AC 2008-1508: PERSPECTIVES ON A FRESHMAN TREATMENT OF ELECTRONIC SYSTEMS

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Perspectives on a Freshman Treatment of Electronic Systems

Abstract.

The conventional approach to curriculum design is that students start with the basics of science and math and gradually progress towards a realistic integration of all their engineering skills in a senior capstone project. That approach is now challenged by changes in the assumed boundary conditions. Students no longer progress through the program in lock-step. Electronics applications have evolved far beyond the components level and many cross-disciplinary skills are needed. Finally, all students require a level of communications, team-working, trouble-shooting and representational skills that take a long time to mature so it is too late to wait till the senior year to introduce them. The paper presents a combined student-faculty appraisal of an alternative approach that covers these issues within the context of systems projects as the core of a 3-credit freshman class. The outcomes affirmed that a freshman group could analyze complex systems and that it is a good way to stimulate interest in electronics as a career.

A new approach to electronic systems

It is all too easy to take the steady evolution of electronics technology for granted. The 43-year-old rhythm of Moore's Law [1] continues to provide products with greater functionality at vastly lower cost and better reliability. It is the drumbeat of technology development that leads to more complex systems at affordable cost and thus to increased productivity and wider applications, not just in engineering but in every sector of business, government and professional services.

A change in University policy in 2004 introduced lower division programs for a campus that had previously relied exclusively on Community College transfers into upper division classes within a 2 + 2 structure. For the electronics program, the change was an opportunity to take a top-down systems view of the subject and therefore more accurately represent the applications that increasingly provide employment for the graduates. The planning process started with a statement of expectations and constraints. They are represented in figure 1.

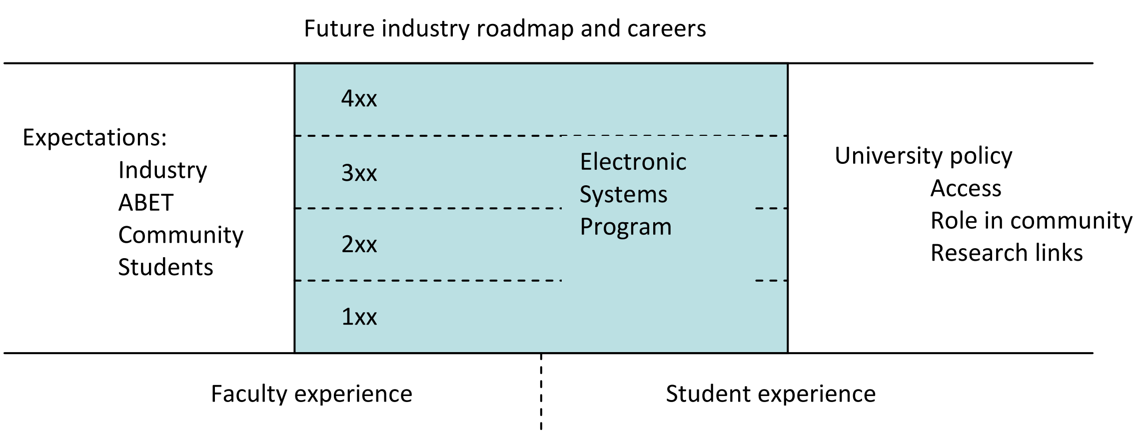

Figure 1. Program boundaries

The change to a systems viewpoint had strong support from two Industry Advisory Boards, alumni and working students. However, it posed an interesting dilemma for the freshman class. Should the class follow a traditional structure and provide the 'fundamentals' laced with reassurances that they would all be used in systems applications 'later'? The alternative was to start to explain systems on day one and then use an educational version of a Just-in-Time process to 'pull' the concepts, theory, tools and examples as they were required. Following advice and support from many external advisors, the second approach was chosen.

The freshman course in Electronic Systems started from scratch in 2005 with 12 students hastily recruited to test the concept. In 2006 and 2007, it achieved its designed format (3 SCH, one delivery per year) with 20 and 22 students respectively and the outcomes from these classes are the basis of this paper. Most of the students were registered for a Technology program but academic distinctions between engineering and technology are largely artificial in the systems context and when the subject and its applications are evolving rapidly.

This paper represents the outcome of a multi-faceted review of progress. The authors are:

1. A student from the Fall 2007 class.
2. A student from the Fall 2006 class
3. The graduate assistant for both classes (preparation and assignments)
4. The responsible faculty member.

Each author brings a different perspective of background experience to the shared experience of the course. However, the stimulus for the paper came from a realization that the outcomes for each author were very different from the expectations they had at the start of the course. The changes are summarized in figure 2.

Author	Starting expectations	Conclusions
1	Focus on individual activities and competencies. No personal component.	It was all about team-work to define the tasks then convince others of conclusions.
2	Conventional class with book, problem drills, tightly focused exams and little scope (or expectation) for individual creativity.	The case studies determined content and sequence but all the expected features of electronics were covered.
3	Mentor and advise students. Not much additional material to learn.	There was a lot to learn. Fortunately, experience allowed it to be done quickly.
4	Reasonably coherent class in terms of experience and basic skills.	Enormously diverse group in each year. Very few assumptions about common skills and understanding can be made.

Figure 2. Comparison of authors' expectations and outcomes.

Formulation of course goals and scope

The first - and largest - step was to recognize that job requirements have changed substantially over the past thirty years. The technology of the 1970s used discrete components and small ICs that were amenable to simple design and manual assembly of prototypes. That is still how most electronics is taught but in practice, that technology is long gone. Now, design and manufacture are highly specialized functions. The smallest building block is typically a printed circuit board that has the processing capability of a 1980 supercomputer. Electronics is no longer the monolithic subject it was once. It now has two distinct communities: the companies who produce the systems on ICs, packages and boards and the system integrators who combine boards with software and mechanical assemblies into larger systems. In the Phoenix area both categories are strongly represented and engineers from both types of company contribute strongly through Advisory Boards, guest speakers and student sponsorship. The top-down approach to systems makes it relatively easy to show how the work of the sub-system producers interacts with the system integrators.

Extended dialog with industry practitioners also showed that there has been almost a complete reversal between the skills that were once general and those considered specialized. The shifts are illustrated in figure 3.

Commonplace in 1978 – Specialized in 2008
Specify electronic functional behavior
Build and test prototypes
Construct mathematical models
Design and lay-out circuits
Use calculus

Specialized in 1978 – Commonplace in 2008
Integrate 'large' systems
Simulation (electrical and mechanical)
Interpret market requirements
Manage massive data sets
Use statistics

Figure 3. Changes in skills considered as specialist and commonplace

These changes in skill emphasis are profound and part of a continuing trend. They present a huge challenge to every academic group to reconcile a rapidly expanding body of knowledge and applications within a time-constrained program of study. It is not a new problem. Electrical engineering is the child of engineering and physics. Electronics has evolved as a further sub-set and the trend will continue. What makes these evolution paths difficult is that the parent subjects cannot be discarded because many disciplines have to be combined constructively to create a working system.

The ground-rules that have been used to create a working solution are:

- Maintain active dialogs with industry to determine trends and priorities.
- Demonstrate to students that it is not enough to know. They have to be able to apply that knowledge in a new application.
- New technology provides ever more powerful electronic building blocks to global markets. Competitiveness lies in being able to specify and exploit combinations of these building blocks quickly and accurately.
- Accept that change is endemic and therefore have a process to manage change.

The process used to manage change for course preparation, delivery and review is shown in figure 4.

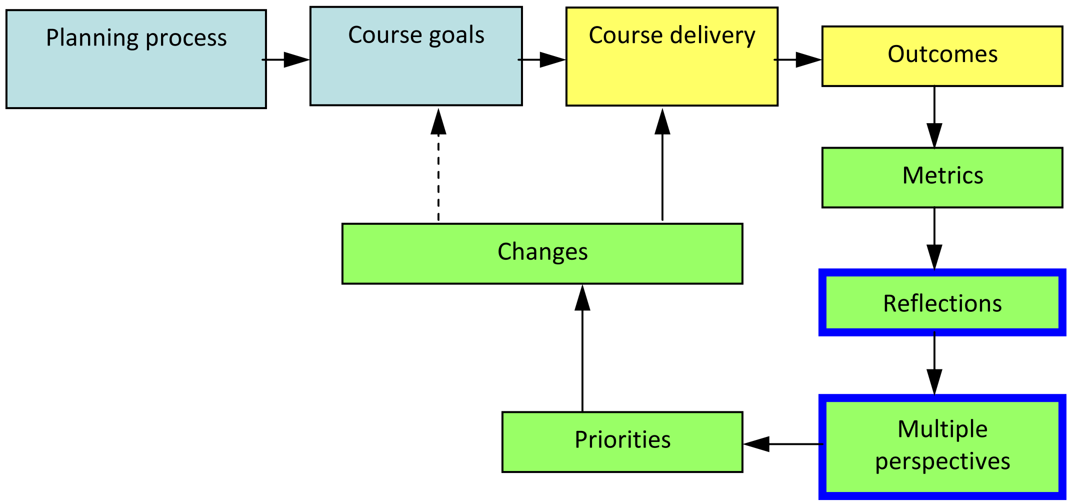

Figure 4. Course planning process.

The standard process of the Department has been adapted to provide more scope for reflections based on the advantages reported by other educators [2]. Soliciting multiple perspectives led directly to the combination of authors for this paper.

The planning process led to the following course objectives:

1. Introduce freshmen to each other and the subject
2. Initiate a positive educational experience at the University
3. Demonstrate student roles in the Department strategy
4. Provide a rationale for the future program of study
5. Show close coupling between the academic program and industry
6. Meet the performance criteria for courses defined by:
   - ABET
   - Essential skills
   - Effective learning practices
   - Match to other (later) courses
   - Range of incoming requirements and capabilities
   - Business trends and future technology
   - Department strategy

Freshman course structure

A freshman class presents some unique challenges. The students don't know each other or how the academic process works and they come from very diverse backgrounds. A reasonable starting point was therefore to build the course around a series of projects and to 'learn by doing'. The core activity was to deconstruct a number of large systems. This top-down approach is not common in the teaching environment (especially for freshmen) but it is a standard industry process so its introduction is appropriate.

By having the projects focus on systems, two additional advantages could be realized. During weekly reports by each project team, everyone in the class could see the common features and therefore ask more questions to probe operation and understanding. Second, the range of activities shown in figure 5 could be covered:

Figure 5. Project scope

The process to analyze system configurations largely followed the practices of INCOSE (International Council for System Engineering) [3]. It uses a series of simple steps that are very generally applicable:

1. Identify stakeholders and their expectations.
2. Quantify system requirements.
3. Determine the factors that determine success for any solution.
4. Break up the system into realizable modules.
   (even at this stage, no explicit technology need be specified)
5. Evaluate options for each module and their inter-dependencies.
6. Select a solution and specify the component sources and specs.

All functions are treated as black boxes. It reflects the way most electronic products are designed and circuit analysis is limited to interconnect questions of power, timing and drive capabilities.

The selection of systems for evaluation was a negotiated process made in week 3 of the semester. The students were provided with a list of viable topics and they used a caucus session to select which to adopt and the four or five participants in each. They could also suggest their own systems and one system each year was selected that way (*). The selections were:

	2006 Systems	**2007 Systems**
1	Car assembly line (*)	GPS and satellite imaging
2	A Las Vegas casino	Electric cars (*)
3	Campus power and data networks	A casino
4	Student registration system	Aircraft simulators
5		The One Laptop per Child project

Each week, a new facet of the system decomposition process was introduced and discussed in the context of the systems being studied. The main topics were:

- Block diagram representation
- System breakdown process
- Define major sub-systems
- Inputs and outputs for each block
- Management and control points
- System evolution history
- Analyze strengths, weaknesses, opportunities and threats
- Supply chain for building blocks
- System management, maintenance and change
- Measures of performance
- Future development options.

Each student was required to submit an electronic copy of four items on the day before class every week:

1. Designated preparation for the class. There is no book that treats the subject adequately so reading material and class slides were posted on Blackboard in advance. The preparation served to highlight individual problems.
2. Identify points that required explanation in class. This process was effective in raising common conceptual issues that required more class time.
3. A team project report. Each person took turns to be the weekly editor. Their duties were to allocate tasks to team members, collect the individual reports, submit a team report the day before class and make a progress presentation to the class.
4. A summative activity on the conclusions for that week's topic (submitted with the following week's preparation). Recognizing lessons learned is a vital systems skill.

Reports were returned within 12 hours so everyone was aware of the issues and priorities at the start of every class. This schedule was a substantial load for everyone. It became clear very quickly that it could only be accomplished if on-time delivery became a priority for everyone. It was a hard lesson for some but fortunately, there were enough working students to confirm that there are no exceptions in the workplace.

Outcomes – technical

At the start of each course, the class was given a set of technical questions to determine the range of experience in the group. The results for five typical questions were:

Question	% positive
Demonstrate use of Ohm's law	65
Use oscilloscope or DVM	45
Predict electron deflection in field	20
Calculate power dissipation in resistor	17
Quote energy in any battery	0

This doesn't mean that one third of the class had never heard of Ohm's law. It did mean that faced with a problem that required its use, only two out of three appreciated that was what they had to do. Given this range of capabilities, some students would have found an introductory course on circuits (say) very straightforward while some of their fellows would have been struggling. By comparison, examining high level systems was a new activity for everyone. For example, no one had ever thought of a casino as an electronic system but everyone knew the functions involved and could contribute to the higher level representation – specifically, the first three levels of system breakdown (requirements, criteria for success and major functional blocks). Reaching that stage in systems analysis was the main achievement of the course. The system analysis activities do not disguise the sad fact that there was a very wide range of capabilities to manage basic concepts. This still has to be addressed in later courses but at least the students see the need to learn more and appreciate where it may be applied.

Digging deeper into the options for each functional module presented many more challenges. All the applications were new and even the students with substantial background experience found it difficult to apply their knowledge in the new context. A good example concerned the formulation of a figure of merit for system performance. The idea of creating a simple equation or ratio presented real conceptual difficulties even when the expressions were restricted to linear and inverse functions. Everyone had learned math in the context that equations are always provided and the task is to insert numbers and find an answer. The idea that an equation could be a simple statement of the relationship between variables was totally new. This is a pity because that is how they will see equations used in most professional applications.

Freshman students are eager to describe systems features using the lay terms that anyone would use for such familiar subjects. However, the jump to use higher level representational tools was a big challenge. This is a difficult conceptual issue that is not explicitly taught in any other course. Electronics has to combine charge behavior with physical features and functional environments. To manage these interactions, there is a tool box with an array of abstract representational techniques. For one electronic function, we can use any or combinations of:

- Algebraic equations
- Boolean equations
- Differential equations
- VHDL statements
- SPICE statements
- A truth table
- A component circuit diagram
- A functional diagram
- A block diagram
- A response surface (eg: I as function of V)
- A simulation
- A plan view of a device
- A cross-section
- A process flow to create the components etc.

Systems-level analysis is a good context to introduce some of these diverse representational tools but the process takes time and it has to be part of a low-level sustained treatment that extends over many courses.

Outcomes – team activities

For many decades, Industry Advisory Boards across the country have regularly requested graduates with better team-working skills. For many decades, academic programs have been fixing the problem. A new lower division program was a great opportunity to start good habits early so team activities were built in as a central feature of the freshman course. Small team reviews provided a very effective way to analyze several systems at once. By having a lock-step sequence to develop the analysis process, each team could report its own findings every week and the others in the class could see that there were many common features in the descriptions of the different systems. This was an effective way to learn about other systems, achieve some sense of common progress and share experience both within and across teams. That's a big positive outcome. It was simple to organize and execute and it has worked well for all the combinations of systems that have been studied.

Successful outcomes, however, are strongly dependent on good communication within the team with each member delivering the agreed work on schedule. In each class there were 4 different types of student based on attitude and experience with roughly equal numbers of each type.

1. Those with substantial work experience (> 7 years) who knew the process and delivered consistently and competently.
2. Those with enough experience to know better but who hoped that the academic expectations of team activities were comfortably low. They eventually delivered.
3. The fast-learners who quickly picked up the positive interactions and decided this was a good way to learn and achieve good results.
4. The clueless. Sadly, they started slowly, looked on every assignment as an imposition and in the end, did not achieve a good grade.

Ideally, each project team would have been a blend of these behavior types. That was not possible so some groups performed better than others according to the combination of their capabilities and effort. This is not so different from an industry-based project where the team rarely has an ideal combination of personalities, experience and skills. In the 2005 and 2006 classes, team output was very unreliable so a more systematic measurement was instituted on 2007. The measure of success was that a team would reliably deliver progress reports 24 hours before their presentation to the class. The preparation process was set up on a weekly cycle:

- Nominate editor for the week (rotates round team members)
- Allocate preparation tasks for each person for the week's focus topic
- Submit individual reports to editor 48 hours before class
- Editor compiles group report and submits 24 hours before class
- TA reviews reports and returns with comments on same day
- Progress report to class.

The on-time submission rates are shown in figure 6.

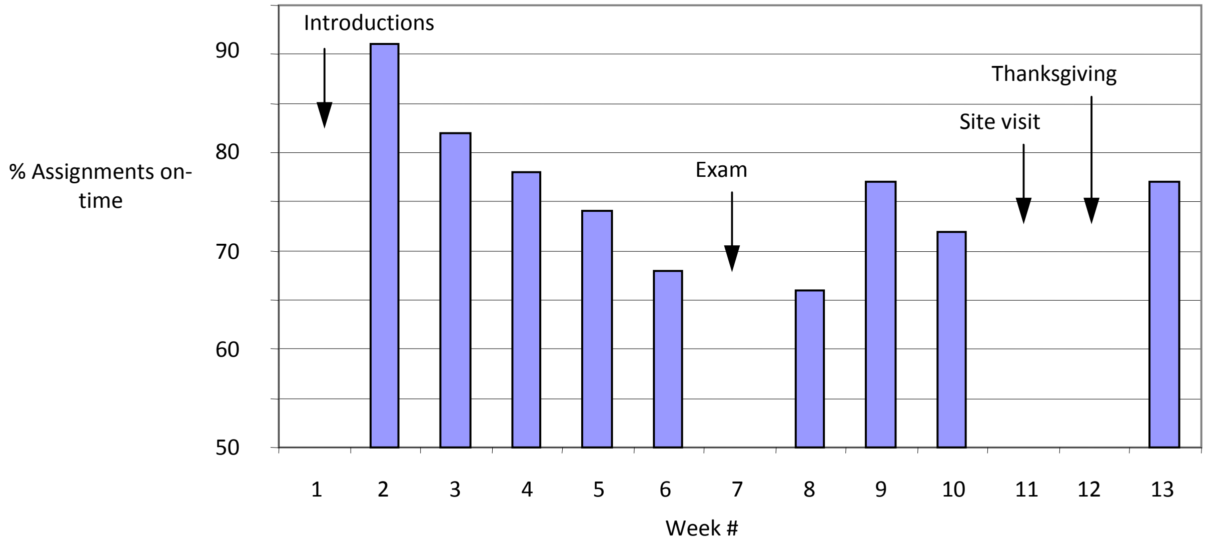

Figure 6. On-time preparation submission rates

Each week, there were 4 short reports (including the team progress) to be submitted 24 hours before the class and figure 6 shows the combined completion rate. There was some serious soul-searching in week 8 and the class went through a rudimentary root cause analysis process that determined the basic issue to be poor time management. Simple techniques were outlined such as subdividing the weekly deliverables into daily tasks. By that stage, each team member had experienced the frustration of being the weekly editor so there was more motivation too. The improvement to about 75% on-time completion seems to be the sort of figure to expect. The relationship between on-time delivery and grade is shown in figure 7.

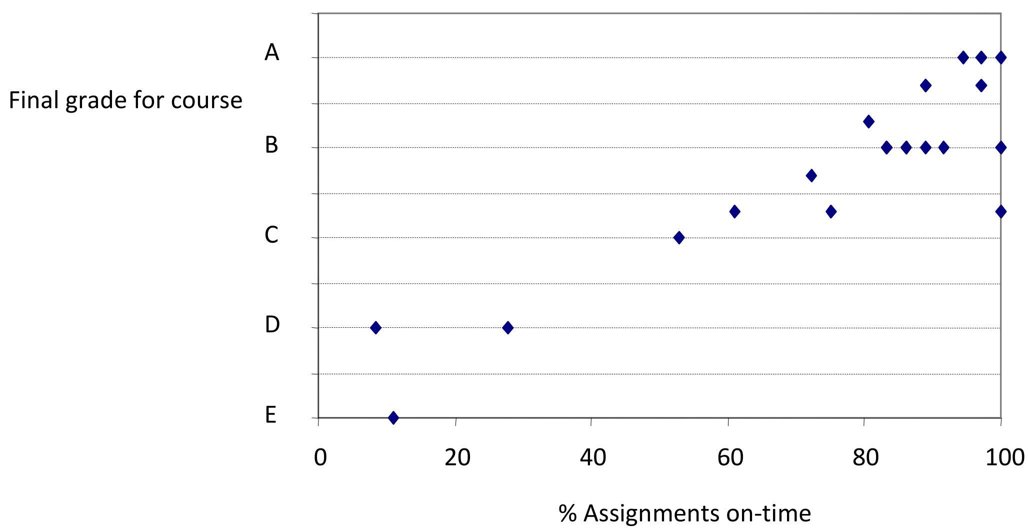

Figure 7: Correlation between final grade for course and on-time delivery of assignments

While there is nothing surprising in this outcome, it is useful in demonstrating to students that effort and due diligence usually bring rewards.

Outcomes – contemporary issues

Career planning became an indirect feature of the course. It was evident from all the projects that electronic systems will continue to change rapidly. It was also evident that there are two diverging career paths. As more functions are integrated on silicon, the specialist design, wafer fabrication, test and packaging functions are also concentrated in fewer international companies. Fortunately, there is a strong cluster of these companies in Arizona so that sector is a common employment route. System integration and support is a much newer but more rapidly growing career path. The course served to illustrate the opportunities and future program of study that would be required.

Information collection and its use is one of the most persistent and difficult contemporary issues faced by students and faculty alike. Gone are the days when the Library was the physical repository of reliable and validated scholarly knowledge. Although the course included an introduction to the Library and its operation, the instinct to start (and all too often, end) searches with Google is now an ingrained habit. Add fluency in the use of 'cut and paste' and there is a significant ethical issue. This problem will not go away so a general solution that can be applied to all courses was adopted. The first step is to show the limited utility of unverified information. Team discussions worked well for that. Second, provide positive incentives in the form of a component of the project report grade for good practice. Third, put good background information in its personal context of enhancing the credibility of the individual and the team output in the weekly team project presentations.

A new set of skills measures was introduced in 2007 following extensive discussion with the Industry Advisory Boards. Students were asked to rate their awareness and commitment to 64 different skills. A simple 3-level scoring system was used:

0 = not significant
1 = mentioned
2 = routinely used
3 = strongly emphasized

The averages for the 2007 class are shown in the tables in the Appendix. For comparison, the professor also rated the extent to which he believed the topics had been emphasized in the course. Finally, the Industry Advisory Board was asked to show the degree to which they thought each skill *should* be emphasized in the program as a whole. Given the different perceptions, there is a remarkably strong alignment between what the students think happened and what the IAB recommends should happen. There was no discernable correlation between the emphasis students put on the skills covered and their final grade.

Conclusions

It has been possible to organize the content of a freshman class using a top-down systems approach. It has enhanced student commitment to the process of self-directed study and provided a good starting point for later courses. It provided a useful overview of the ongoing evolution of the subject and the wide range of associated career options.

The following conclusions were written by the student authors of the paper.

The stress on team-work was strongly appreciated by students with work experience. It was harder for the others to accept the responsibility to collect and organize team reports on schedule but they eventually got the message. Each person discovered his or her strengths and weaknesses. Many students appreciated the opportunity to develop their own project style and excelled. Other students struggled. When the semester was completed, everyone emerged with a new set of problem solving tools, a better understanding of their personal abilities and business techniques that are applicable in industry. The traditional treatment of electronics had some validity in the past but times have changed. The subject is dynamic and students who are prepared to manage continuous change will have successful careers.

For some, the change of pace, style and content was shock therapy. There were no equations to memorize, plug in familiar numbers and use mechanically. The math that was used was not in textbooks and its validity had to be determined by the team. Problems rarely had single solutions and choices had to be made based on the applications context and critical thinking. Progress came through personal commitment and accountability. Not everyone took to the process at once. It was likened to "jumping from an airplane without knowing how to use the parachute". But everyone survived.

References

1. G E Moore, 'Cramming more components on to integrated circuits', Electronics, Vol 38, No 8, April 1965. Also at : http://download.intel.com/museum/Moores_Law/Articles-Press_Releases/Gordon_Moore_1965_Article.pdf
2. M Cama et al. 'Assessing reflective judgement thinking in undergraduate multidisciplinary teams'. Proc ASEE Annual Conference, Honolulu, 2007, # 1706.
3. Information about the activities of the International Council for Systems Engineers can be found at: http://www.incose.org.

Appendix : Skills rating by class, faculty and IAB

0 = not significant
1 = mentioned
2 = routinely used
3 = strongly emphasized

	Personal skills	Class	Faculty	IAB
1	Accountability for all outcomes	2.3	3	2.7
2	Time management	2.6	3	1.8
3	Team working	2.6	3	2.4
4	Vision for role beyond short term	2.1	2	2
5	Safe working - mindset	1.9	1	2.4
6	Ethical working	2.6	2	2.6
7	Accurate working	2.3	1	2.6
8	Available and responsive	2.3	3	2.4
9	Problem formulation	1.9	2	2.6
10	Problem solving	2.0	2	2.5
11	Able to prioritize	2.1	3	2.6
12	Develop effective solution strategies	2.0	2	2.2
13	Capability for life-long learning	2.0	3	2
14	Personal role in the global economy	1.6	1	1.1

	Communications	Class	Faculty	IAB
1	Understand requirements	2.4	3	2.4
2	Information selection & priority	1.9	2	2.1
3	Structure to suit time and audience	1.9	2	1.3
4	Effective format for presentation	2.5	2	1.7
5	Computer use - select software	1.8	2	1.9
6	Written fluency and precision	2.0	3	2.1
7	Effective technical voccabulary	1.6	2	2
8	Dialog in all settings	1.5	2	1.8
9	Effective listening	2.1	3	2.7
10	Understand and use body language	1.6	1	1.5
11	Demonstrate value added	1.7	2	2.3

	Career preparation	Class	Faculty	IAB
1	Baseline - have a relevant resume	1.6	1	2.2
2	Interview behaviors	1.8	1	2.6
3	Role to technologists in companies	2.0	2	1.6
4	Typical career paths	1.9	2	1.6
5	Know drivers for change - technical	1.9	2	2
6	Business drivers for change	2.0	2	1.7
7	Changes in skills needed	2.0	2	2.1
8	Know what you can (not) do well	2.0	2	2.1
9	Know what you (do not) like	2.1	2	1.8
10	Know when you (do not) work best	2.0	1	2
11	Know how hard you can(not) work	2.0	3	1.5
12	Work on the skills that don't change	1.7	2	1.7

Business issues		Class	Faculty	IAB
1	Professional culture in industry	2.0	2	1.6
2	Team working to deliver better	2.5	3	2.4
3	What drives technology	2.5	2	1.6
4	What is driven by technology	2.4	2	1.6
5	Global business operations	1.9	2	2
6	EHS processes & disciplines	1.7	1	2
7	Data structuring and effective use	1.9	3	2.4
8	How to specify requirements	1.9	2	2.2
9	Project management	2.3	2	2.3
10	Product life cycles	1.6	2	1.6
11	Advocacy for task outcomes	1.5	3	1.7
12	Quality processes	2.0	1	2.6
13	Root cause and field management	1.8	2	2.1
14	Validation & qualification	1.7	1	2.3
15	Costs of all operations	2.0	3	1.9
16	Supply chain	1.8	2	1.6
17	Legal & ethical issues	1.5	1	2

Systems topics		Class	Faculty	IAB
1	Electronic system architectures	1.9	3	2
2	Component design, function	1.9	1	1.9
3	Component selection	1.8	1	1.9
4	Design and realization of tools	1.7	2	2.1
5	Role and limitations from materials	1.7	2	2.2
6	How all parts of system are made	1.7	3	1.9
7	Technology roadmaps & bottlenecks	1.8	3	1.7
8	Data acquisition	1.6	2	2.7
9	The technical basis of safe practice	2.0	2	2.2
10	Design for "…. ility"	1.9	2	2.4