A GENERIC REFERENCE SYSTEM ALLOWING DATA-FUSION WITHIN CONTINUOUS IMPROVEMENT PROCESSES OF ENGINEERING EDUCATION PROGRAMS

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ABSTRACT

Accreditation standards entail continual improvement processes (CIP): *i. to assess program outcomes* in terms of graduate attributes, and *ii. to apply the collated results* to amend the program. CIPs closed loops fuse data from many courses. This stretches course-oriented evaluation practices beyond their existing capabilities. Specific subject matter rubrics provide detailed feedback, but lack the generic qualities that would allow *merging* the results from different courses or subject matters assessing the same graduate attributes. To gauge progress, a CIP thus needs a reference system stable in time, and well suited for accreditation standards over the years of the curriculum. This paper proposes a reference system yielding proficiency levels that suit CDIO and the European Qualification Framework (EQF) looking at: specialisation, cognitive apprehension, complexity, independence, and participation. These facets are divided in ranked progressions with associated key words / phrases. A computer-assisted generation tool for student performance expectations statements span 1,350 rank combinations and millions of statements to build generic rubrics, tailored to reflect current practices in existing learning activities. From the rank-matrix of the facets, the results from courses covering different subject matters can then be compared and their data be merged. A proof of concept generator tested on ten courses is discussed.

INTRODUCTION

Worldwide, engineering education is reorienting itself towards outcomes-based assessments. To name a few, the Conceive-Design-Implement-Operate [CDIO] (Crawley *et al.*, 2007), the International Engineering Alliance [IEA] (2013), and the Canadian Engineering Accreditation Board [CEAB] (2013) share this initiative. All foster near identical sets of professional characteristics referred to as graduate attributes.

Outcomes-based assessment focuses on what is learned and usable in a genuine context. Some issues remain: a) linking broad outcomes to specific indicators, b) ensuring coverage, and c) defining *proficiency levels*. CDIO proposes a 5-level scale, whereas the EQF favors eight (Education and culture DG, 2008). The DOCET project concluded improvements in the CDIO scale were desired about *complexity* and *independent* work (Bisagni *et al.*, 2010).

This paper proposes an information framework for outcomes-based assessments in existing learning activities, merging the data from courses covering different subject matters for a program-level view of attributes mastery. Requirements for the straightforward generation of generic rubrics and summary sheets to document the students' mastery of CEAB attributes are presented, with the objective of continually improving the engineering curriculum.

CONTINUAL IMPROVEMENT PROCESSES

CIPs are often depicted as simple loops. Engineering programs spread over many years, incorporate 30 to 40 courses, and hundreds of assignments. Subject matters cover a wide scope, with a spread of breadth and depth. Students need “pointers” as to the subject matters, as much as about their mastery of order 1 graduate attributes or their order 2 breakdown into *elements*. Course internal rubrics tend to be topic specific. A *program approach* becomes an abstraction detached from the daily activities. The ideal automation analogy would be closer to a network of interrelated events, each with its fast feedback loop (internal rubrics), and each feeding a larger slower loop with data fusion, to describe the global state of the system, with a possible external reference, and adaptive parameters. Figure 1 depicts some of the requirements of this larger and slower loop requiring data fusion.

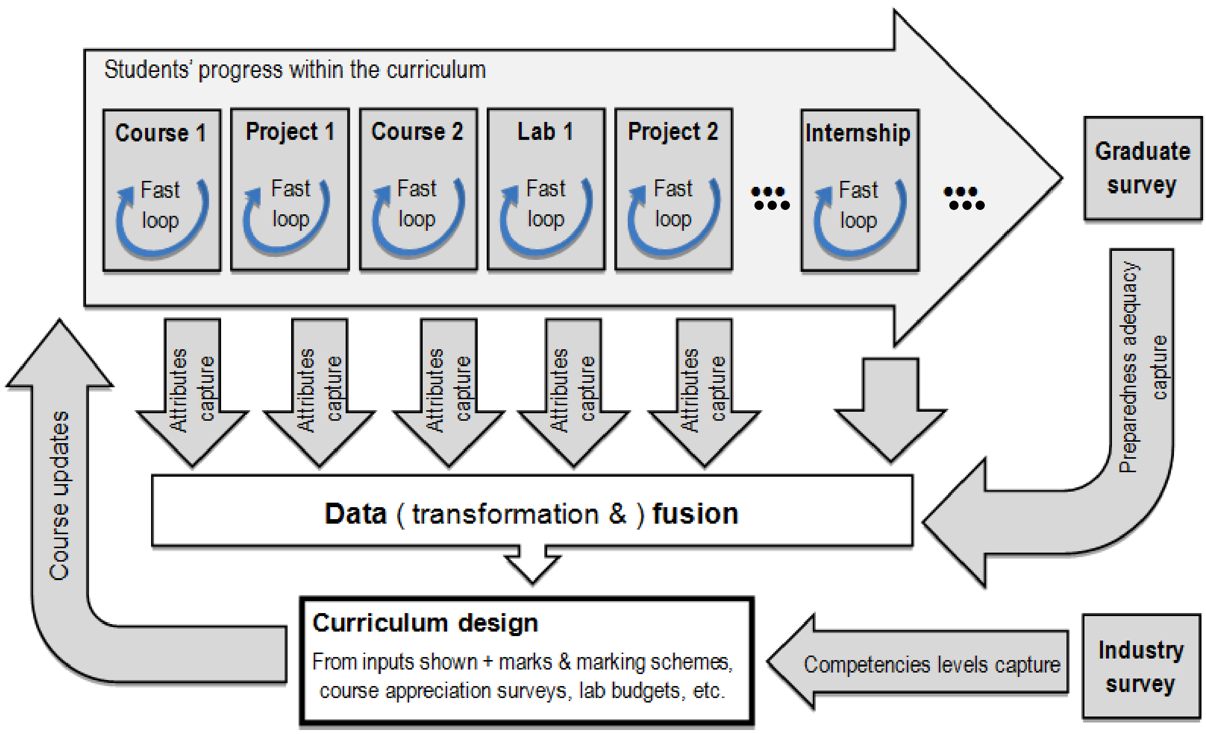

Figure 1. Data fusion within the continual improvement process, showing the “slow” feedback loop, the necessity for expectations statements independent from subject matters, and the advantage of an attributes capture tool as a seamless extension of existing practices inside courses.

OVERVIEW OF THE WORKING PROTOTYPE

The system is simple to use by teachers, helping the acceptance of the CIP demanded by the accreditation standards. The prototype hides the complex mechanics allowing future data fusion behind a simple interface. The core uses inputs from simple drop-down lists of standardized generic phrases by which the teacher tailors facet by facet a codified expectation statement for a generic rubric adapted to his current practice. The codified statements use key verbs / phrases whose origins are detailed in the paper.

The user is simply presented with drop-down menus in four sheets: 1) a “check sheet” to declare an ITU-like contribution of a course, 2) a “generation sheet” to assemble an expectation or work statement (Figure 2), 3) a CEAB attributes oriented “rubric sheet” for the assessment of individual students (per major assignment), and 4) a “group log sheet” to summarize these assessments, and to simplify future data fusion at a greater scale.

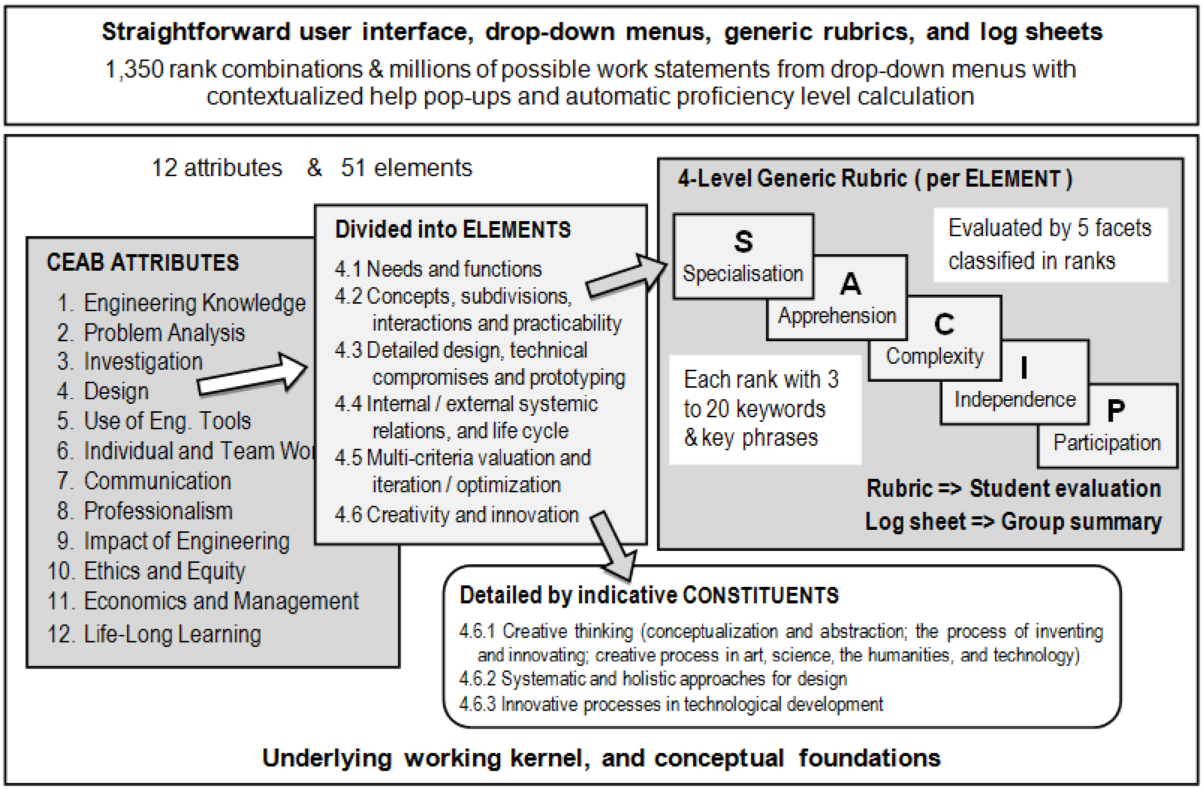

Figure 2. Conceptual view of the working prototype, with an underlying core (order 1: CEAB ATTRIBUTES, order 2: ELEMENTS, order 3: CONSTITUENTS, rubric & log sheet generators), and the visible interface layer (contextualized lists, pop-ups, and automatic proficiency level calculator). CDIO Syllabus topics are found in elements and constituents, while meta-levels attitudes are embedded in the proficiency scale.

GLOBAL CONTEXT AND FOUNDATIONS OF THE REFERENCE SYSTEM

Accreditation Board Requirements and the CDIO Syllabus

The 12 CEAB graduate attributes (ATTRIBUTES) match those of the Washington Accord, and are traceable to the Eur-ACE framework. A correlation was established between order 2 and order 3 topics of the CDIO Syllabus and the ATTRIBUTES in Cloutier *et al.* (2010a). In 2011, Mechanical Engineering at Polytechnique has broken down order 1 ATTRIBUTES into 51 order 2 ELEMENTS traceable to the CDIO Syllabus, and into order 3 CONSTITUENTS. A unified CDIO / CEAB / Eur-ACE / IEA set results, to express expectations along the curriculum.

As of 2013, the CEAB standard did not define *proficiency levels* or a *scale*. In 2010-2011, the Department devised the multi-facet reference frame found herein, from the CDIO proficiency levels and the DOCET initiative. Verifications were sought with a number of employers from 2010 to 2012. (Polytechnique has not embraced this reference frame as of this writing.)

Testing tentative proficiency levels and components of the data fusion loop

All courses of the two programs under the Department were mapped against ATTRIBUTES and ELEMENTS, documenting the perceived contributions: an exercise similar in nature to the CDIO ITU-mapping of a program. Each course associated assessment tools to learning objectives on the course syllabus, often with the intent of an intuitive proficiency level in mind. The stage was set for further analysis and reflection, discussions about the internal consistency, coverage and coherence of courses. First hand opinions about proficiency levels helped refine the tentative descriptions of Table 1 in Cloutier *et al.* (2010b).

An ATTRIBUTES & ELEMENTS -based *internal* survey tool was programmed on Moodle. Students in the first and the last year of the curriculum selected their perceived entry and hopeful graduation proficiency levels against ATTRIBUTES and ELEMENTS. The first year survey helps students and professors "set the reference" through exchanges and discussions, and focus on a "pull" instead of a "push" motivation. For final year students, it provides the improvement process with a "students' perspective" of the grounds covered by a program.

An ATTRIBUTES & ELEMENTS -based *external* survey tool was programmed: 1) outcomes-based accreditation justifies a CDIO-like approach in surveying the needs of the labour market, and 2) the CEAB standards benefits from a specific survey to convey the message better. Internal and external surveys act longitudinally. With time, former students will have answered all three surveys for a better understanding of ATTRIBUTES & ELEMENTS, reducing the variance of interpretation, and providing better information with smaller samples.

A reference frame must cover from the 1st year of a program to well into the years of professional practice, and not limit itself to levels of proficiency "upon graduation". It must rest on factors that pertain to the exercise of engineering, over and above academic success.

Taxonomies

Taxonomies were used to provide ranks that quantify the ATTRIBUTES. Taxonomies in the cognitive (Anderson *et al.*, 2001) and affective (Krathwohl *et al.*, 1964) domains, in problem solving (Plants *et al.*, 1980), and for hybrid approaches (Miller, 1990) were considered. Bloom's revised taxonomy of cognition was adopted to express the intellectual load of assignments. Krathwohl's taxonomy of the affective domain was used to express the extent of commitment or participation. Bloom-Anderson and Krathwohl, cognitive-affective full combinations were preferred to the subset of Miller's pyramid. Plant's taxonomy was seen as appropriate to problem solving, but too specific to encompass all CEAB ATTRIBUTES.

Usual Bloom-Anderson / Krathwohl interactions focus on "preferred pairs" (Ford *et al.*, 2001), in turn from the cognitive and affective domains: a somewhat "linear progression" towards cognitive-affective integration. The breadth of educational engineering programs makes one depart from this "linear progression" towards complexity and/or creativity. "Preferred pairs" foster a "first know then do" approach that could impede initiatives in learning by discovery. "Preferred pairs" of cognitive/affective ranks were thus not considered in the reference frame. It was however recognized strong opposing polarities should be flagged as suspicious.

Complexity

The CEAB Standards refer to "complex problems" and "complex activities", without defining *complexity*. Engineers Canada have co-signed the Washington Accord in 1989, and this organization eventually defined complexity within the range of problem solving and the range of engineering activities (see 4.1 & 4.2 on pp. 6, 7 of Graduate attributes (IEA, 2013).

Seven to nine aspects determine the extent of complexity: 1) depth of knowledge required, 2) range of conflicting requirements, 3) depth of analysis required, 4) familiarity of issues, 5) extent of applicable codes, 6) extent of conflicting requirements, and 7) interdependence of component parts or sub-problems; and maybe the range of consequences and the judgement required by decisions. Notice their pervasive presence in any problem, and the difficulty of incorporating all in a single academic learning context. It was chosen to highlight the major aspect of a learning situation, notwithstanding the presence of minor aspects.

Autonomy (Independence) of work

Autonomy of work is an important factor on the labor market, but no taxonomy was found. It is also a "natural" facet in the discourse of professors about the aptness of students.

This self-directing freedom was seen as the *independence with which one can complete his objectives while in a dynamic and uncertain context, can successfully engage in appropriate interactions, and can operate within flexible structures*. This description was not perceived as providing convenient indicators for observation. Self-directing freedom can also be classified by type: exercising skills, affecting resources, setting goals, planning actions, … This "field-practical" breakdown was seen appropriate for capstone projects, but not easily applicable across a curriculum. However, it remains a meta-level attitude one wants to assess.

Independence of work translates into the frequency of a supervisor's verifications, and in the conditions under which such verifications are to be sought. A gradation of the supervision required can be observed. It has the advantage of being intuitively related to current practices in both the academic and the labour environments. Independence was thus graded by the frequency of supervision/coaching, from "step-by-step" to "occasional" (see Table 1).

Table 1. Ordinal rank labels (Specialization-Apprehension-Complexity-Independence-Participation) of the five SACIP facets, allowing 1,350 combinations for undergraduate courses. Some combinations express strong polarities (*e.g.* highly complex problem with step by step guidance), and should be flagged as suspicious. A five-facet SACIP matrix defines a unique "position" in this space.

Facet		**S**pecialization	**A**pprehension (Bloom-Anderson)	**C**omplexity (Int. Eng. Alliance)	**I**ndependence (Supervision)	**P**articipation (Krathwohl)
Ordinal rank and rank label (echelon)	**1**	Fundamentals	Remembering (12 key verbs)	Narrowly defined (8 key phrases)	Step-by-step (6 key phrases)	Receiving (3 key phrases)
	2	Specialty basics	Understanding (14 key verbs)	Broadly defined (8 key phrases)	Sustained (6 key phrases)*	Responding (3 key phrases)
	3	Specialty advanced	Applying (23 key verbs)	Complex (8 key phrases)	Periodical (6 key phrases)*	Valuing (3 key phrases)
	4	Specialty graduate 1 **	Analyzing (15 key verbs)		Punctual (6 key phrases)*	Organizing (3 key phrases)
	5	Specialty graduate 2 **	Evaluating (10 key verbs)		Occasional (6 key phrases)*	Characterizing (3 key phrases)
	6		Creating (22 key verbs)			

* Under predetermined conditions, resorting to the lower ordinal rank in unforeseen conditions.
** Graduate ranks of Specialization are not used for CEAB accreditation, and removed from the drop-down lists.

Opportunities for Added Value

Students can receive feedback through *i.* simple marking schemes, *ii.* subject matter specific rubrics, and *iii.* ATTRIBUTES / ELEMENTS generic rubrics. The second may have the advantage of clearer guidance towards higher marks. The third could better serve reflection and a global self-image, and better nurture the *quest for generalization* in the learning process. *Generalization* is – after all – the last step of any problem solving methodology. “Learning how to prepare for professional practice” is a meta-problem, longitudinally covering the curriculum. Applying ways to reveal this meta-layer towards generalization can be a powerful motivator, providing *meaning* in the eyes of the student and answer fundamental concerns.

PROPOSED REFERENCE SYSTEM AND IMPLEMENTATION

Five-Facet Seven-Level Scale

Facets

The five facets of any proficiency level (observation) or quantized echelon are shown in Table 1. Although this does not span a vector space, one can picture facets as axes defined by unit vectors, and echelons as hyper-foils.

Echelons as “Hyper-Foils”, and General Descriptors

Seven “hyper-foils” or echelons are defined over this five-facet “space”. The quantum leap between them requires more than a major increase in *one* facet. (For instance, it should not be possible to traverse multiple echelons by an increase in the ordinal rank of cognitive apprehension alone.) General level descriptors refer to the facets, as seen in Table 2.

Table 2. The seven echelon scale, and general descriptors. For a general descriptor to become detailed yet generic, statements like “occasional supervision” will be developed into a number of equivalent traits that are transversal across different subject matters of course credits.

Echelon number and label	General descriptor
E0. “Ignores everything about…”	(As if...) Has not heard of it OR Has not been evaluated;
E1. “Has been exposed to…”	Has heard about it. Cannot use. Does not contribute. Would require step-by-step supervision.
E2. “Participates and contributes to…”	Executes routines. Uses on request. Small predefined tasks. Would require steady supervision.
E3. “Executes with signs of discernment…”	Repeats with nuances. Recognizes the condition and applies. Responsibility of execution for planned routines, validation of choices needed. Would require periodic supervision, steady in the unforeseen.
E4. “Understands and explains his decisions…”	Defends choices and explains reasons. Resorts to, chooses, applies spontaneously, with regularity. Autonomous for known branched out tasks, validation of decisions for unknown tasks. Would require punctual supervision (periodic in new situations).
E5. Takes initiatives with little risk…”	Acts / proposes over the range of usual situations bearing consequences. Foresees repercussions / sensitivities with good judgment. Frequent autonomous actions and initiatives with little risk. Would require occasional supervision in important adaptations
E6. “Ready for professional practice…” **(Onset of Eng. Practice, after 3 to 4 years as “Engineer in training”)**	Decides / Commits resources on his own for usual situations bearing tactical consequences. Plans medium-term wide repercussions / sensitivities with judgment. Continuous autonomous actions and initiatives without risk. Would require occasional confirmations in cases with strategic repercussions.
E7. “Can lead or innovate if…” **(Well versed Eng.)**	Manages / leads others in the commitment of resources in strategic situations. Continual autonomous actions. Mentor. Adapts / develops / creates solutions.

Students enter a curriculum with different abilities, backgrounds, and hobbies. It is abusive to pretend the curriculum has sole control over their progression to professional preparedness, and equally abusive to pretend that “we the teachers” are in control of their learning: that we know, master, and provide the factors by which each and every student can be made to progress. Best to honor their capabilities, and admit they will follow different paths towards not the “same”, but “equivalent” end points in the space of professional preparedness.

Equivalent “preparedness states” (or *echelons*) then coexist on a “hyper-foil”. It is sensible to impose the quantum leaps between echelons not be dependent on a single facet. It is also sensible to allow multiple paths between echelons, some students progressing more by cognitive apprehension, while others make better use of autonomy or find motivation in the complexity of “real world” situations. This diversity must be allowed between courses, as a symptom of richness and not one of lack of control.

It follows these level descriptors are general, and both a reference frame and a computer-assisted tool allow multiple equivalent detailed descriptions of each and every echelon. In turn, these detailed descriptors must be *generic*, and not “course subject matter specific”.

Rationale to Compute Numeric Proficiency Levels From Facet Ranks

Teachers need to match expectation statements with the scale echelons: have a clear idea of the proficiency level required from the student. One must consider three fundamental aspects when associating a proficiency level to a set of ordinal rank labels or “rank matrix”:

1) the rank matrices in the neighborhood of an echelon must make an acceptable natural cluster and not encompass what would appear as outliers,
2) computed proficiency levels should reflect natural plateaux found in facets (*e.g.*, the permutation of Evaluation and Creation between Bloom and Bloom-Anderson should translate into near equivalent proficiency levels when the only change in the rank matrix comes from these ranks of the cognitive apprehension factor), and
3) provision for weighing the factors should be provided, in order to reflect the specific “personality” of a program or Engineering School.

Finally, scaling factors should limit the result of the computation to a near [0 - 7] range.

Plateaux – Diminishing Returns at the Extremes

Figure 3 exemplifies how a sigmoid can account for *i.* strictly Remembering bringing little contribution to professional practice, while *ii.* Evaluating and Creating being so close to one another for some taxonomies to reverse their order. The scale adjusted sigmoid would be $S_A(r_A)$, where r_A is the selected ordinal rank for the “cognitive Apprehension level” chosen.

The ordinal ranks of the remaining facets are so selectively compressed to a [0;3] range by sigmoids $S_C(r_C)$, $S_I(r_I)$, $S_P(r_P)$. The steepness of the sigmoids being one of the multiple ways a program can tailor the output to reflect its “personality”.

Proficiency Level – Scalable Weighted Geometric Mean –Like Calculation

Proficiency is calculated as in Eqn (1):

$$P(r_S, r_A, r_C, r_I, r_P) = (S_S(r_S)^{k_S} \cdot S_A(r_A)^{k_A} \cdot S_C(r_C)^{k_C} \cdot S_I(r_I)^{k_I} \cdot S_P(r_P)^{k_P})^m + n, \quad (1)$$

where k, m, and n are some of the parameters used to tailor the behavior of the proficiency function. Other tailorable parameters are internal to the sigmoid functions themselves.

$S_A(r_A)$

	Cognitive Apprehension (Bloom-Anderson taxonomy)				
	R [0;6]	R [-1;+1]	Sigmoid		Scaling
		0,3333	λ	Sig.[0;3]	constants
		1	4		
	0	-1	0	0	-0,05597
Remembering	1	-0,6667	0,1	0,1462	
Understanding	2	-0,3333	0,2	0,5932	
Applying	3	0,0000	0,5	1,5	
Analyzing	4	0,3333	0,8	2,4068	
Evaluating	5	0,6667	0,9	2,8538	
Creating	6	1	1	3	3,11194

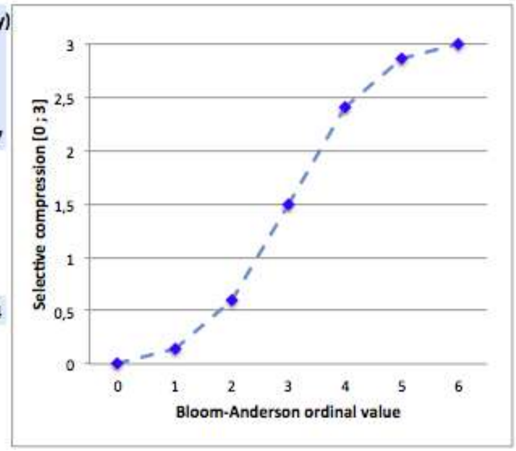

Figure 3. Impact of *Apprehension*. At the lower end, the sigmoid expresses the diminishing contribution of "simply remembering" (1) and – to a lesser extent – of "passive understanding" (2), and at the higher end, the close resemblance between *Evaluating* (5) and *Creating* (6).

Rank Selection, Rank Matrix, and Data Fusion

Choices made by a user as in Figure 4 build a rank matrix per element of a CEAB attribute. This matrix is used to sort courses in comparable sets by ELEMENTS, and maybe by year of the curriculum. Data fusion of the assessment results is made possible after sorting "by element & by rank", from a pertinent subset of courses in the curriculum. Other elements of the attribute may conceivably call for a different subset. This provides flexibility for data fusion, without imposing equivalent elements to the courses forming these flexible subsets. Flexibility often lowers the resistance to change.

When a course undergoes an improvement by the CIP, a new rank matrix may arise from the selections made in the facet drop-down menus. The computerized proficiency level then helps determine to what extent the assignment – as designed or chosen for the assessment of an attribute – blends well into the curriculum. If required, the course is easily assigned to different subsets, by the sorting process making use of the rank matrix by CEAB ELEMENT.

The sorting process reconstructing appropriate subsets of courses by Element is easily automated. The concept and prototype presented herein thus naturally "accompanies" small to large changes brought over by the CIP.

Richness and Coverage

The number of possible rank matrices is 1,350: the product of the ranges in the ranks of the five facets. By the computational equation of proficiency levels, this total is broken down by echelon as shown in Table 3. (More sets yield the higher echelons when graduate course credits are considered, as it should.)

This is an incomplete summary of richness though. Rank descriptors are labels under which keywords / key phrases are listed. This makes the number of possible statements 200 to 500 folds higher than the number of rank matrices. Under each rank, some key phrases can thus better correspond to traditional course credits, while others suit projects or labs: enough to ensure proper coverage and diversity.

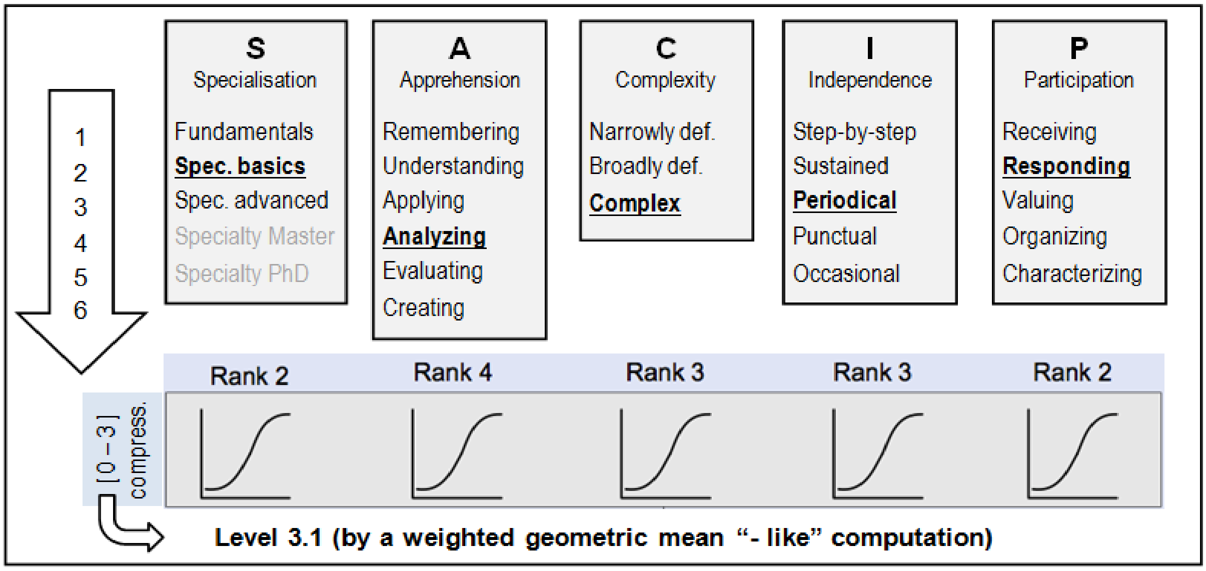

Figure 4. Proficiency level calculator of the working prototype. The rank matrix {24332} follows from the SACIP selections by the user. The kernel applies sigmoidal compressions for [0-3] outputs fed to a weighted geometric mean "-like" computation. The computed proficiency level 3.1 ensues. An opportunity for improvement would be to apply fuzzy logic to the computation of the proficiency level.

Table 3. Distribution of SACIP sets of ranks between echelons (E6 corresponding to a graduate with three years of professional experience). Sets with low complexity clustered around a lower proficiency. High complexity has a more or less flat distribution across E3, E4 and E5 (cognitive apprehension, independence of work, and participation playing a major role in this).

Scale Echelons	Total sets	Depolarized sets	Depolarized sets by Complexity rank C = 1	C = 2	C = 3
E0	1	1	1	0	0
E1	510	88	46	41	1
E2	420	47	8	25	14
E3	202	57	1	30	26
E4	119	68	0	39	29
E5	62	43	0	19	24
E6	28	28	0	10	18
E7	8	8	0	0	8
0 to 7	**1350**	**340**	**56**	**164**	**120**
1 to 5	**1313**	**303**	**55**	**154**	**94**

Expectation Statement Generator and Rubric Output

The construction of an expectation statement is illustrated in Figure 5**Error! Reference source not found.**. The number of such statements for a SACIP rank matrix is the product of the possibilities of each of the five facets: each rank matrix generates some 2,000 statements. Numerous rank matrices yielding equivalent echelons as shown in Table 3, lower echelons are expressed by over a million statements and higher echelons for students nearing graduation (E4 & E5) expressed by some 200,000 statements, all with cross-curriculum consistency and traceable justifications.

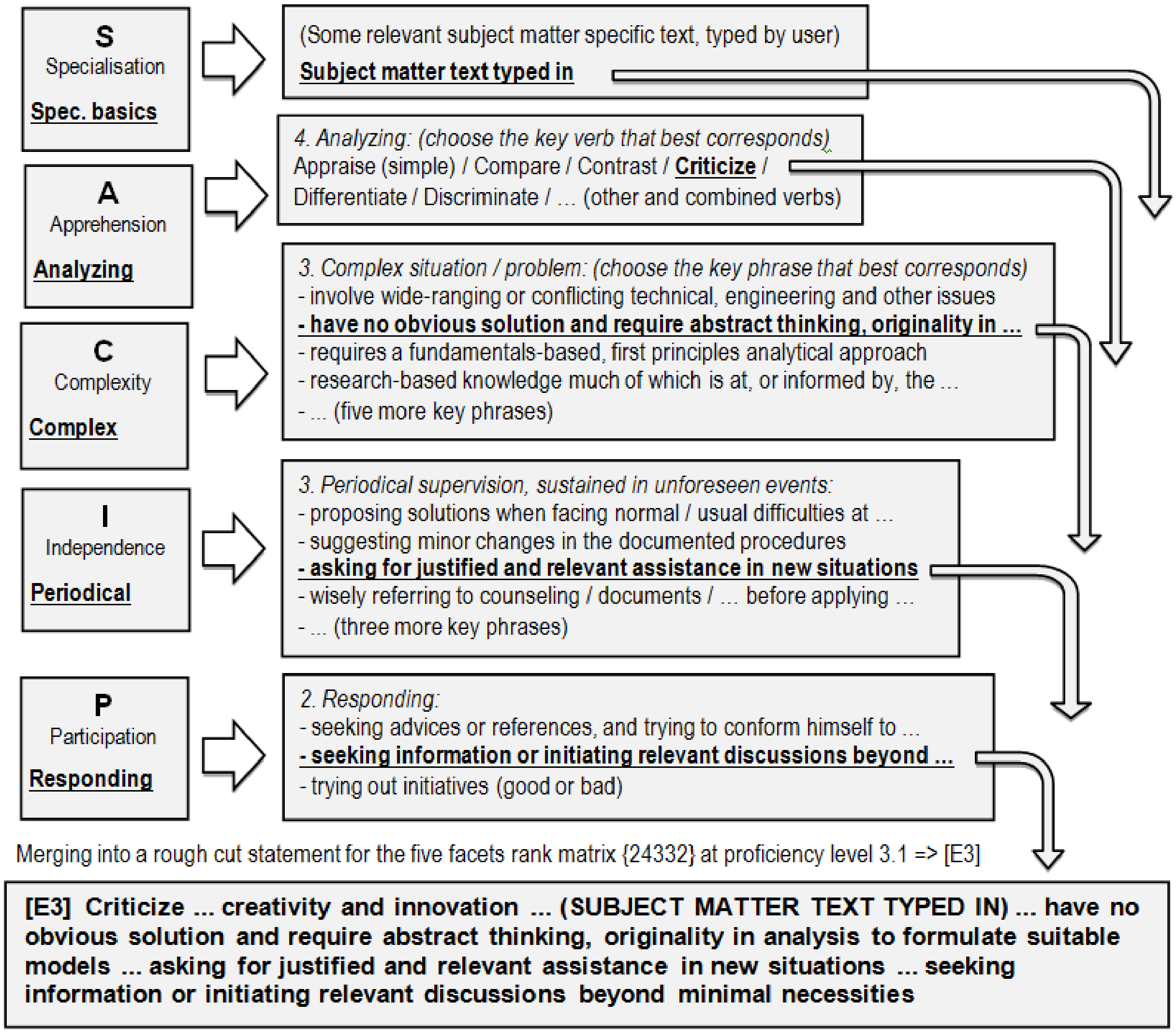

Figure 5. Generation of an expectation statement through simple selections from contextualized drop-down menus. The teacher selects what best matches his current practice, thus favouring a strong link between the ATTRIBUTES / ELEMENTS and the appraisal at the proficiency level targeted.

As in Table 4, the assessment can then take the Boolean form "(a) AND (b) AND (c) meet expectations". If not, "(a) OR (b) OR (c) is above/under expectations". This allows the straightforward generation of CEAB attributes/elements related rubric outputs. Fixed complexity component is imposed by the context: { have no obvious solution and require abstract thinking, originality in analysis to formulate suitable models }.

Table 4. Example of rubric output (complexity remaining a fixed parameter of the assessment context).

Exceeds targeted echelon	Meets targeted echelon	Nears targeted echelon	Fails targeted echelon
(a) OR (b) OR (c) clearly above expectations	(a) Criticize ... creativity and innovation ... (SUBJECT MATTER TEXT) ... (b) asking for justified and relevant assistance in new situations ... (c) seeking information or initiating relevant discussions beyond minimal necessities	(a) OR (b) OR (c) are uncertain against expectations	(a) OR (b) OR (c) clearly under expectations

TESTING IN PROGRESS

The prototype tool is being tested on two curriculum: Mechanical Engineering, and Aerospace Engineering. The following has been completed:

- mapping the ITU-Control intentions of courses;
- selecting the courses serving as accreditation control points;
- meeting with professors and teaching assistants to present the tool.
- producing generic rubrics to assess elements of the attributes.

Finally, the following are under way:

- using the rubrics in selected courses;
- presenting preliminary compiled data.

Implementation Process

Over 15 professors responsible for selected courses have built rubrics using the expectation generator, by themselves or accompanied. Thirty-seven rubrics required to assess the CEAB attributes in two programs have been completed, using the expectations generator tool.

The initial resistance rapidly faded with hands-on use of the expectations generator, and the observation of the close link between the proposed expectations statements and the current intents – sometimes found to be implicit – in the assignments given to students.

Further explicit linkage between the expectations statements and specific elements in student deliverables remains to be documented. Common level expectation statements will then allow to corroborate the proficiency expressed in the different student works submitted.

Displaying Summaries

A graphical compilation tool has yet to be chosen to help understand the merged data. In view of the complexity and richness of the data it was temporarily chosen to present it as distributions rather than single aggregate indicators. Figure 6 shows the proposed form for “Problem analysis”. More data presentation schemes will be explored in the coming months.

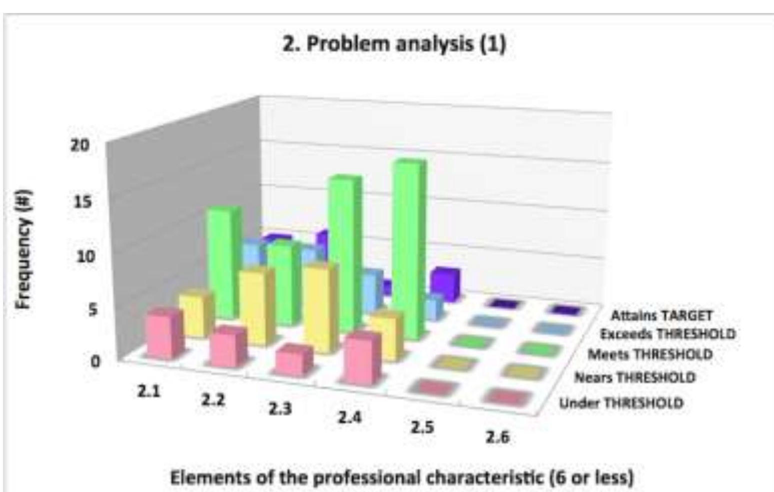

Figure 6. Data presentation for a single course and one attribute. Four elements of the attribute are evaluated out of six possible (horizontal axis), number of students (vertical axis), echelon achieved (depth axis).

CONCLUSION

The paper presented an information framework for outcomes-based assessments in existing learning activities. The characteristics of this framework allow merging the data from courses covering different subject matters for a program-level view of CEAB attributes mastery by students. Requirements for the straightforward generation of generic rubrics and group log sheets to document these results were presented, together with the factors that will likely make the change acceptable in the eyes of the teachers. The subdivision of the 12 CEAB attributes in 51 elements and many indicative constituents ensure coverage, while supplying enough granularity for existing learning activities to find their mapping over these lists.

Five facets define proficiency: Specialty (depth of disciplinary knowledge), Apprehension (cognitive load), Complexity (as per the IEA resolutions), Independence (frequency of supervision / degree or autonomous action), Participation (depth of commitment). Ordinal ranks in every facet allow the construction of a rank matrix. A proficiency level can be computed from this rank matrix, and proficiency echelons range from E0 to E7.

From the combination of the ordinal ranks and key phrases, over a million different expectation statements can be generated for some echelons, while remaining equivalent for the data fusion of assessment results. These variations are rich enough for a teacher to find an echo of his current practice, specific enough to satisfy accreditation requirements, and generic enough to allow data fusion from courses covering different subject matters.

A working prototype hides the mechanics in its core. It presents simple drop-down menus and assembles rubrics and log sheets. Tested on 10 courses and some 100 expectations statements, teachers could build statements that reflected current practices, and sometimes found advantage in revealing their implicit expectations. The perceived fidelity of the statements and robustness of the codified statements are ingredients for a smooth transition to outcomes-based assessments required of the CEAB standards while addressing meta-level attitudes and selt-image of the students, and the implementation of a true curriculum continual improvement process with meaningful data fusion from different courses.

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