3 Determining the Appropriate Levels of Student Proficiency for Syllabus Topics

The topical Syllabus is a detailed list of skills in which a graduating engineer should, in principle, have developed some level of proficiency. However, in order to translate this list of topics and skills into learning objectives, we must establish a process to determine the level of proficiency that is expected in a graduating engineer. This process must capture the inputs and opinions of all the potential stakeholders of the educational program and encourage consensus building based on both individual viewpoints and collective wisdom. It has been our experience that this can be most effectively achieved by conducting well formulated surveys. The faculty then reflects on the survey results and makes informed decisions.

Such a generic survey process will be described below, followed by the specific implementation of the process for the program in Aeronautics and Astronautics at MIT. In actuality, the specific example of the survey process was conducted first, and then generalized, with lessons learned, to the generic one described below. Therefore the details of the MIT implementation will vary slightly from the recommended process. The detailed results of the MIT survey will also be presented. They are of course unique to this program and university, but are typical of the kind of results that a survey will generate.

3.1 Recommended Survey Process for Defining Desired Levels of Proficiency

The recommended survey process for determining the desired level of proficiency of the second (X.X) and third (X.X.X) level Syllabus topics is described below.

Identify the stakeholder communities to survey. Undergraduate education has a large number of stakeholder communities who might be included in the survey and consensus process. These will certainly include the faculty, and under ABET guidelines, should reach outside the university. One can consider including alumni groups of various ages, industry representatives, and peers at other universities. Standing and *ad hoc* advisory boards, administrators and faculty in other departments at the same university can also be included. Depending on local culture, current undergraduate students can be surveyed as well.

Our recommendation is to survey faculty, mid- to upper-level leaders of industry, a set of relatively young alumni (perhaps five years or so from graduation) and a set of older alumni (perhaps 15 years from graduation). These alumni will still be young enough to remember what they learned as undergraduates, yet have some maturity to reflect on the importance of undergraduate education and its role in their career. It is interesting to survey students to determine the degree to which their views change as they mature at the university and after they enter the workforce. However, the data from current students should probably be kept separate in the analysis from that of other stakeholder groups.

Conduct the survey to determine expected levels of proficiency. A survey questionnaire must be constructed and the survey actually conducted. The questionnaire must be clear and concise and ask questions on the desired levels proficiency in such a way that information is collected for each item in the topical

Syllabus at the second, or X.X, level, and at the third, or X.X.X, level. Both quantitative and qualitative responses should be solicited. A set of rubrics or definitions must be used to insure reasonable consistency of quantitative responses.

A recommended approach is to ask the respondent to rate the expected level of proficiency of a graduating engineer on a five point activity based scale, developed for this use at MIT. The proficiency scale was devised to anchor the responses in easily understood rubrics. Table 6 shows the scale, which is based

1.	To have experienced or been exposed to
2.	To be able participate in and contribute to
3.	To be able to understand and explain
4.	To be skilled in the practice or implementation of
5.	To be able to lead or innovate in

Table 6: MIT activity based proficiency scale.

on "activities", and ranges from "To have experienced or been exposed to" at level 1, to "To be able to lead or innovate in" at level 5. These levels were meant to resemble the progressive development of skills in a professional engineer, from those of an apprentice to those of a senior leader.

The CDIO Syllabus contains 16 items at the second (X.X) level, 13 of which are in Parts 2 through 4. These latter parts arguably contain the topics for which outside opinion is most useful in establishing expected levels of competence. These 13 items contain 67 attributes at the third (X.X.X) level. A meaningful survey can be constructed around 13 questions, but not 67. Therefore a two step process is recommended.

In the first step, the respondent is asked to rate, on the absolute five point activity based scale, "the expected level of proficiency of every graduating student in …", followed by the thirteen X.X level topics. An opportunity for the respondents to comment qualitatively on each X.X section should also be provided.

In the second step, within each X.X section the respondent is asked to pick one or two subsection topics at the X.X.X level for which a relatively higher level of proficiency should be expected. Relatively higher should be interpreted as one step higher on the activity based proficiency scale. Likewise the respondent is asked to pick an equal number (one or two) subsection topics for which a relatively lower level of proficiency is acceptable. This question must be asked in such a way that the pluses and minuses cancel and the mean level of proficiency is not raised or lowered.

Sample survey forms tailored for the purpose of asking these two questions are found in Appendix H. It is also recommended that the entire topical Syllabus, as well as other information on the program be sent or made available to respondents as background reading. A survey group of 20 to 30 representative individuals is usually shown to capture all of the important trends in stakeholder opinion.

Compile the data from the survey and examine it. Qualitative and quantitative data on the 13 second level and the 67 third level topics will be obtained from respondents in two or more stakeholder groups. The qualitative comments should be examined for trends and used in the updating of the customized syllabus. The quantitative responses should be used to guide the determination of the expected levels of proficiency of students at graduation.

The quantitative responses can be analyzed for their mean and variance. The mean of all inputs will give a consensus indicator of the level of proficiency expected of graduating students. Comparison of the means of the different stakeholder groups will indicate the degree of consensus. Statistical tests, such as ANOVA and Student's t tests, can be used to determine if differences in the means are significant.

One of the interesting outputs of this data phase is a sense of the degree of agreement on the expected levels of proficiency. If all stakeholder groups are in agreement, then it is obvious that consensus has been reached. If, on the other hand, there is significant disagreement on the expected level of proficiency on a Syllabus topic, then follow up discussions, closer reading of the qualitative inputs, and debate may be necessary to come to consensus. Use the survey data as guidance in assigning final levels of expected proficiency to the X.X and X.X.X topics, but make choices that align with the context and local program goals. Be cautious about setting the goals at too high a level.

The final result of the survey and consensus process is an expected proficiency rating of each of the 67 attributes at the third level of the topical Syllabus found in Appendix A.

A clearer understanding of the process will be derived by examining the example shown below of customizing the topical Syllabus for the program in Aeronautics and Astronautics at MIT.

3.2 Example: Establishing the Desired Levels of Proficiency for Graduating MIT Engineers at the CDIO Syllabus Second Level

When developing a customized version of the CDIO Syllabus for the program in Aeronautics and Astronautics at MIT, three surveys were conducted. The first established the desired levels of *proficiency* at the second, or X.X, level, and the second established the same information at the X.X.X level. Note that two separate surveys were conducted, unlike the recommended procedure described above.

An additional survey was also conducted simultaneously with the first, which asked respondents to rank the relative *importance* of a second level (X.X) topic, as measured by the resources that should be dedicated to its teaching. These responses are presented and discussed in Appendix E. Note that, *a priori*, there is no reason to believe that respondents would answer similarly to the resource vs. proficiency questions. However it was found that both surveys contained essentially the same information, and therefore an independent question on importance is not warranted.

Following the procedure recommended above, the stakeholder groups were first chosen. These included faculty, industry leaders, and two alumni groups. In the surveys, the "faculty" are primarily the faculty of the Department of Aeronautics and Astronautics at MIT, with a few respondents from other engineering departments. The "industry" respondents are primarily mid- to upper-level leaders and managers in the aerospace industry. Many hold positions which put them in contact with universities, usually in an advisory, liaison, or review capacity. A few teach part time. The two alumni groups consist of the "older alumni" of the Department, who are 14, 15, and 16 years from graduation with a Bachelor's Degree, and the "younger alumni", who are 4, 5, 6, and 7 years from graduation. The groups were chosen to be about a decade apart to determine if there was any significant shift in opinions with increased professional experience.

The survey was sent to approximately 40 faculty, with N=22 respondents, approximately 40 industry leaders, with N=16 respondents, approximately 160 young alumni, with N= 34 respondents, and approximately 180 older alumni, with N=17 respondents. Except for the older alumni, these return rates are considered quite high.

The survey packet included a description of the CDIO Syllabus, the Syllabus itself, excerpts from the four primary comprehensive documents correlated with the Syllabus (Tables 2 to 5) and the survey forms. Respondents were asked to use the five-level scale to indicate the expected level of proficiency (Table 6). The specific question we asked of respondents was:

> *For each set of the attributes, please indicate which of the five levels of proficiency you desire in an engineering student graduating from MIT. Feel free to include a brief statement elaborating this level of proficiency.*

Figure 7 shows the results of the survey, with the four respondent groups indicated. The data is also summarized in Appendix F (Table F2). The asterisk in Figure 7 indicates statistically significant differences among the respondent groups within any topic. Note that of the 78 (13x6) possible pair-wise comparisons performed using Student's t test, there were only two where a statistically significant difference (□<0.05) occurred, both in the same section. Industry respondents believe a graduating senior should be *less* proficient at the design process than the two alumni groups. This may be a result of the fact that alumni in the age groups surveyed are primarily concerned with design processes and emphasize proficiency in that area, while the industry respondents are at a higher level in the organization, where the detailed skills of design are less important.

The most significant result of this survey is the uncanny similarities in opinion among the groups. This degree of agreement was unexpected. It essentially settles all arguments about the desired level of proficiency we now expect in our graduating students.

Because the responses of the groups were so similar, the four data sets were combined and the average expectation in proficiency was determined. The

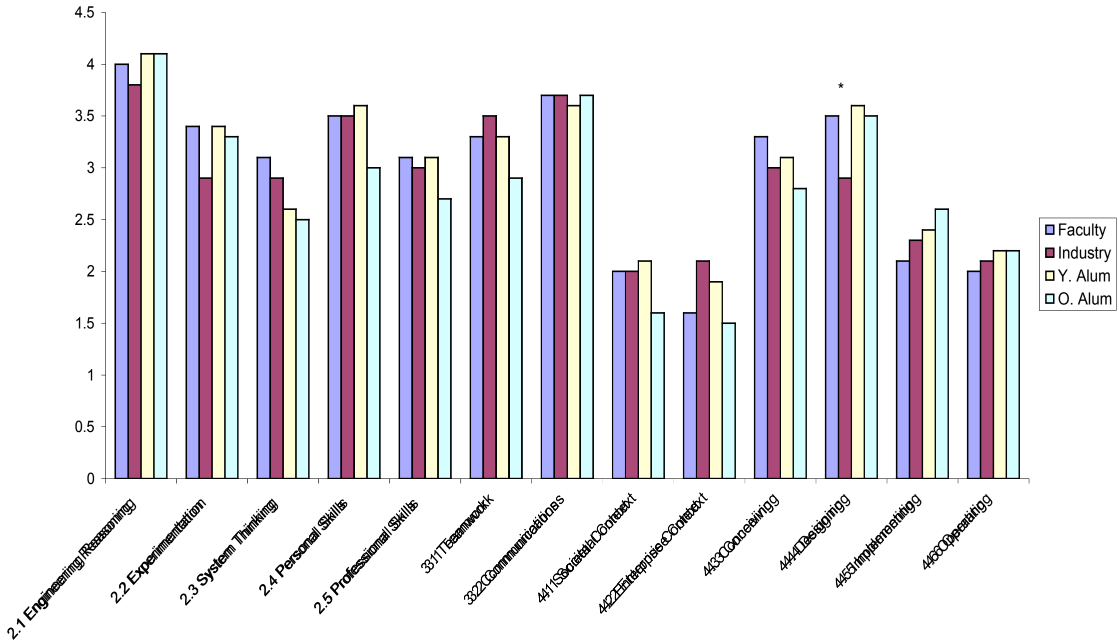

Figure 7: Proficiency expectation by survey group. Asterix designates statistical differences.

average proficiency is shown in Table 8, in Appendix F, and is indicated in parentheses in the customized form of the Syllabus, found in Appendix C. In order to determine the areas in which students are expected to have relatively higher, or lower, levels of proficiency, the mean for each attribute was compared with the mean for all responses, again using a Student's t test. Figure 8 displays the results, indicating those with statistically higher levels of expected proficiency with an "H" and lower levels with an "L."

In this comparison of expected proficiency, Engineering Reasoning and Problem Solving (2.1), Communication (3.2), Designing (4.4), and Personal Skills and Attitudes (2.4) fell in the "high" category, with proficiency levels between 3.4 and 4. These three topics appear consistently in various documents as among the most important skills of engineering, and their high ranking is not a surprise. These correspond to an ability "to be skilled in the practice" of these topics.

The Societal Context (4.1), the Enterprise and Business Context (4.2), Implementing (4.5) and Operating (4.6) are rated quite "low," with proficiency levels near 2 (corresponding to "an ability to contribute"). The low ranking on the Societal Context (4.1) and the Business Context (4.2) were not clarified by reading respondents comments. Comments by respondents did specifically indicate that the low rankings on Implementing (4.5) and Operating (4.6) are indicative of the fact that these topics may be better learned on the job, or may be too domain-specific to teach at a university.

Type of Topic	Activity Based Proficiency Level						
		1 To have experienced or been exposed to	2 To be able to participate in and contribute to	3 To be able to understand and explain	4 To be skilled in the practice or implementation of		5 To be able to lead or innovate in
Cognitive	a b c	Recall Recall Recall	Describe/define Describe/define List/recognize/ state	Discuss/explain Interpret/translate Locate & classify/ identify	S1 S2 S3 S4 S5 E1 E2 E3 E4	Apply Choose/select Demonstrate/execute/practice Employ/use/utilize Prepare/schedule Analyze/examine/appraise Compare/discriminate/reconcile Elicit/question Experiment/test	formulate/construct formulate/construct formulate/construct formulate/construct synthesize/plan/create evaluate evaluate estimate evaluate
Cognitive Process		Recall	Describe/define	Discuss/explain		demonstrate/execute/practice	evaluate
Affective		Has been exposed to the idea of (exposed to)	Accepts the need for (accepts)	Engages in discussions regarding (discusses)		Demonstrates belief in (demonstrates)	Resolves conflicting issues in (resolves)

Table 8: Bloom Verb Patterns used in the CDIO Syllabus

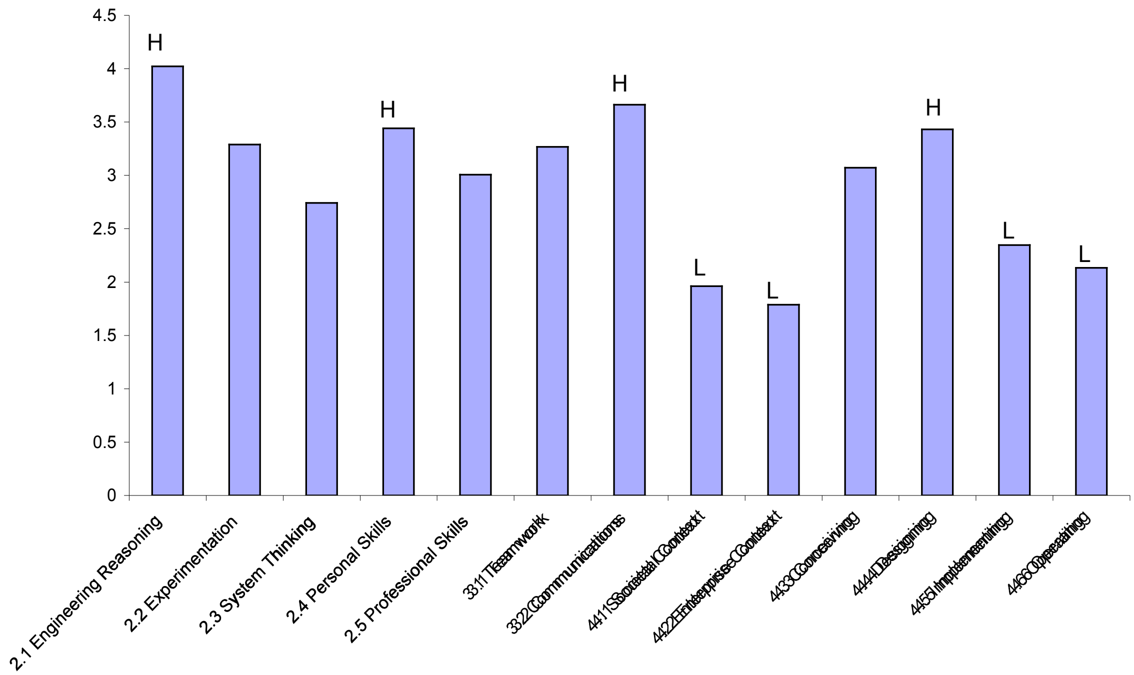

Figure 8: Mean proficiency levels for all groups combined. H and L indicate statistically high and low compared to the average proficiency.

3.3 Example: Establishing the Desired Level of Proficiency for Graduating MIT Engineers at the Syllabus Third Level

A second, separate survey was later conducted to gain more detailed insight into the proficiency expected in third-level (X.X.X) Syllabus attributes. Specifically, survey participants were asked to consider which third-level attributes required a higher (or lower) level of proficiency than its parent second level (X.X) topic. The task posed in this survey was:

> *For each X.X topic of sections 2 through 4 of the Syllabus, identify one (or two) of the X.X.X attributes for which you think that students should develop a relatively higher level of competence than the mean indicated for the corresponding X.X level topic. Likewise identify one (or two) attributes for which it is sufficient that students achieve a relatively lower level of competence.*

Survey participants were instructed to assign one plus (+) to indicate the one X.X.X attribute that they felt should be developed at one level higher in proficiency than the X.X section rating, using the activity-based scale (Table 6). Respondents were also instructed to assign one minus (-), indicating a skill to be developed at a relatively lower level of proficiency, in order to avoid changing the section's mean level of proficiency. In sections with five or more X.X.X attributes, respondents were allowed to assign a maximum of two pluses and two minuses. A refined version of the survey form, which combines the X.X and X.X.X surveys, is shown in Appendix H.

The 44 respondents were classified into two groups. The first group consisted of 26 MIT Department of Aeronautics and Astronautics faculty members, and the second consisted of 18 industry representatives. Of these industrial representatives, 11 were mid- to senior- career technical leaders of their enterprises. Seven additional respondents had significant life-long industry or government experience and, in addition, had some part-time or short-time affiliation with the MIT faculty. This latter group was asked to respond to the survey from the perspective of industry, and hence their responses were grouped with the industry representatives. (The survey responses were also analyzed with these seven respondents grouped with the faculty. No qualitative differences were found with the results reported below.)

Survey results were analyzed with two purposes in mind: 1) to identify those attributes for which there was significant disagreement in expected levels of proficiency between the two groups surveyed; and 2) to determine which third-level attributes survey participants felt required an increased or decreased level of proficiency relative to the level of proficiency assigned to the attribute's second level (X.X) topic.

In order to identify attributes for which there was disagreement between the MIT faculty and industry representatives, comparisons for significant differences were made. This was accomplished first by assigning a value of 1 to each plus response, and –1 to each minus response. A t-test was used to determine whether the difference of the means was significantly different than zero (□ < 0.05). A summary of all the data is given in Appendix F. The tests revealed that there was statistically significant disagreement for only 9 of the 67 third level attributes. Of those nine, shown in Figure 9, only four indicated what we

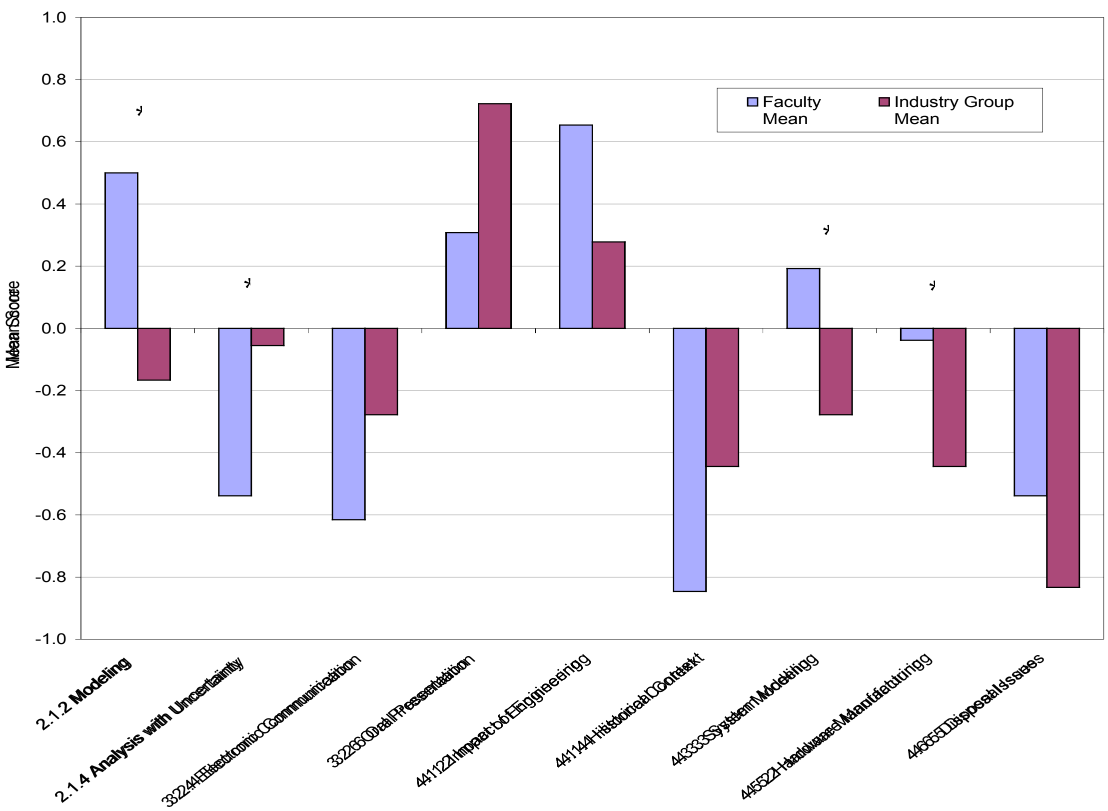

Figure 9: Third level syllabus attributes for which there was significant statistical disagreement between two survey groups. Asterisk signifies a qualitative disagreement.

consider real qualitative disagreements, and are marked with "RD". We judged that a real qualitative disagreement arose when one group thought the proficiency for an attribute should remain unchanged or decrease, while the other group thought it should increase (or vice versa). For the other five attributes for which there were statistically significant disagreements, the difference was only in the *amount* the proficiency should be increased (or decreased).

We believe these four items of qualitative disagreement do reveal some differences in values between the faculty and industry. For example, in section 2.1 Engineering Reasoning and Problem Solving, there were two disagreements. On attribute 2.1.2 Modeling, the faculty rated the desired proficiency as increased (relative to the mean for section 2.1), while the industry representatives rated it as unchanged. In contrast, in the same section, attribute 2.1.4 Analysis with Uncertainty, the faculty rated it as decreased, while industry rated it unchanged. This probably reflects a real difference in values: the faculty valuing modeling, while industry valuing the ability to deal with uncertainty. This difference over the value of modeling appeared again in section 4.3 Conceiving, where the faculty rated attribute 4.3.3, Modeling of System and Ensuring Goals can be Met, as unchanged, while industry rated it as decreased. The qualitative disagreement over attribute 4.5.2 Hardware Manufacturing is more difficult to understand, and is discussed below.

Opening up the interpretation of the data to allow for examination of trends, i.e. cases where 0.05 < □ < 0.15, reveals some further interesting biases. Industry has relatively more interest: in Formulating Hypotheses (2.2.1), in contrast with faculty interest in Experimental Inquiry (2.2.3); in Leadership (3.1.4), in contrast with faculty interest in Team Operation (3.1.2); in Setting System Goals and Requirements (4.3.1) and Defining Function, Concepts and Architecture (4.3.2), in contrast with faculty interest in Modeling (4.3.3); and in Hardware/Software Integration 4.5.4, in contrast with faculty interest in Hardware Manufacturing (4.5.2). On the other hand, the faculty has relatively more interest in Critical Thinking (2.4.4), in contrast with industry interest in Perseverance Flexibility (2.4.2).

Overall an image emerges that the faculty are slightly more interested in detailed, deterministic, and analytic processes, while industry is slightly more interested in higher level, more conceptual processes in the face of uncertainty. Based on the differences in culture between industry and academia, these minor differences are understandable. However the main conclusion of the two surveys is that there is overwhelming agreement between faculty and industry on the expected levels of student proficiency, and relatively few statistically significant, qualitatively important differences in opinion. Having noted these, we feel confident in using the mean of the faculty plus industry sample as a basis for setting the expected levels of expected proficiency for our students in the 67 third level X.X.X attributes of the CDIO Syllabus.

The results of the means of the survey data suggest that some adjustments to the levels of proficiency are required for third-level attributes in order to determine the *absolute* levels of proficiency expected of each student for every X.X.X level attribute. This was achieved by a relatively simple algorithm. The mean change in level of competence for each X.X.X attribute (obtained from the later more detailed survey) was added to the desired level of competence for the X.X level topic (obtained from the earlier survey) to obtain an interim average target level of proficiency for the X.X.X attribute. This sum was then rounded to the nearest integer, to obtain the final level of competence for the X.X.X level attribute. These interim and final levels of proficiency are listed in Table F3, and are indicated on the customized Syllabus of Appendix C in parenthesis for each X.X.X item, in the format (interim level/final level).

The net result of this two phase survey process was an overwhelming agreement among the interested stakeholders (alumni, faculty, and industry) on the average levels of proficiency expected of graduating engineers in each of the 67 third level attributes. The few and minor qualitative differences of opinion are understandable, and can be considered when deriving detailed learning objectives. At this point we have arrived at the desired goal - a complete, concise and consistent set of attributes desirable in a graduating engineer, with a consensus on the expected level of proficiency for each.