A NEW CMM-EDU PROCESS IMPROVEMENT AND ASSESSMENT MODEL USING SEI-CMM APPROACH – ENGINEERING EDUCATION CAPABILITY MATURITY MODEL :(E^2-CMM)

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ABSTRACT

We propose a maturity model called E^2-CMM, for computing and assessing Engineering education quality which is inspired by the Software Engineering Institute - Capability Maturity Model (SEI-CMM)[2]. Similar to CMM[22], the Capability Maturity Model for Engineering Education System (E^2-CMM) can be used to rate educational sector according to their capability to deliver high quality education on a five level scale. Furthermore, E^2-CMM can be used in order to improve an institution's education capability by implementing the best practices and organizational changes it describes. In this paper, we explore a maturity model[1] suitable for educational sector to improve the standard and quality of an educational system. For this purpose, we have selected Capability Maturity Model (CMM) as our base model for developing E2-CMM framework for continuous quality assessment in education sector. . Finally, this paper concludes by describing the capability assessment methodology and an algorithmic approach for educational organization.

KEYWORDS

Accreditation, Assessment, Capability Maturity Model, Education Process Improvement, ISO 9001:2000, Quality Model

1. INTRODUCTION

Higher education, as we see today, is a complex system facilitating teaching and learning, research, industrial interface and collaboration with international standards and extensions. And also, as more and more higher Educational Institutions are coming forward for assessment and accreditation there is a need to evaluate incremental improvements of the on-going education system.

Maturity models are useful for the organizations that emphasize on incremental process improvements. In the higher education, maturity models can assist institutions in determining where they are by improving a set of processes in given maturity level. According to Manford and McSporran [12] Maturity models have the following characteristics and assumptions:

DOI : 10.5121/ijsea.2010.1403

- The aspect of measurement ─ how long did the particular task take? How much did the development cost the organization?
- A maturity matrix ─ a number of levels or stages are defined that represent improved capability and performance in particular organizational processes. Organizations proceed to the next level of maturity as they fulfill its requirements.
- That, processes which are better defined, can lead to better products.

The best-known maturity model is the Software Capability Maturity Model (SW-CMM) [13] from Carnegie Mellon university, although there are many CMM-like models that exist in industry; System Engineering Capability Maturity Model (SE-CMM), Software Acquisition Capability Maturity Model (SA- CMM), System Engineering Capability Assessment Model, EIA/IS 731System Engineering Capability Model, System Security Engineering CMM, FAA Integrated CMM, IEEE/EIA 12207, ISO/IEC 15288, ISO/IEC 15504 [21] and ESI Project Framework [14].

Although these maturity models are not without their inherent limitations, they focus on one particular area of knowledge and ignore the rest. For example SEI's CMM focus on improving processes in an organization but ignores the people and staff development. For such related issues of staff, P-CMM was developed by Curits, Hefley and Miller [15] to increase the skills and knowledge of workforce in an organization. A third model associated with the CMM, the Personal Software process (PSP) proposed by Humphrey [16], concentrates on the individual software engineer. This model recognizes that process improvement can and should begin at individual level. The CMM is a framework that characterizes an evolutionary process improvement path towards a more mature organization. An organization can use CMM to determine their current state of software process maturity and then to establish priorities for improvement. An organization's current state of maturity can be categorized as Initial, Repeatable, Defined, Managed, or Optimizing.

The five levels of Capability Maturity Model (CMM) can be described as [17]:

- **Initial:** The development process is characterized as ad hoc, and occasionally even chaotic. Few processes are defined, and success depends mainly on individual effort and heroics.
- **Repeatable:** Basic project management processes are established to track cost, schedule, and functionality. The necessary process discipline is in place to repeat earlier successes on projects with similar applications.
- **Defined:** Management and development activities are documented, standardized, and integrated into a family of standard processes for the organization.
- **Managed:** Detailed measures of the process and product quality are collected so that the process and product are understood and controlled.
- **Optimizing:** Continuous process improvement is facilitated by feedback from the process and from piloting innovative ideas and technologies.

In order to sustain educational standards, efforts are being made in the international educational sector to employ different quality frameworks, for example, ISO9000 [7][8] and Total Quality Management (TQM). These quality frameworks [3], are basically designed for industrial sectors and have to be carefully customized to meet the needs of the educational sector.

2. NEED FOR THIS MODEL

There is a lot of similarity between the software situation that prevailed in the world a few years ago and the IT/engineering/MBA education situation currently prevailing in the country. Some year ago, the high demand for software had led to the creation of thousands of software companies. These organizations often took the customers for a ride – not delivering what was promised, overcharging, poor quality, etc. The buyer had no visibility into their capability for delivering the service and had to buy it almost on faith, and many buyers felt cheated. To take control of this situation, the department of defense in the US, which was the major customer for software, set up the software engineering institute (SEI). The charter of SEI was to evolve the capability maturity model (CMM) [6] which can be used to provide suitable visibility into the capability of a supplier for providing the software service.

The current situation in technical and management education in India is similar. Due to the high demand, fueled largely by the boom in knowledge-based industries like the IT sector, many private colleges have come up for education in IT, engineering, and management – currently 90% or more of the colleges are private. Many of these colleges and institutes do not have the capability of providing the training they claim to provide, but the customer (the students and parents) have no way to judging their capability, and "buy" the education at high prices [11]. And in the end, they frequently feel cheated and that did not get value for their money as the education provided added few skills, and was of little help in procuring proper employment. What is worse in this scam is that not only do people loose money, the youth also loose precious years of their lives.

Clearly, to service the huge demand, participation of the private sector is essential. Like in software, what is currently needed is a capability maturity model for education which can be used to evaluate the capability of the education providers, and provide proper visibility to the customers about the different aspects of their capability. Such a system can also be helpful to the colleges to do focused improvement to enhance their capability

3. THE PROPOSED E^2-CMM MODEL

This section describes the E^2-CMM process taxonomy, framework and assessment model. E^2-CMM is a five-level model to evaluate the maturity of an engineering education process and to provide educational practices.

It is a framework that describes the key elements of an effective education process, and it serves as a guide for improving education practices, including planning, administration, academics, engineering, management, and education maintenance[3][4]. Such practices help an educational organization to set goals for effective outcomes in terms of commitment, accountability and quality [5].

Education process maturity implies that the organization's processes are well defined, managed, controlled and effective. E^2-CMM maturity levels define a scale for measuring the maturity of an educational process. Achieving a maturity level, results in an increase in the capability of the educational process.

3.1. Taxonomy of the E^2-CMM process model

The E^2-CMM process hierarchy and domains and its size are mentioned in Table 1, which defines the configuration of the E^2-CMM process model. As shown, the KPs and KPAs used in E^2-CMM, corresponds to the key practices and key process areas, respectively..

Table I. Process Hierarchy and Domains of the E^2-CMM Model

Taxonomy	Category	Process	Practice
Process scope	Process Capability levels (PCLs)	Key Process areas (KPAs)	Key practices (KPs)
Size of domain	5	44	234

3.2. Proposed Framework of E^2-CMM.

E^2-CMM models an engineering education process system into five process maturity levels, with 44 key process areas, and 234 key practices. A hierarchical structure of the E^2-CMM framework is shown in Table 2.

The abbreviation used are as follows:-

ML_0 : Zeroth Maturity level. ML_1 : First Maturity level. ML_2 : Second Maturity level.
ML_3 : Third Maturity level. ML_4 : Fourth Maturity level.

$KPA_{i,j}$: j^{th} KPA at level I N_{kpa} [i] : # of KPA at level i.

P_{kp} [i,j]): Pass threshold value of key practices for a particular key process areas

Table 2. E^2-CMM Framework

MATURITY LEVEL (ML_i)	KEY PROCESS AREAS (KPA[i,j])	Identified KPAs (N_{kpa} [i, j])	Identified KPs (N_{kp} [i])	Pass Threshold (P_{kp} [i,j])
ML_0	**Initial**	**N_{kpa} [0] = 0**	**N_{kp} [0] = 0**	0
$KPA_{0.1}$	Adhoc process			
ML_1	**Repeated**	**N_{kpa} [1] = 18**	**N_{kp} [1] = 106**	**P_{kp}[1] = 95**
$KPA_{1..1}$	Resource Management		6	5
$KPA_{1..2}$	Financial resource, allocation and utilization		2	2
$KPA_{1..3}$	Physical facilities		6	5
$KPA_{1..4}$	Learning Resources		7	6
$KPA_{1..5}$	Course Curriculum		6	5
$KPA_{1..6}$	Administrative Support		6	5
$KPA_{1..7}$	Leadership		7	6
$KPA_{1..8}$	Staff and Students relationship		6	5
$KPA_{1..9}$	Management and organization skills		7	6
$KPA_{1.10}$	Communication and social skills		4	4
$KPA_{1.11}$	Teamwork		2	2
$KPA_{1.12}$	Human Resources(faculty and staff)		7	6
$KPA_{1.13}$	Human Resources(students)		4	4
$KPA_{1.14}$	Management Responsibility		10	9

$KPA_{1.15}$	Product realization.		5	5
$KPA_{1.16}$	Measurement, analysis and improvement		4	4
$KPA_{1.17}$	Educational Change Management		8	7
$KPA_{1.18}$	Teaching-Learning and assessment practices		9	8
CL_2	**Defined**	**N_{kpa} [2] = 11**	**N_{kp} [2] = 54**	**P_{kp} [2] = 49**
$KPA_{2.1}$	Educational subcontract management		1	1
$KPA_{2.2}$	Educational organization process focus		6	5
$KPA_{2.3}$	Student support and progression		4	4
$KPA_{2.4}$	Supplementary practices		6	5
$KPA_{2.5}$	Healthy practices		6	5
$KPA_{2.6}$	Strategy planning		2	2
$KPA_{2.7}$	Opportunities for knowledge up-gradation		6	5
$KPA_{2.8}$	Learning outcomes		6	5
$KPA_{2.9}$	Technical Competencies		5	5
$KPA_{2.10}$	Technology driven teaching aids		3	3
$KPA_{2.11}$	Generic Competencies		9	8
CL_3	**Refined**	**N_{kpa} [3] =9**	**N_{kp} [3] = 46**	**P_{kp} [3] = 41**
$KPA_{3.1}$	Teaching – Learning and Evaluation .		7	6

$KPA_{3.2}$	Research, Consultancy and Extension		8	7
$KPA_{3.3}$	Redefining educational quality in terms of outcomes		4	4
$KPA_{3.4}$	Internal Quality Assurance Cell (IQAC)		6	5
$KPA_{3.5}$	Process management		3	3
$KPA_{3.6}$	Personality development		5	5
$KPA_{3.7}$	Academics		5	5
$KPA_{3.8}$	Industry Institute Interface		3	3
$KPA_{3.9}$	Responsiveness		5	5
CL_4	**Quantifiable matured process**	**N_{kpa} [4] = 6**	**N_{kp} [4] = 28**	**P_{kp} [4] = 25**
$KPA_{4.1}$	Organizational performance results		6	5
$KPA_{4.2}$	Quantitative and qualitative focus on teaching and learning		3	3
$KPA_{4.3}$	Measurement Analysis and knowledge mgt.		2	2
$KPA_{4.4}$	Maturity and stability of the institution		5	5
$KPA_{4.5}$	Educational Quality Assurance		8	7
$KPA_{4.6}$	Continuous Evaluation System		4	4

3.3. The E^2-CMM Process assessment model

The process capability model is a yardstick for education process assessment [9].

3.3.1. Performance Scale

The performance rating scale for the KPs of the E^2-CMM Model is defined in Table 3. It employs a kind of yes/no evaluation for the KP's existence and performance. In table 3, the pass thresholds provide a set of quantitative measurements for rating KP's performance with the scale

Table 3. Performance scale of the kps

Scale	Description	Rating threshold
5	Yes	> 90%
4	Yes	80 – 90%
3	No	< 80%
2	Doesn't apply	--
1	Don't know	--

3.3.2. Process Capability Scale

Based on the education process capability model, a capability scale is described in table 4. For each capability level i, the number of identified KPs (N_{kp}) and the minimum required number of KPs for satisfying an assessment ($P_{kp}[i,j]$) are listed, respectively

Table 4. E^2-CMM Process Capability Scale

Capability level (CL_i)	Actual KPs (N_{kp} [i,j])	Pass Thres- hold (P_{kp} [i,j])
CL_0 : Initial	N_{kp} [0] = 0	P_{kp}[0] = 0
CL_1 :Repeated	N_{kp} [1] = 106	P_{kp} [1] = 95
CL_2 : Define		P_{kp} [2] = 49
CL_3 : Refined	N_{kp} [3] = 46	P_{kp} [3] = 41
CL_4 : Quanti-fiable matured process	N_{kp} [4] = 28	P_{kp} [4] = 25
Total: 5	234	210

4.E^{2}-CMM CAPABILITY DETERMINATION METHODOLOGY

STEP: 1 - Key Practices - Performance Rating Method.

Let r_{kp} [i,j,k] be the rating of the performance of kth KP of j^{th} KPA at level i. Then r_{kp}[i,j,k] can be rated according to the practice performance scale as defined in table 3, i.e.;

r_{kp}[i,j,k] = 5, if the performance of KP k, KPA j at level i is at least 90% satisfied

4, if the performance of KP k, KPA j at level i is satisfied in the range of 80-90%

3, if the performance of KP k, KPA j at level i is less than 80% satisfied

2, if the performance of KP k, KPA j at level i does not apply in the assessment

1, if the answer for the KP k, KPA j at level i is “don’t know” in assessment

The number of KPs of a particular KPA j satisfied at a level i, is assessed according to the following equation

$$SATkp[i, j] = \# \{KP [j, k] \mid Passed\},\ k = 1 \ldots Nkp[j]$$

$$= \# \{KP [j, k] \mid r_{k} [j, k] = 5 \vee r_{kp} [j, k] = 4 \vee r_{kp} [j, k] = 2\}$$

$$= \sum_{k=1}^{N_{kp [j, k]}} \{SATkp [j, k] = 1 \mid rkp [j, k] = 5 \vee rkp [j, k] = 5 \vee r_{kp} [j, k] = 4 \vee r_{kp} [j, k] = 2$$

for j = 1 to TKPA

Where # is a cardinal calculus that counts the number of KPs that satisfy or that do not apply in the assessment, and $N_{kp\ [i,\ j]}$ is the number of defined KPs of KPA j at level I and TKPA is the number of KPA's

A pass threshold, P_{kp} [i, j], for a KPA j at capability level is defined as:

$$P_{kp\ [i,\ j]} = N_{kp\ [i,\ j]} * 90\%$$

This means that 90% of the KPs defined for a KPA j at a level i should be satisfied for fulfilling the requirements of process capability at this level as shown in table 2, i.e.

$$SAT_{kp} [i, j] \geq P_{kp\ [i,\ j]}$$

$$\geq N_{kp\ [i,\ j]} * 90\%,$$

Where SAT_{kp}[i, j] is the number of key practices of KPA j at level i satisfied

STEP: 2 – Key Process Area – Performance.

Using the calculated SAT_{kp}[i, j] for all KPAs of all levels, the satisfied KPA for a given level is determined using the equation, i.e.

$$SAT_{KPA}[i] = \sum_{j=1}^{N_{KPA[i]}} \{SAT_{kp} [i, j] = 1 \mid SAT_{kp} [i, j] \geq P_{kp\ [i,\ j]} \quad ; I = 1 \ldots 4$$

Step: 3 - Process Maturity Level – Determination Method

The Maturity level is estimated based on the number of KPAs satisfied at a particular level, if the satisfied KPAs is equal to the actual KPAs at that level then it is found that the process have attained that level of maturity.

The process is said to have attained level 0 if,

if ((SAT_{KPA}[i] < ACT $_{KPA}$[i]) && (I == 1)) && if ((SAT_{KPA}[i] < ACT $_{KPA}$[i]) && (I == 2)) && if ((SAT_{KPA}[i] < ACT $_{KPA}$[i]) && (I == 3)) && if ((SAT_{KPA}[i] < ACT $_{KPA}$[i]) && (I == 4)) then

PCL $_{achieved}$ = 0;

The process is said to have attained level 1 if,

if ((SAT_{KPA}[i] == ACT $_{KPA}$[i]) && (I == 1)) && if ((SAT_{KPA}[i] < ACT $_{KPA}$[i]) && (I == 2)) && if ((SAT_{KPA}[i] < ACT $_{KPA}$[i]) && (I == 3)) && if ((SAT_{KPA}[i] < ACT $_{KPA}$[i]) && (I == 4)) then

PCL $_{achieved}$ = 1;

The process is said to have attained level 2 if,

if ((SAT_{KPA}[i] == ACT $_{KPA}$[i]) && (I == 1)) && if ((SAT_{KPA}[i] == ACT $_{KPA}$[i]) && (I == 2)) && if ((SAT_{KPA}[i] < ACT $_{KPA}$[i]) && (I == 3)) && if ((SAT_{KPA}[i] < ACT $_{KPA}$[i]) && (I == 4)) then

PCL $_{achieved}$ = 2;

The process is said to have attained level 3 if,

if ((SAT_{KPA}[i] == ACT $_{KPA}$[i]) && (I == 1)) && if ((SAT_{KPA}[i] == ACT $_{KPA}$[i]) && (I == 2)) && if ((SAT_{KPA}[i] == ACT $_{KPA}$[i]) && (I == 3)) && if ((SAT_{KPA}[i] < ACT $_{KPA}$[i]) && (I == 4)) then

PCL $_{achieved}$ = 3;

The process is said to have attained level 4 if,

if ((SAT_{KPA}[i] == ACT $_{KPA}$[i]) && (I == 1)) && if ((SAT_{KPA}[i] == ACT $_{KPA}$[i]) && (I == 2)) && if ((SAT_{KPA}[i] == ACT $_{KPA}$[i]) && (I == 3)) && if ((SAT_{KPA}[i] == ACT $_{KPA}$[i]) && (I == 4)) then

PCL $_{achieved}$ = 4;

5. RELATED WORK

As there are different meaning and interpretations of quality, there are different models of quality assurance as well. Across the world, institutions follow different models of quality assurance; particularly country specific and institution specific models. These models are mostly process oriented and emphasize on the development of a quality assurance system. There are five popular models of quality assurance: Baldrige Criteria [18], ISO 9000-2000 [7], CMM [5], Six Sigma and total quality management. In addition to these models, there are other accreditation models like ABET, NBA, NAAC, AB of ICAR and DEC.

6. CONCLUSION

In this paper, we have proposed a Capability Maturity Model for Engineering Education, which helps in improving the practices of key educational processes and contribute to enhance the overall quality education. For this, we adopted CMM [15] [2] [23] as our base model and proposed a new Engineering Educational Capability Maturity Model (E^2 – CMM).This paper also explains the key components of E^2-CMM framework. The five levels of maturity provides a finer grained measure of the education process maturity in the scale of 0 to 4, thus facilitating the process of articulation between institutions at the same level and giving an encouraging assessment of institutions, instead of an all-or-nothing accreditation decision. Based on this model, the assessment methodology is derived to predict the capability level or performance level of an Educational Organization. Next, an algorithm has been designed to implement an E^2-CMM tool. This E^2 – CMM model can be used for continuously evaluating the education process which serves as the mantra for effective accreditation of higher education system. Using this tool, one can predict the quality, maturity and standard of an education system more precisely and concisely compared to ISO standards. Finally, it is concluded that quality assurance is not the destination, but a journey to continuously improve the higher education system. In the future, we will implement and evaluate this framework, statistically and empirically [19] to assess the quality and maturity level of higher education process using neural network [20].

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