it considered in June. The LACCEI hopes that the model could be used to facilitate communications among peer institutions at the same level, to provide identifying experts from institutions one or more levels higher to assist in the improvement of engineering and technology programs, and provide the recognition of engineering programs to facilitate participation in the International Registry of Professional Engineers.

Background on the Capability Maturity Model

In 1986, the Software Engineering Institute (SEI) at Carnegie Mellon University with the Mitre Corporation began developing a multi-level model-based process improvement model, called the Capability Maturity Model (CMM)[7, 8], which was based on earlier quality management work by Deming[9], Crosby[10], and Juran[11]. The model measures an organization's *process capability*, the inherent ability of a process to produce planned results. As the process capability increases, the results become predictable and measurable, and the most significant causes of poor quality and productivity are controlled or eliminated.

The original CMM model was the Capability Maturity Model for Software (SW-CMM), used to enhance the capabilities of the software development organization to deliver software on time, within cost, and meeting the objectives of the system and the customer. Its documented success resulted in the proliferation of CMM-based models to improve engineering processes, which in 1998, prompted industry, the US government, and the SEI to begin the Capability Maturity Model Integration (CMMI) project[12], providing a single, integrated framework for improving multi-disciplinary engineering processes in organizations. Their success, acceptance and maturation prompt a closer look at the potential application of CMM-based models to improve the process of engineering education.

The next sections presents an overview of the CMM, and the proposed CMM-based model for engineering and technology program assessment, called Engineering Education Capability Maturity Model (EECMM), which was first proposed by LACCEI in 2004[13]. The goal of using this model is to facilitate incremental improvement and produce the documentation required for facilitating higher engineering program accreditation by Professional, Regional, and National accrediting organizations. The documentation required for ABET accreditation has been mapped to the appropriate process maturity level, thus guiding and facilitating the evaluation process.

The Capability Maturity Model

The SEI developed the CMM to assist the Department of Defense in assessing the quality of its contractors. It rates an organization's process maturity on an ordinal scale from 1 - low to 5 – high. The CMM bases the rating on a survey with required documented evidence to verify the answers. The model provides principles and practices that lead to better outcomes. These are organized in five levels, providing a path to incremental adoption of best practices, more process visibility and control, and improved outcomes.

Figure 1 shows the progression through the levels. Each level forms a foundation from which to achieve the next level, so trying to skip maturity levels could be counterproductive. An organization can adopt specific process improvements at any time, however, it should be understood that processes without proper foundation fail under stress. Following the CMM framework tends to produce stability in process improvement since the required foundations have been successfully institutionalized.

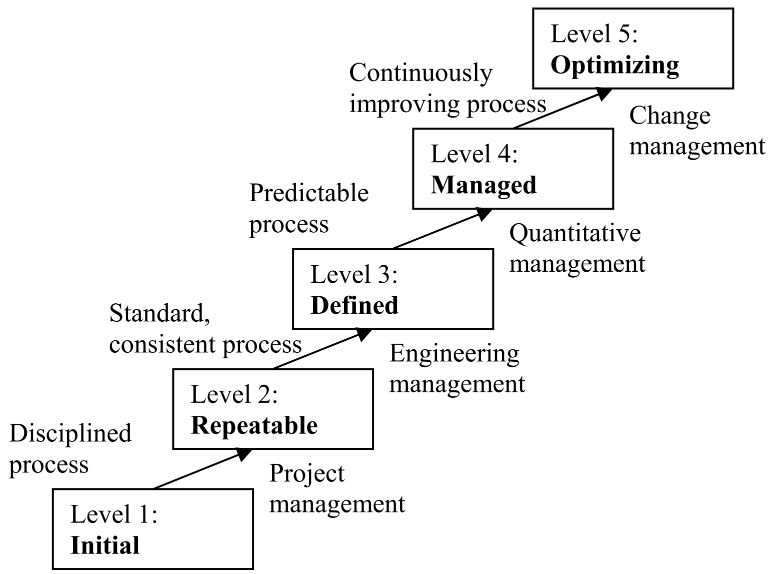

Figure 1: The Five Stages or Maturity Levels of the Capability Maturity Model[7]

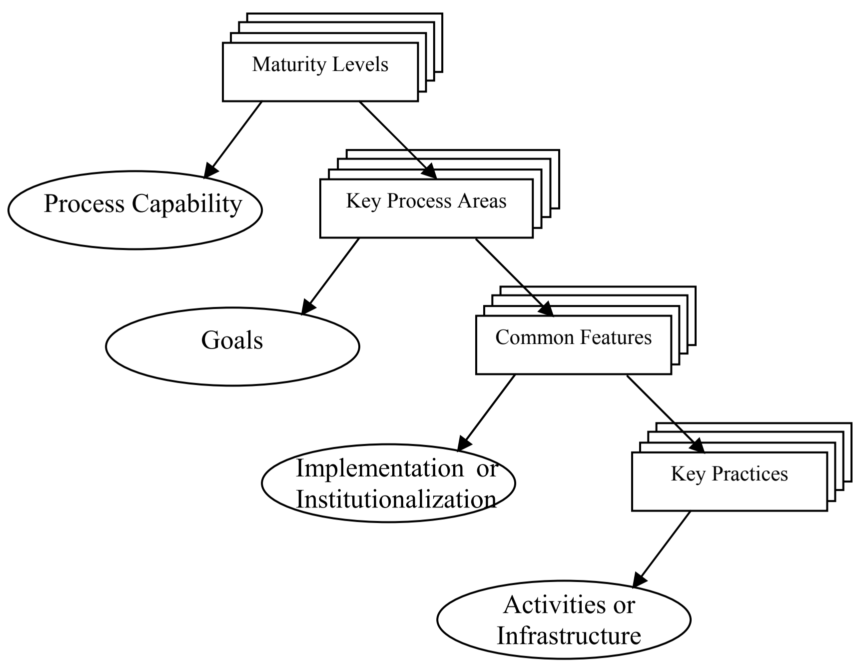

Figure 2. The Internal Structure of the Maturity Levels in CMM[7]

Except Level 1, each maturity level has an internal structure shown in Figure 2. A maturity level indicates a capability to perform a process with predictable results and is associated with a set of *key process areas* on which an organization should focus as part of its improvement effort in order to achieve their goals. Each key process area is organized into five sections called *common features*:

- *Commitment to perform* – the policies, leadership practices and actions that ensure that the establishment and continued use of the process
- *Ability to perform* –the practices that address resources, training, orientation, tools, and organizational structure that ensure that the organization is capable of implementing the process.
- *Activities performed* – the practices that address plans, procedures, work performed, corrective action, and tracking.
- *Measurement and analysis* – the process measurement and analysis practices that ensure that procedures are in place to measure the process and analyze the measurements.
- *Verifying implementation* – the management reviews and audits practices that ensure that activities comply with the established process.

These common features specify the *key practices* described by activities or infrastructure, that when collectively addressed accomplish the *goals* of the key process area. An organization is satisfies a key process area when the process area is both implemented and institutionalized.

Proposed Engineering Education Capability Maturity Model

The proposed model, called Engineering Education Capability Maturity Model[13, 14, 15, 16], has been presented to LACCEI, the American Society of Engineering Education (ASEE), the Organizations of American States (OAS) Engineering for the Americas Symposium, together with two related models for assessment of engineering students and faculty. The model is still under development and comments are invited. The model uses the same framework of the CMM when describing the capability maturity of an engineering program. The names of the 5 levels of process capability maturity described in Figure 1 remain the same. Below we describe the 5 levels of capability maturity and the related key practices in terms of an educational, rather than a business, domain. The adoption, implementation and institutionalization of these practices is critical to attaining accreditation for an engineering program. The mapping to the appropriate CMM level facilitates the information gathering and process adoption process as expertise is gained in accreditation procedures and documentation.

Level 1: Initial – At this lowest level few processes are defined. Processes are adhoc and mostly reactive. Productivity and quality vary. Success depends on individual effort. Current levels of quality and productivity of peer programs/institutions are not known. To advance to the next level, the institution needs to identify and analyze peer programs, define its mission, goals, and objectives, and impose more structure and control on the process to enable more meaningful measurement.

Level 2: Repeatable – The institution has developed policies for managing the educational programs and procedures to implement those policies. Disciplined processes are established to identify the inputs and outputs of the process, the constraints and the resources used to produce the final product. Basic project management practices are used to track cost, retention and productivity and compare them with peer institutions. There is some discipline among faculty in documenting course syllabi, goals, objectives, learning outcomes, results and feedback, so that successful course delivery can be repeated. A strong curriculum for each degree program includes engineering sciences, humanities, social sciences, communication skills and an appropriate professional component. The institutional requirement for achieving Level 2 is that there are policies that guide the degree programs in establishing the appropriate management processes, their program planning and tracking are stable and earlier successes can be repeated. The program's process is effectively controlled by a program management system, following realistic plans based on the performance in previous terms. The key process areas addressed by Level 2 institutions are:

- Degree program and course management
- Quality assurance
- Management of adjunct faculty
- Program and course tracking and oversight
- Program planning
- Identification of peer institutions

Level 3: Defined – The educational process for both management and educational activities is documented, standardized, and integrated into a standard process for the institution. Mission, goals and objectives are published in the catalog and posted. All programs use an approved, tailored version of the institution's standard process for developing and maintaining degree programs and courses. This level includes all characteristics for Level 2.

- Learning outcomes for each course is published in syllabi
- Documentation of strategies to achieve learning outcomes
- Mission statement for University and College of Engineering are published
- Educational objectives for each engineering program are published and appear in the catalog
- Peer reviews of proposed programs and courses
- Integrated program management
- Training program
- Involvement of constituencies in reviewing and updating educational objectives
- Institutionalized processes
- Faculty credentials are documented

Level 4: Managed – Detailed measures of the educational program and courses are collected and used to quantitatively understand and control both the process and the programs. This level includes all characteristics for Level 3.

- Documentation and implementation of functional feedback and assessment processes designed to determine whether intended outcomes are being achieved
- Quality management
- Quantitative process management
- Comparison with peer institutions
- Documentation sufficient staff allocation and compensation
- Documentation of good facilities and strong institutional support
- Involvement of constituencies in evaluating program outcomes

Level 5: Optimizing – Continuous process improvement is enabled by quantitative feedback from the process and from testing innovative ideas and technologies. This level includes all characteristics of Level 4.

- Educational process change management
- Technology change management
- Defect prevention: Student retention management, Graduation rate management
- Total faculty involvement
- Feedback results in changes in educational program

These five levels and the key process areas that have been identified with each level are a beginning towards building a Capability Maturity Model for Engineering and Technology Education. Accreditation agencies, such as ABET tend to accredit institutions that are at level 5 in our model. The proposed model gives institutions that have not been accredited a framework that could yield the necessary process definition, implementation, assessment and improvement to eventually attain accreditation. The model provides a common language to discuss progress in process improvement and a logical progression in achieving higher capability maturity levels.

In the CMM advancing from level 3 to level 4 requires having software applications that store and provide access to important documents, automatically accumulate metrics, and track progress through the process. Such a tool would be very useful for storing program descriptions and requirements, course syllabi and expected learning outcomes, sample exams and assignments, scanned examples of student work, program and course assessment and survey results, and a myriad of other documents that usually are only compiled and examined when a program is undergoing accreditation. The archive of documents provided by such a tool would allow

- ongoing evaluation and process improvement,
- comparison of course outcomes and assessments to
    - courses offered in subsequent semesters within the institution and
    - courses offered at peer institutions, and
- the tracking of collection and timely submission of required documents

Conclusions

The model provides a systematic approach to reaching an accreditable engineering program. It organizes activities according to the educational maturity level, thus providing a step-by-step approach that would be appropriate for institutions and nations not experienced in the accreditation process. The model also provides a more descriptive system of determine where an organization is in their accreditation, providing a score 0-5. This model will be considered in June 2006 at a LACCEI Accreditation and Certification Workshop as one of the possible models for accrediting engineering programs in the Caribbean. The proposed model needs to be developed in more detail, identifying the key process areas at each level and the activities that would produce improvement to the process capability. Two additional CMM-based models are under development to assess the capability maturity of engineering students and engineering faculty. ASEE is invited to collaborate in the design and assessment of this model. The model will hopefully facilitate moving towards an engineering program accreditation mechanism to recognize and license engineers recognized throughout Latin American and the Caribbean, the Americas and, ultimately, globally. Comments and assistance in developing more a more detailed model is sought. .

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