Title: What do engineers want? Examining engineering education through Bloom's taxonomy

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What do engineers want?

Examining engineering education through Bloom's taxonomy

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Abstract: *Using Bloom's taxonomy as the basis for an empirical investigation, this paper examines what engineering students and professionals want from engineering education. Fifty engineering students, from Computer Science and Information Technology courses, were asked to rank activity verbs in order of their impression about frequency of their occurrence in their assignments and examinations. Another group of sixteen students was asked to rank activity verbs as per their learning effectiveness. Thirteen professional Engineers were also asked to assign ranking to activity verbs in order of their perceived importance. A set of fifteen examination papers were then scrutinised for the usage of these activity verbs.*

Data analysis revealed that there is high correlation between students' impression and examination papers. It also demonstrated that there is high correlation between what engineering students and professionals want. However, a negative correlation was discovered between what students and professional engineers want and the activity verbs used in evaluative and non-evaluative tasks. Other established criterion for imparting good engineering education, such as the guidelines provided by ABET (Accreditation Board for Engineering and Technology) are discussed in light of the findings of this study. We conclude that, to foster creativity, critical thinking and innovative problem solving amongst engineering students we need to develop flexible curricula that aim to engage the students in higher-level cognitive activities. Changing the verb set used by engineering educators can be employed as a catalyst to facilitate this strategic transformation in engineering curriculum.

Keywords*: Active learning, Activity verbs, Bloom's taxonomy, Engineering education, Higher order learning.*

Introduction

Many economies worldwide are rapidly advancing from the traditional industrial base and embracing a shift to information and / or service base. This shift often entails solving open ended and multi-disciplinary problems. Such real-world problems typically involve an overlay of technological and social imperatives. This demands a significant shift towards higher-order learning in university education, in general, and Engineering education in particular. This shift has been predicated by education researchers including Fennimore and Tinzmann (1990), who suggest that, “Changes in society itself require higher-order learning”. Traditional courses, even in applied disciplines like engineering, emphasise topics over process. Goel (2003) argues that curriculum is often interpreted as fixed course structure and course content. Educational goals are considered to be achieved by giving the answers, or, at best, the ability to find answers. Training students to seek right questions is not on the agenda of teacher centric (or even worse, text book centric) standard courses.

The role of experience in the creation of knowledge is grossly under estimated, and learning is interpreted as knowledge acquisition rather than knowledge construction. Schank (1995) states that conventional teaching methods involving only lectures, and problem set format, neither promote creativity nor do they develop the independent thought processes that are desired in the future endeavours of students in the real world. Other authors (e.g. Felder (1988), Suresh Kumar (2001) and Kolodner (1995)) have also expressed similar thoughts. There are comments in the literature (e.g. Bruner (1996) and Fennimore and Tinzmann (1990)) that these methods are based on impoverished conception that a course provides a learning experience in which an omniscient teacher explicitly tells or shows presumably unknowing learners something they presumably know nothing about.

Standard courses for engineering students generally aim to impart a predefined and fixed amount of established knowledge, concepts, and skills; and do not emphasise exploration, imagination, and creativity. Such a format is unsuitable for a self-directed and discovery oriented learner. Repeated learning experience in this format makes many creative and discovery oriented students disinterested in the course, forcing resigned conversion to dependant and passive learners.

Thus, there is an urgent need to transform engineering curricula to a more flexible format that engenders creative learning. Our aim is to involve current and past students in developing the agenda for this transformation. Goel (2004) reports the findings of an initial comparative study of engineering students and working professionals.

This paper reports the outcomes of the continued comparative study of the students’ impression of their experience as a learner, with perceptions of professional engineers on what do they want from a course in an engineering discipline. This study uses Bloom’s taxonomy of cognitive processes as the basis for investigating learning outcomes. Association of the various Bloom’s levels with activity verbs was used as the instrument to get feedback from the participants of the study.

Bloom’s Taxonomy

Benjamin Bloom (1956) classified the cognitive process into six major levels arranged in a hierarchical order. Beginning with the simplest level and increasing in complexity, the cognitive levels are: Knowledge, Comprehension, Application, Analysis, Synthesis and Evaluation. Several authors (e.g. Krumme (2002) and TALS (1998)) have given a summary and commentary on his work.

The simplest level 'Knowledge' exhibits previously learned material by recalling facts, terms, basic concepts and answers. The 'Comprehension' level demonstrates understanding of facts and ideas by organizing, comparing, translating, interpreting, giving descriptions and stating main ideas. 'Application' is about solving problems by applying acquired knowledge, facts, techniques and rules in a different way.

'Analysis' represents the act of examining and breaking information into parts by identifying motives or causes; making inferences and finding evidence to support generalizations. 'Synthesis' aims at compiling information in different ways by combining elements in new patterns or proposing alternative solutions. 'Evaluation' is about presenting and defending opinions by making judgments about information, validity of ideas or quality of work based on a set of criteria.

The last three levels are considered to represent higher-level cognitive activities that require and develop mental faculties of creativity, critical thinking and innovative problem solving. This paper reports a quantitative analysis of activities formally assigned to engineering students using this taxonomy as a metric.

What do engineers want?

The main aim of this study was to understand the degree to which the formal components of traditional teaching-learning-evaluation process in engineering education succeed in creating opportunities for enhancing higher-order thinking skills through practice.

Activity Verbs for Bloom's Cognitive Levels

Several authors (Bloom (1956), Krumme (2002) and TALS (1998), have reported mappings of activity verbs to different Bloom levels. Existing Bloom-level-to-activity-verb-lists mappings were extended to include the verbs that were not found in the current literature. Following mapping was used in this research.

Level 1 - Knowledge: acquire, cite, define (studied definitions), derive, fill in the blanks, identify, label, list, name, obtain, prove (studied theorem, studied method), recall, recite, recognise, reproduce, show (studied fact, studied method), and state.

Level 2 - Comprehension: arrange, associate, categorize, change, clarify, classify, compare, convert, describe, discuss, distinguish, draw, exemplify, explain, illustrate, interpret, match, outline, rephrase, represent, restructure, rewrite, sort, summarize, tell, and translate.

Level 3 - Application: apply, calculate, compute, demonstrate, determine, estimate, evaluate (computation), experiment, find, practice, show (understanding fact in the direct context of studied material), solve, and transform.

Level 4 - Analysis: analyze, conclude, contrast, debug, deduce, detect, differentiate, discriminate, examine, extend, extrapolate, generalize, infer, justify, point out, predict, rearrange, select, specify, test, and verify.

Level 5 - Synthesis: build, combine, comment, compose, constitute, construct, correlate, create, define (new things), design, develop, devise, document, formulate, implement, integrate, modify, organize, plan, prepare, present, produce, propose, prove (unstudied things), reorganize, report, revise, schedule, sketch, and synthesize.

Level 6 - Evaluation: appraise, argue, assess, decide, evaluate (the options), judge, question, review, revisit, standardize, validate, value, and weigh.

A survey was conducted amongst two groups of engineering students and professional engineers. These three groups were requested to respond to three different but complimentary questions around a unified and alphabetically sorted list of activity verbs. The first group of about fifty 2nd year Computer Science and Information Technology students was asked to select and individually rank the identified verbs based on the frequency of their usage in teaching-learning-evaluation process. A second group of sixteen students was asked to rank the verbs according the learning effectiveness of the verb. Thirteen professional engineers were requested to select and rank 10-15 verbs, that if used more often by the faculty, will help in better preparing the students for professional life.

Their responses were collated into three different groups, and a group rating was calculated for every verb. A combined rating of group perception about a verb was statistically extracted from individual ranks: where a large numerical value of the combined rating by the first group of students would imply a perception of high usage of that verb, and a smaller numerical value would imply infrequent or zero usage. A high numerical value for the combined rating assigned by the second group of students would imply that most of them learn more when that verb is used to communicate the activity for evaluative or non-evaluative tasks, and a small numerical value would imply that few or none of them experience effective learning when that verb is used. Similarly, a high numerical value for the combined rating assigned by professional engineers' would imply that most of them want the verb to be used often, and a small numerical value would imply that few or none of them recommend it to become or continue as a commonly used verb in administering evaluative or non-evaluative tasks.

Table 1 gives a sample of the data extracted from the respondent feedback. Respondents assigned contiguous natural numbers starting from 1 without any upper limit as ranks to the verbs of their choice. Some chose to give a unique rank to every verb thereby assigning ranks in the range of 1 to around 50. Many chose to give a common rank to many verbs in the range of 1 to around 10. They had the freedom of not assigning any rank to some verbs. A lower numerical value implies higher ranking, 1 being the highest rank. A student respondent from the first group of 50 students assigned the rank of 1 to verb(s) that (s)he felt are most often used by the faculty. On the other hand students from the second group of 16 students assigned the rank of 1 to the verb(s) that they consider to facilitate maximum learning and professional engineers assigned the rank of 1 to the verb(s) that they felt should be used most often by the faculty.

Table 1: Extracted samples of Activity Verb-Rank Survey

Activity Verb (j =1 to 128)	**Bloom Cognitive level (i =1 to 6)**	$Rank_{kj}$ by first group of Students as per the verb usage (k = 1 to 50) Blank entries indicate that k^{th} respondent did not give any rank to j^{th} verb **[What students think they get]**						$Rank'_{kj}$ by second group of students as per verb's learning effectiveness (k=1 to 16) Blank entries indicate that k^{th} respondent did not give any rank to j^{th} verb **[What students think works well for them]**					$Rank''_{kj}$ by Professional Engineers as per their recommendation (k=1 to 13) Blank entries indicate that k^{th} respondent did not give any rank to j^{th} verb **[What professional engineers recommend]**				
		1	2	3	4	.	50	1	2	3	..	16	1	2	3	..	13
…..	……	..	.	..	..	.	..	.	.	..	..	..	.	.	..	..	..
2. Analyse	Analysis (4)	8	8	8	5	.	20		2	2	..	1	1		4	..	2
…..	……	..	.	..	..	.	..	.	.	..	..	..	.	.	..	..	..
10. Calculate	Application (3)	3	3	3	1	.	1				..				7	..	
…..	……	..	.	..	..	.	..	.	.	..	..	..	.	.	..	..	..
37. Design	Synthesis (5)	12			3	.			4	3	..	4		1	1	..	
…..	……	..	.	..	..	.	..	.	.	..	..	..	.	.	..	..	..
54. Explain	Compre-hension (2)	2	2	2	1	.	8				..					..	11
…..	……	..	.	..	..	.	..	.	.	..	..	..	.	.	..	..	..

Verb Specific Group ratings, $V_{Rj\text{-student-I}}$, $V_{Rj\text{-student-II}}$, and $V_{Rj\text{-professional}}$, are defined as follows:

$V_{Rj\text{-student-I}}$ is the sum of multiplicative inverse of valid ranks for j^{th} verb by first group of students, i.e.:

$$V_{Rj\text{-student-I}} = \sum_{k=1 \text{ to } 50} (1/Rank_{kj})$$

Where $Rank_{kj} \neq 0$, and represents the perceived usage rank given by k^{th} student to j^{th} verb. There were 50 student respondents.

$V_{Rj\text{-student-II}}$ is the sum of multiplicative inverse of valid ranks for j^{th} verb by second group of students, i.e.:

$$V_{Rj\text{-student-II}} = \sum_{k=1 \text{ to } 16} (1/Rank'_{kj})$$

Where $Rank'_{kj} \neq 0$, and represents the perceived learning effectiveness rank given by k^{th} student to j^{th} verb. There were 16 student respondents.

$V_{Rj\text{-}professional}$ is the sum of multiplicative inverse of valid ranks for j^{th} verb by professional engineers, i.e.:

$V_{Rj\text{-}Professional} = \sum_{k=1 \text{ to } 13} (1/Rank''_{kj})$ Where $Rank''_{kj} \neq 0$, and represents the recommended usage rank given by k^{th} professional engineer to j^{th} verb. There were 13 professional respondents.

Verb Specific Group ratings, $V_{Rj\text{-}student\text{-}I}$, $V_{Rj\text{-}student\text{-}II}$, and $V_{Rj\text{-}professional}$ were then normalized with respect to the maximum values of $V_{Rj\text{-}student\text{-}I}$, $V_{Rj\text{-}student\text{-}II}$, and $V_{Rj\text{-}professional}$ respectively to calculate activity verb-specific normalised group ratings as follows:

$$V'_{Rj\text{-}student\text{-}I} = V_{Rj\text{-}student\text{-}I} / \max_j \{V_{Rj\text{-}student\text{-}I}\}$$
$$V'_{Rj\text{-}student\text{-}II} = V_{Rj\text{-}student\text{-}II} / \max_j \{V_{Rj\text{-}student\text{-}II}\}$$
$$V'_{Rj\text{-}professional} = V_{Rj\text{-}professional} / \max_j \{V_{Rj\text{-}professional}\}$$

Hence, $V'_{Rj\text{-}student\text{-}I}$, $V'_{Rj\text{-}student\text{-}II}$, and $V'_{Rj\text{-}professional}$ all have a value between 0 to 1. Values close to 1 indicate that most respondents from the specific category have assigned a high rank to jth verb, whereas low values indicate low ranks by most the respondents. Table 2 shows the samples of $V'_{Rj\text{-}student\text{-}I}$, $V'_{Rj\text{-}student\text{-}II}$, and $V'_{Rj\text{-}professional}$.

Table 2: Extracted samples of Activity Verb specific normalized group ratings

Activity Verb (j =1 to 128)	**Bloom Cognitive level (i=1 to 6)**	What students think they get $V'_{Rj\text{-}student\text{-}I}$	What students think works well for them $V'_{Rj\text{-}student\text{-}II}$	What professional engineers recommend $V'_{Rj\text{-}professional}$
…..	……	…..	…..	……
2. Analyse	Analysis (4)	0.37	0.79	1.00
…..	……	…..	…..	……
10. Calculate	Application (3)	1.00	0.03	0.24
…..	……	…..	…..	……
37. Design	Synthesis (5)	0.20	1.00	0.72
…..	……	…..	…..	……
54. Explain	Comprehension(2)	0.78	0.13	0.13
…..	……	…..	…..	……

Based on these activity verb-specific normalised group ratings ($V'_{Rj\text{-}student\text{-}I}$, $V'_{Rj\text{-}student\text{-}II}$ and $V'_{Rj\text{-}professional}$), the following three lists were created in descending order of their numeric ratings:

i. Ordered List of activity-verbs as per their usage rating: Students' normalized group rating $V'_{Rj\text{-}student\text{-}I}$ by the first group of students, representing their experience of the verb usage was found to be in the following descending order:

calculate, explain, prove (studied theorem, studied method), define (studied definitions), write, solve, compute, show (studied fact, studied method), evaluate(computation), derive, state, describe, determine, find, analyse, justify, comment, distinguish, consider, illustrate, compare, apply, classify, identify, fill in the blanks, differentiate, conclude, examine, discuss, develop, implement, name, create, deduce, obtain, exemplify , construct, specify, design, categorize, estimate, propose, draw, generalize, demonstrate, recall, cite, summarize, convert, predict, formulate, argue, prepare, list, tell, point out, combine, sort, modify, represent, rearrange, devise, clarify, transform, compose, change, present, outline, rewrite , match, show (unstudied fact in the direct context of studied material), contrast, evaluate (the options), interpret, validate, organize, translate, label, build, decide, discriminate, produce, relate, recognise, synthesize, standardise, integrate, extend, plan, assess, recite, associate, document, reproduce, select, detect, arrange, infer, and judge.

This ordered list is a consolidation of what students think they get to do as part of teaching-learning-evaluation process. The activity verbs not appearing in this list were not given any rank by any student. This list indicates that most faculty members assigned activities directly asking students to calculate, explain, prove (studied theorem, studied method), define (studied definitions), write, solve, compute, show (studied fact, studied method), evaluate (computation) or derive.

ii. Ordered List of activity-verbs as per their learning effectiveness: Students' normalized group rating $V'_{Rj\text{-student-II}}$ by the second group of students, representing activity-verb's learning effectiveness was found to be in the following descending order:

design, analyse, understand, build, apply, adapt, implement, create, develop, demonstrate, validate, define (new things), show (unstudied fact in the direct context of studied material) , illustrate, compare, enjoy, correlate, argue, research, evaluate (the options), compile, propose, derive, summarize, evaluate(computation), find, discover, explain, suggest, submit (deadline), show (studied fact, studied method), question, present, modify, devise, compute, construct, debate, solve, incorporate, focus, critique, improve, justify, examine, differentiate, prove (unstudied theorem), change, contrast, organize, associate, experiment, utilise, study, integrate, express, challenge, act, survey, transform, establish, interpret, grade, collaborate, administer, describe, progress, produce, duplicate, discuss, decide, contribute, conclude, teach, support, determine, prove (studied theorem, studied method), calculate, perform, accept, use, quote, negotiate, deduce, formulate, consider, categorize, simulate, relate, expand, chart, view, test, standardise, judge, document, combine, clarify, assemble, arrange, trace, rewrite, generalize, experiment, sketch, plan, perceive, exemplify , define (studied definitions), write, structure, restructure, memorise, convince, classify, anticipate, state, revise, reconstruct, restate, invent, simplify, convert, communicate, reason.

This ordered list is a consolidation of what students think results in more effective learning for them. The activity verbs not appearing in this list were not given any rank by any student. This list indicates that most students experience maximum learning when asked to design, analyse, understand, build, apply, adapt, implement, create, develop, demonstrate.

iii. Ordered List of activity verbs as per professional engineers' recommendations: The professional engineers' normalized group rating $V'_{Rj\text{-professional}}$, representing their recommendations was found to be in the following descending order:

> analyse, design, develop, implement, evaluate (the options), integrate, build, conclude, define (new things), acquire, demonstrate, justify, assess, organize, formulate, estimate, summarize, categorize, validate, document, standardise, identify, appraise, calculate, manage, represent, review, reproduce, devise, apply, comment, generalize, specify, explain, extend, state, schedule, compare, present, classify, compute, consider, constitute, debug, decide, define (studied definitions), distinguish, examine, extrapolate, interpret, modify, name, point out, prove (unstudied theorem), recognise, reorganise, rephrase, report, revise, revisit, solve, synthesize, test, transform, transmit, weigh, create, prove (studied theorem, studied method), show (unstudied fact in the direct context of studied material), change, illustrate, practice, verify, question, clarify, discuss, propose, restructure, compose, recall, differentiate, and find.

This ordered list is a consolidation of what professional engineers recommend should be done more often as part of teaching-learning-evaluation process. The activity verbs not appearing in this list are the ones not selected by any professional engineer. As per this list, professional engineers recommended that the faculty should repeatedly direct or ask students to analyse, design, develop, implement, evaluate (the options), integrate, build, conclude, define (new things) or acquire (knowledge).

There is a significant similarity between the second and the third list. This demonstrates that most of the students preferred learning style is in alignment with the demands of the post university professional life. However, there are very serious difference in the first and other two lists, so much so that none of the top ten verbs of the first list also appears in one of top ten slots of either of the other two lists. While universities focus on regularly updating their curriculum, the differences in these lists demonstrate the need for transforming the teaching-learning-evaluation processes from a content-based curriculum to a process-based curriculum.

These three lists were further distilled using Bloom level to verb list mapping. All the verbs belonging to one Bloom level were grouped into one unit and Bloom Level Specific Consolidated ratings $L_{R\text{-student-I}}$, $L_{R\text{-student-II}}$ and $L_{R\text{-professional}}$ were computed as follows:

$L_{R\text{-student-I}}$, $L_{R\text{-student-II}}$ are the sum of $V_{Rj\text{-student-I}}$ and $V_{Rj\text{-student-II}}$ respectively for all the verbs belonging to the i^{th} Bloom level, i.e.:

$$L_{Ri\text{-student-I}} = \sum_j V_{Rj\text{-student-I}} \quad \text{Where the } j^{th} \text{ verb belongs to the } i^{th} \text{ Bloom Level}$$

$$L_{Ri\text{-student-II}} = \sum_j V_{Rj\text{-student-II}} \quad \text{Where the } j^{th} \text{ verb belongs to the } i^{th} \text{ Bloom Level}$$

$L_{Ri\text{-professional}}$ is the Sum of $V_{R\text{-professional}}$ for all the verbs belonging to the ith Bloom level**,** i.e.:

$$L_{Ri\text{-Professional}} = \sum_j V_{Rj\text{-Professioanl}} \quad \text{Where the } j^{th} \text{ verb belongs to the } i^{th} \text{ Bloom Level}$$

Bloom Level Specific Consolidated ratings $L_{R\text{-student-I}}$, $L_{R\text{-student-II}}$ and $L_{Ri\text{-professional}}$ are then normalised as follows:

$$S_{R\text{-student-I}} = \sum_{i=1 \text{ to } 6} L_{Ri\text{-student-I}}$$
$$S_{R\text{-student-II}} = \sum_{i=1 \text{ to } 6} L_{Ri\text{-student-II}}$$
$$S_{R\text{-professional}} = \sum_{i=1 \text{ to } 6} L_{Ri\text{-professional}}$$
$$L'_{Ri\text{-student-I}} = L_{Ri\text{-student-I}} / S_{R\text{-student-I}}$$
$$L'_{Ri\text{-student-II}} = L_{Ri\text{-student-II}} / S_{R\text{-student-II}}$$
$$L'_{Ri\text{-professional}} = L_{Ri\text{-professional}} / S_{R\text{-professional}}$$

The next stage of this research investigated verb usage in question papers. The sample comprised fifteen question papers of different subjects, given to around 1200 engineering students of 1st, 2nd and 3rd year Electronics, Computer Science (CS), and Information Technology (IT) and Biotechnology disciplines. Bloom level specific consolidated ratings, $L_{Ri\text{-Exam}}$ were computed from this data as follows:

$L'_{Ri\text{-Exam}}$ is the Fraction of i^{th} Bloom level questions across all question papers.
Where,

$L_{Ri\text{-Exam}}$ = Number of Questions belonging to i^{th} Bloom level

$$S_{R\text{-Exam}} = \sum_{i=1 \text{ to } 6} L_{Ri\text{-Exam}}$$
$$L'_{Ri\text{-Exam}} = L_{Ri\text{-Exam}} / S_{R\text{-Exam}}$$

Table 3 tabulates $L'_{Ri\text{-student-I}}$, $L'_{Ri\text{-student-II}}$, $L'_{Ri\text{-professional}}$ and $L'_{Ri\text{-Exam}}$ where large values indicate high ranks by most of the respondents.

Table 3: Comparison of Bloom Level specific normalized consolidated ratings

Bloom's Cognitive levels(i)	What students think they get $L'_{Ri\text{-student-I}}$	What students get in examinations $L'_{Ri\text{-Exam}}$	What students think works well for them $L'_{Ri\text{-student-II}}$	What professional engineers recommend $L'_{Ri\text{-professional}}$
Knowledge	0.24	0.36	0.04	0.09
Comprehen-sion	0.24	0.16	0.11	0.10
Application	0.22	0.40	0.13	0.10
Analysis	0.14	0.04	0.15	0.19
Synthesis	0.14	0.05	0.46	0.38
Evaluation	0.02	0.00	0.11	0.15

Table-4 gives the correlation coefficients between these three ratings (each can be viewed as an arrays of 6 elements) using Correl function of MS-Excel. Correl function calculates the correlation coefficient $\rho_{x,y}$ as a measure of similarity between two arrays X and Y as follows:

$$\rho_{x,y} = \text{Conv}(X,Y) / (\sigma_x \cdot \sigma_y) \quad ; \text{ where } -1 \leq \rho_{x,y} \leq 1$$

$$Conv(X,Y) = (1/n) \Sigma_{i=1 \text{ to } n} (x_i - \mu_x)(y_i - \mu_y) \text{ where}$$
σ_x and σ_y are the variance of X and Y respectively
μ_x and μ_y are the mean of X and Y respectively.

Table 4: Correlation between different consolidated ratings

	What students think they get **L'**$_{\text{Ri-student-I}}$	What students get in examinations **L'**$_{\text{Ri-Exam}}$	What students think works well for them **L'**$_{\text{Ri-student-II}}$	What professional engineers recommend **L'**$_{\text{Ri-professional}}$
What students get in examinations **L'**$_{\text{Ri-Exam}}$	0.77		-0.25	-0.57
What students think works well for them **L'**$_{\text{Ri-student-II}}$	-0.22	-0.25		0.96
What professional engineers recommend **L'**$_{\text{Ri-professional}}$	-0.38	-0.57	0.96	

Correlation

In Table 4, a high correlation of 0.77 is observed between the perception of fifty 2nd year CS and IT students and the data collected from the fifteen question papers that were administered to around 1200 students of different seniority in Electronics, CS, IT and Biotech disciplines. This implies that in spite of the differences in disciplines, subjects and seniority, there is not much difference in the cognitive level of activities that engineering students are engaged in. The professional engineers place high emphasis (combined rating of 0.71) on engaging the students in activities that require higher order cognition at the level of analysis, synthesis or evaluation as compared to the emphasis (combined rating of 0.29) on simpler activities requiring lower level cognition at the level of knowledge, comprehension or application. Interestingly, most of the engineering students experience more effective learning (combined rating of 0.72) when they are engaged in activities that require higher order cognition as compared to much lower perceived effectiveness (combined rating of 0.28) of the learning that occurs as a result of their engagement in activities requiring lower order cognition. This demonstrates that most of the engineering students' preferred learning style is in alignment and having a very high correlation of 0.96 with the recommendations of the professional engineers. However, The prevailing practice amongst the majority of engineering educators demonstrates an opposite preference leading to negative correlation of -0.22 and -0.25 with the preferred learning style of their students and -0.38 and -0.57 with professional engineers' recommendations.

Thus, the kind of the activities that a typical engineering student is generally engaged in, do not help in enhancing creativity, critical thinking and innovative problem solving. It is clear that most of the activities students formally engage in as part of teaching-learning-evaluation process promote rote-learning and conformity rather than creativity, critical thinking and innovative problem solving. This view was expressed by faculty as well during informal discussions.

What Do Students Need?

From the last section we can conclude that professional engineers want the students to be engaged in learning processes that promote creativity. The students also experience much higher learning when engaged in such processes. According to Arney (1999), the conception of creativity includes an interrelated set of intellectual skills of creative thinking, critical thinking, and innovative problem solving; personal characteristics of versatility, tolerance for ambiguity, willingness to take risks, open-mindedness, confidence, and curiosity, and values of discipline, perseverance, and responsibility. Further, Arney (1999) defined three intellectual skills:

1. **Creative thinking** is defined as the consideration of a broad range of new, sometimes abstract, ideas and the establishment of new connections and relationships among these ideas.
2. **Critical thinking** is the performance of careful and exact analysis, ultimately leading to a deeper understanding of an issue.
3. **Innovative problem solving** is defined as combining knowledge with imagination to produce solutions to problems.

Orthodox teacher centric lectures tend to cover a set of topics, and experiential development of these skills. Personal characteristics or values are not a committed goal of a typical lecture driven education system.

According to a survey reported by Goel (2004), an overwhelming majority of responding students and faculty members felt that:

- Creativity is very important for engineering profession.
- Creativity can be fostered through instruction and training.
- Current engineering education, in general, does not enhance creativity.
- Design assignments, real-life like assignments and discussions play a very important role, while written exams do not contribute much in fostering creativity.

This survey provided an interesting insight: that along with the students, most of the engineering faculty are also concerned about current educational system's weakness in fostering creativity. Therefore, it is imperative that the reasons of this weakness need to be isolated and creativity fostering aspects of teaching-learning-evaluation process identified, promoted and used more frequently.

ABET (2002) recommends that engineering graduates must have the following abilities:

1. Ability to apply knowledge of math, science, and engineering.
2. Ability to design and conduct experiments, as well as analyze and interpret data.
3. Ability to design a system, component or process to meet desired needs.
4. Ability to function in multidisciplinary teams.
5. Ability to identify, formulate and solve engineering problems.
6. Understanding professional and ethical responsibilities.
7. Ability to communicate effectively.
8. Understanding the impact of engineering solutions in a global and societal context.
9. Recognition of need and ability to engage in life-long learning.
10. Knowledge of contemporary issues.
11. Ability to use the techniques, skills and modern engineering tools necessary for engineering practice.

Hence, it can be deduced that engineering curriculum needs to be crafted to promote the reasoning process and creativity rather than carefully visiting a set of topics. Gary (1999) argues that curriculum should provide opportunities for transforming a problem statement into a model, conjecturing solutions, selecting or developing the appropriate mathematics, examining the analysis, and continuing to transform the conjecture into a solution. Bruner (1996) proposed that preparing students for solving real life problems require a different paradigm of education and learning skills, including self-directed learning, active collaboration, and consideration of multiple perspectives. Problems of this nature do not have "right" answers, and the knowledge to understand and resolve them is changing rapidly, thus requiring an ongoing and evolutionary approach to learning.

Conclusions

This study shows that engineering students report more effective learning when they are engaged in higher order cognitive activities through active learning. Even in the opinion of professional engineers, faculty should engage students in higher level cognitive activities like analyse, design, develop, implement and so on. However, as this study also demonstrates, most of the engineering faculty give assignments and activities that engage students in lower level cognitive activities like calculate, explain, prove (studied theorem, studied method), define (studied definitions) and so on. While universities keep updating the content list of the curriculum, the learning deficiency of most popular teaching and assessment techniques demonstrate the need and scope of transformation of the teaching-learning-evaluation processes from content based curriculum to process based curriculum. In order to foster creativity, critical thinking and innovative problem solving amongst engineering students and make the engineering education more in alignment with the suggestions of professional engineers, faculty need to bring a strategic transformation and flexibility in the curriculum to engage the students in higher level cognitive activities. Changing the activity verb set offers a way to realise this strategic transformation.

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