Session 1602

# Identifying Specific, Measurable "Skills" Perceived as Requisite for Graduating Aerospace Engineers

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## Introduction

In the last 15 years engineering educators and industry practitioners have attempted to identify what skills a graduating engineer needs to acquire during his/her undergraduate education in order to be successful at design activities. The efforts to identify these design skills are hampered by both the lack of precision in the terms used to describe design skills and by the broad and vague nature of the requests to improve these skills as part of an undergraduate curriculum. A research study conducted over five years by the first author compared the specific skills requirements provided by industry practitioners to the published perceptions of engineering educators regarding the desires of industry practitioners.[1] The resulting lists of skills from the two cohort groups (industry practitioners and engineering educators) were then compared to the observed behaviors of nine different semesters of a senior engineering design course.

## Summary of the Research

Purpose. At the onset of the study, the researcher observed that educators and practitioners were engaged in activities to improve the skills with which engineering students graduate. The efforts were found to be hampered by a lack of precision in the terms, a lack of metrics with which to measure student performance, and a lack of specific goals and requirements perceived as necessary for successful design activities. Numerous studies reviewed during the research have had stated goals and objectives; however, the goals lacked sufficient specificity to facilitate measuring success or failure.

The purpose of the study was to first identify a set of specific skills perceived as important by industry practitioners and to then compare this set of skills to those perceived by engineering educators as industry-desired. This would determine if the sets of skills given by the practitioners and the educators intersected. A further exploration compared the outcomes from the two cohort groups to the observed behaviors of students in a senior capstone engineering design course.

The requisite skills identified by this research were those deemed necessary by industry practitioners for successful participation in design activities resulting in complex systems. For this study, a "complex system" is one whose definition and development resulted from trades between contradictory needs and desires from diverse disciplines and information sources, and which exceeded the ability of three to five individuals or disciplines to accomplish. The characteristics of this design process were defined by inter-related outcomes between decisions made by people, between disciplines, and between components, where the reliability of the final product was critical.

Methodology. The following description of the methodology is by necessity, brief. A full discussion of the methodology is provided in Ref. 1. To obtain a complete understanding of the problem and data, a rigorous qualitative methodology was developed from generally accepted practices, employing cross-case observation and triangulation between all three cohort groups. The three groups were: 1) industry practitioners, 2) academic educators and industry academics, and 3) senior engineering students in an aeronautical and astronautical engineering program. "Academic educators" are individuals who did the majority of their work and research within an academic environment. "Industrial academics" are individuals employed by companies, but were primarily involved in academic and theoretical activities as opposed to production activities.

A literature survey provided perceptions about design skills from the *academic educator and industry academic* cohort. Academic research activities were well-documented and as such were viewed as the most comprehensive source of data from this group. The data were collected based on a methodology developed *a priori* to specifically identify perceived success or required skills from the literature.

The data were collected from the literature by reading selected texts and identifying single words or phrases describing successful design activities or activities negatively affecting success. The bibliography for this research contained 63 separate texts and is included in the thesis [1]. Sources were located using a formalized literature search methodology and key word search. Each concept was entered on a color-coded card, green for support and red for complaint or statements that no problem exists. The cards were then subjected to open coding to identify categories. After categories were generated, the concepts were subjected to axial coding to identify defined measurable characteristics responding to the expressed concerns. After three weeks, the researcher reviewed the cards with a fresh perspective to determine if any of the cards would fit better in other or new categories. With the exception of three cards, the sort remained unchanged. At this point the coding process and triangulation were considered complete.

There were 635 individual data points generated which were sorted into 49 specific characteristics and 9 broad categories. Frequency distributions were then prepared of the number of occurrences of each characteristic. The most important skills were identified as those with the greatest frequency of occurrence.

*Industry practitioners'* perceptions were developed using structured interviews, because these were not readily available through other data sources. The results of the literature review and the observational study were used to develop descriptive scenarios and a guide for the interviews. There was an opportunity to provide answers to open-ended questions and the responses were categorized based on similarities in key concepts and phrases. The advantage of the oral survey was the ability to discuss, explain, and request clarifying information to further elucidate the answers which was important in identifying skills.[2] The scenarios, a description of the types of information the interview would cover, and demographic questions were supplied to the participant prior to the interview. The interview guide questions were not supplied *a priori* so that the responses would be more extemporaneous and the participant would be less likely to script answers or put positive spin on the answers due to the presence of questions regarding negative experiences.

The tool was validated based on face validity (did it look right), an internal validation question, and the success in developing data that could be used in subsequent analyses. The objective was to obtain responses specific to the technical skills practitioners involved in design believed were necessary to achieve successful designs. These technical skills were independent of soft skills such as teamwork or communication skills, and independent of traditional formulaic activities, defined as analysis in this study (given a set of variables, what is the solution of a given equation). The respondents were also requested to describe an example from their experience in which the lack of possession or use of these skills resulted in some form of problem with the design, i.e. required excessive rework, product did not perform to the desired level, or a program was lost.

The participants were practitioners involved in design at companies with technically complex products or systems. The participants were not required to be traditionally educated engineers but were required to have been out of school and in career a minimum of five years. They had to be currently involved in design activities, managers who had performed engineering design activities in the past, or individuals currently leading design teams. Participants were selected based on input from academic and professional experts, chain sampling during the interviews and personal experience. A total of eleven practitioners participated in the survey. Each survey was a minimum of 60 minutes long.

Each of the participants was questioned on their own perceptions of what skills an individual participating in design activities needed to possess to be successful. The participants were not permitted to stop at broad or vague answers but were questioned until the answers were very specific. Extensive notes were taken throughout the interview using personal shorthand and including as many direct quotes as possible. The transcriptions were prepared as Microsoft© text files and imported into Atlas TI © hermeneutic software. The demographic information supplied by the participants was incorporated into each transcript. Using the coding function in Atlas TI©, each file was coded for demographic information: age, profession, gender, max degree, what degree(s), time in career, etc. This permitted confirming adequate representation in the sample set. The sample set was found to include at lease one representative in each of seven age brackets and representatives from B.S., M.S., and PhD.

The sample population included engineering and non-engineering majors, individuals who had attended school straight through their advanced degrees and those who had returned later. Job responsibilities included concept and preliminary design engineering functions, design and product support functions, researchers, and a “wise old elder”. Represented industries included electronics manufacturers, aerospace propulsion manufacturers, aerospace component manufacturers, airframe manufacturers, and space vehicle manufacturers. Both military and civilian products were represented. Respondents were responsible for writing code, for design components for manufacture, for supporting products and for providing research data.

After coding the transcripts were read and open-coded based on the text. Some codes were direct, for example the definitions and descriptions of design and of engineering. In other cases, particular success indicators were identified in a similar manner to that used during the literature survey. Whenever a statement was made suggesting the presence or lack of a success trait, it was coded such. In order to maintain the statement context, entire sentences were captured in the coding process as necessary.

After all of the data was coded, printouts of the coded data were prepared. The resulting dataset contained 171 individual data points. This supports the premise that a sample size of eleven was sufficient to obtain valid and reliable data on success skills. It is suggested that a larger sample size would have provided similar results, with larger frequency values. The most important skills were identified as those with the greatest frequency of occurrence.

*The student observations* were generated through participant observations of eight sessions of a senior Aeronautical and Astronautical Engineering design course at Purdue University between fall 2000 and spring 2004. To observe and explore the design thought process of the engineering students, the researcher acted as a technical resource for the students. This allowed the researcher to ask specific questions and aided the students in articulating their thought process during the design activity. This articulation facilitated making observations that were more complete than passive observation. The participation of the researcher was presented to the students by the instructor as similar to the participation of the teaching assistant. It was assumed this would minimize any bias in the student behavior due to the researcher's participation. Instructors were requested to comment on their perceptions of any differences in general behavior between classes that were observed and previous sessions that were not observed. Based on the instructors' responses, it was concluded that the researcher's presence in the class did not noticeably change the students' behaviors. This indicated it was reasonable to attribute the observations to the students' perceptions of the design activity as opposed to the presence of the researcher.

Although the students were limited by their practical design experience, the students were generally less than one semester from graduation and the results should have been directly applicable to the condition of engineers when they graduate.

## Research Results

During the analysis of the data it was found that the cohort groups' responses generally aggregated around the generally accepted human resource construct of knowledge, skills, and abilities. It was determined this construct was the most useful means of handling the data from the three cohort groups. This can be demonstrated graphically and is shown in Figure 2.

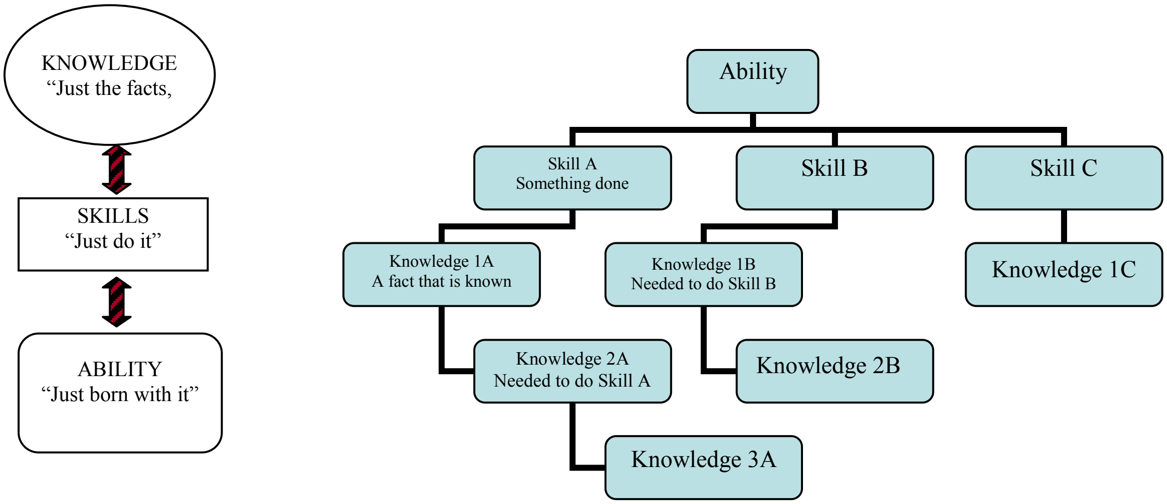

Figure 2 – Relationship between knowledge, skills, and abilities

Academic Educators. The results from the literature survey representing the engineering educators suggested that more than 60% of the characteristics presented as needed skills were actually broad descriptions of abilities. The concepts lacked precision or a means to assess success in demonstrating the concepts. It was concluded that this high-level data was part of the reason that there was a lack of defined goals and metrics and why there was not a clear answer to the question what needs to be taught.

The most frequently suggested concept was the ability to design. All of the major categories identified are presented in Table 1.

Table 1 - Major Categories from Literature Survey

| Major Category | No. Responses |
|---|---:|
| Having the ability to design | 168 |
| Take from theory to product (build something) | 119 |
| Intrinsic skills | 91 |
| Technical skills | 78 |
| Societal/environmental/business | 58 |
| Address "-ilitites" | 51 |
| Technical Interactions (people) | 41 |
| Risk and Safety | 22 |
| Profession familiarity | 7 |

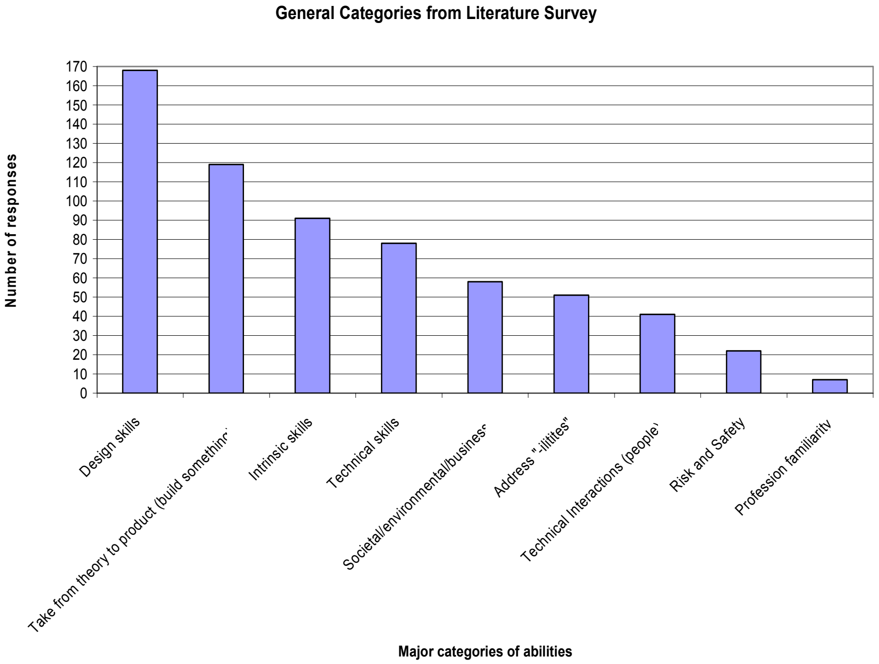

Figure 3: Frequency distribution of the general categories identified in literature

It was observed that some of the broad categories contained more sub-concepts than others. The ability to design contained 12 sub-categories of which three contained sub-concepts of their own resulting in a total of 19 sub-categories. The ability to deal with the –ilities, on the other hand, was comprised of only the single concept, dealing with the –ilities (i.e. maintainability, supportability, reliability). Because of this, care had to be taken when considering the most important skills or abilities based on frequency.

Based on the frequency distribution of the broad categories, the most important ability expressed in the literature was the ability to design, 168 responses, followed by the ability to take something from theory to a product (build something), 119 responses. The third category was possession of a variety of intrinsic skills with 91 responses. The ability to deal with the –ilities was sixth with only 58 responses. What is noteworthy was that while the –ilities could be further divided into specific topics, i.e. maintainability, supportability, etc., the concepts were all topic specific applications of the same basic ability. Under design, however, the sub-categories were related but were quite diverse; the customer, the tools, the activities, the process. Each of the sub-categories was not a different specific topic of the same concept, but rather entirely different concepts only related by their support of the ability to design. As a result, if only the frequency distributions of the broad categories were considered, important data was obscured. In order to minimize this obfuscation, the results from all of the individual concepts were evaluated.

It was also noted that measuring the presence or successful use of the most frequent concepts could not be easily done. The concepts lacked direct measures or specificity such that the presence of a concept could be answered with yes or no. For example, "Student shall be able to design." Did the student design, yes or no? What is the measure of the possession of this concept? To be useful, the educator needs to be able to directly measure the concept. The identified concepts did not provide sufficient specificity to permit direct measurement.

Industry Practitioners. The structured interviews of industry practitioners permitted discussions that prevented answers lacking specificity. The most important skill perceived as requisite by the industry practitioners was the ability to sketch, to render in three dimensions and to understand the renderings. The skill was not the use of computer graphics. One respondent specifically noted that the use of the "fancy toys" facilitated understanding the artifact. But he pointed out that the computer graphic tools did not help if the individual did not have a conceptual understanding of the spatial relationships described by the graphical output.

It was also noted that the skill of sketching was suggested to permit rapid communications between individuals. It was suggested that this was particularly useful between individuals from different disciplines. It was noted that a large amount of information can be easily and efficiently transmitted through a reasonable drawing, that it was not even necessary to be "an artist." Sketching also permitted visualization of inter-relations between components. Interferences, impacts, and ripple effects could be more easily identified through a spatial rendering of the artifact.

The use of spatial representations and sketches provided the first approximation of how things would be integrated. Furthermore, it provided an assessment of the ability of the participants to visualize the entire artifact or product. Not only could the entire artifact be visualized, but is also provided an assessment of the ability of the participants to internalize the entire product.

A second set of skills identified by the industry practitioners as being important was the recognition and understanding that formulas and theories represent or model actual behaviors and responses of tangible artifacts. This skill was not the same as a skill in manipulating formulas. The skill facilitated the understanding of how changes in one part of the design affected other parts of the design. A related skill was recognizing reasonable input and output from the formulas. The interview participants also noted that in using the formulas and theories, it was an important skill to recognize and use appropriate fidelity. As an example one participant asked "Just because a calculation could give three decimal places, did it make sense to use them?" Similarly one participant noted, "is a full stress analysis which utilizes resources necessary at a given point in the design, or was a rough paper analysis sufficient?"

The third skill expressed by the industry participants was the recognition of need and a willingness to obtain input. The skill involved admitting ignorance which it was admitted no one liked to do. But a successful engineer would put aside their fear of appearing ignorant and ask the question anyway. Furthermore, the skill required the individual to get help rather than ignoring an area of the design that was not understood. The skill provided an assessment of the ability to work collaboratively and to network. It also supported the development of a breadth of understanding. One participant noted that it was important to know a little bit about other disciplines in order to better understand how one's area of expertise impacts and interacts with other professionals' areas of expertise.

Other outcomes of the presented skills included the observation that the skills facilitated taking appropriate and educated risks. They facilitated producing a product which worked as desired with minimal rework or redesign. The skills helped in identifying the requirements and desires of the customer and then being responsive to them. The skills supported the ability to perform effective and appropriate trade studies.

To summarize, the desired skills desired by industry practitioners were:

- A willingness to use sketches and understanding 3-D renderings
- Recognition of a need for and an effort to obtain input
- Recognition and understanding of the reality that formulas represented and modeled
- Recognition of reasonable input and output from the formulas

A graphical representation of the frequency response of industry practitioners is shown in Table 2 and Figure 4.

Table 2: Results of Practitioner Interviews

| | | | |
|---|---|---|---|
| A | Know your discipline (Depth) | **7** | |
| | | 1 | Knowledge |
| | | 4 | Skills |
| | | 1 | Ability |
| | | 1 | Trait |
| | | | |
| B | Broad educational background | **9** | |
| B1 | Breadth | 8 | Skill |
| B2 | Use tools correctly | 1 | Ability |
| | | | |
| C | Ability to work cross-disciplinary | **69** | |
| C1 | Behaviors | ***47*** | |
| | Collaboration & Networking | 12 | Skill |
| | GIGO | 6 | Skill |
| | Ability to integrate | 5 | Ability |
| | Curious & Open-minded | 4 | Trait |
| | See beyond your part | 4 | Skill |
| | Understand impact on whole –s | 4 | Skill |
| | Understand impact on whole-a | 3 | Ability |
| | All knowledge is important-s | 3 | Skill |
| | Set priorities/KISS | 3 | Ability |
| | All knowledge is important-a | 2 | Trait |
| | Recognize needs | 1 | Skill |
| C2 | Professional Communications | ***19*** | |
| | Get input | 11 | Skill |
| | Be able to say I don't know/wrong | 5 | Skill |
| | Be open /communicate promptly | 2 | Skill |
| | Get feedback | 1 | Skill |
| C3 | Learn | ***3*** | |
| | | | |

| | | | |
|---|---|---|---|
| D | Visualization | **16** | |
| D1 | Sketch | 16 | Skill |
| | | | |
| E | Roles & Responsibilities | **16** | |
| E1 | Understanding yours and others | 6 | Knowledge |
| E5 | Correct decisiveness | 6 | Skill |
| E6 | Perfection & tenacity | 4 | Trait |
| | | | |
| F | Design | **18** | |
| F1 | Informed solutions | 8 | |
| | Trades | 4 | Skill |
| | Informed/appropriate risk taking | 3 | Skill |
| | Accurate root cause analysis | 1 | Skill |
| | Recognize the right answer | 5 | Skill |
| | Know how the world works | 3 | Knowledge |
| | Proactive doing/not reactive | 2 | Skill |
| | | | |
| | TQM | **21** | |
| | Innovative/willing to stretch | 6 | Skill |
| | Have a vision/goals | 5 | Ability |
| | Do your job, right, without fanfare | 3 | Skill |
| | Trusted | 2 | Trait |
| | Deal with pressure/critiques | 2 | Trait |
| | Creative | 2 | Trait |
| | Able to plan | 1 | Ability |

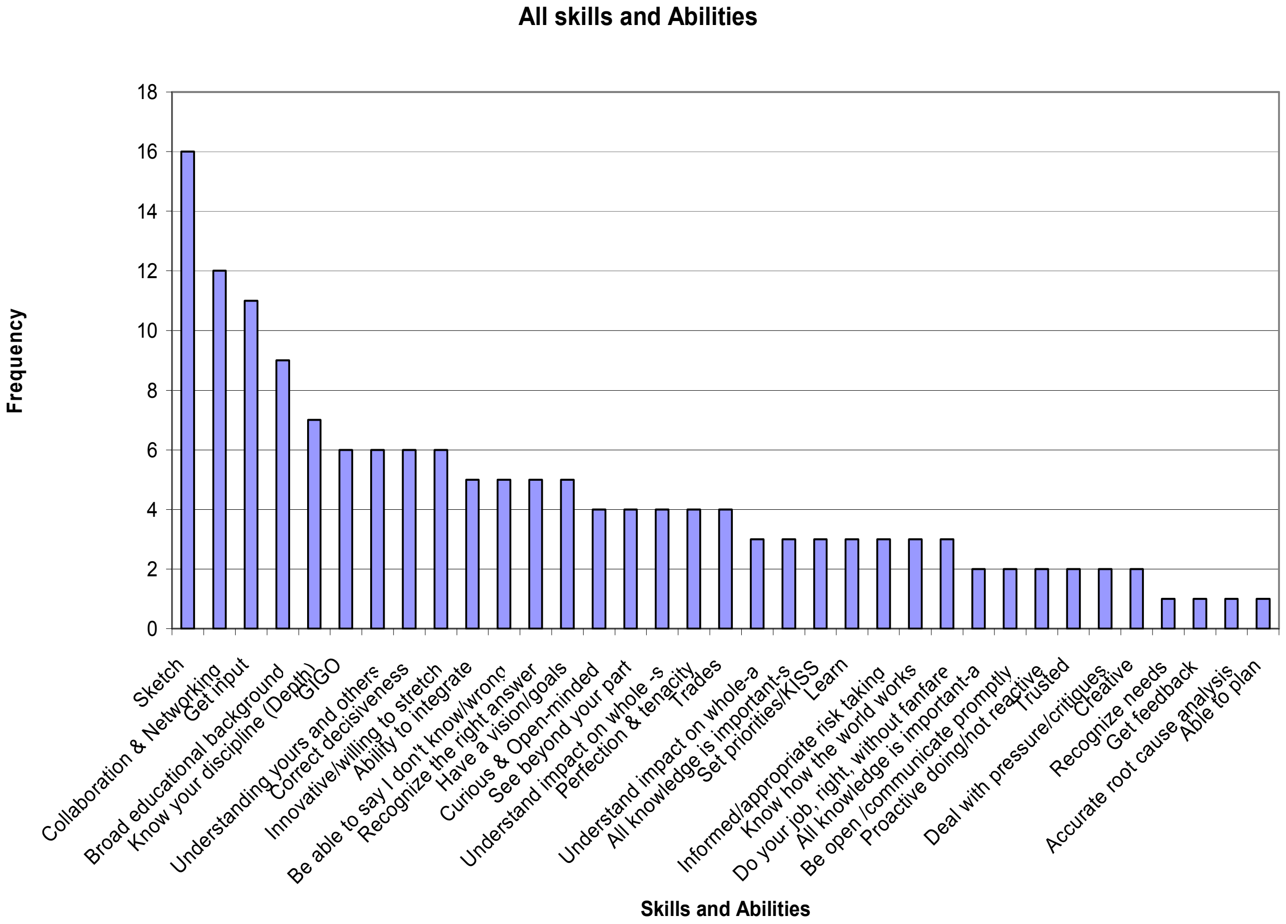

Figure 4: Frequency response for industry practitioners

<u>A Subtle Difference in Perceived Importance between the Educators and the Practitioners</u> The results from the academic literature suggested that the ability to design was an ultimate output goal of the academic experience. To that end research and academic activities have revolved around <u>how</u> to provide a better design experience as the purpose of education as opposed to providing education in <u>what</u> were the desired skills of industry supporting design. Industry practitioners suggested that possession of the presented, more fundamental skills would result in the ability to design, but that the ability to design was not the ultimate goal.

<u>Student Observations.</u> The senior capstone design course observed by the first author was taught by four different instructors, had a variety of projects and task emphases, had different class sizes, and used a variety of different instructional methodologies. Generally, the expressed goals of the course were to proceed through a design activity, including conceptual design, preliminary design, detail design, and system integration. The course required students to utilize knowledge from all of their courses and including knowledge and skills outside the scope of this study. In fall semesters the goal was to result in a flying aircraft, requiring students to also consider

manufacturing and flight test inputs. The spring semesters goal was to develop a complex paper design meeting a specific customer mission goal.

Originally it was planned to generate frequency distributions similar to those prepared for the academic researchers and the industry practitioners and compare the student behaviors directly to the identified skills. During the analysis of the data it was determined the data was not conducive to such analysis. The student behaviors were very diverse and did not break down into specific questions or execution of concepts which could be identified as skills. The evaluation of the student behaviors indicated a stronger correlation to knowledge-garnering activities. The students expressed questions and the desire to be instructed with what problems and solutions were being requested, and what facts they should be learning.

The observational data was reviewed for behaviors described by the most important concepts identified from the first two cohorts. The analysis of each class included a listing of key observations, graphical representations of several key behaviors identified in the literature survey and the practitioner interviews as being important, and an assessment of the design success. Observations were major points and did not include all of the observations of behaviors that were made. All of the observations were used in the analysis. For example the behaviors of a class that involved the concept of obtaining input were reviewed and the presence or absence of behaviors related to the concepts over the entire semester were subjectively rated. If there was the appearance of behaviors contained in the concept, it was subjectively rated as “1”. If there were no observances, the behavior was rated as “0”, and actively resisting or actively refusing to provide requested behaviors were rated as “-1”. An example of the rating is shown in Figure 1.

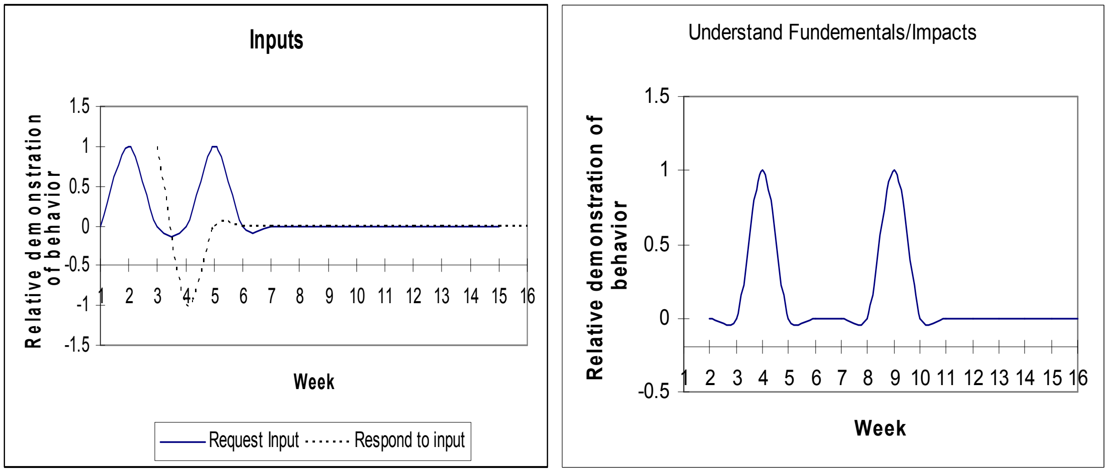

Figure 1 Example of subjective rating of an individual semester’s behaviors against an identified important skill

It was observed that no matter who taught the course, what the specific goal of the course was, or how the course was structured, the students behaved in generally similar manners. The students demonstrated a range of success in performing requested analysis activities. But with single isolated instances, the students did not demonstrate synthesis. The students would respond to specific requests for specific analyses when given the analysis to perform and the data to use, but did not demonstrate skills in selecting necessary analyses for a task or selection of data needed to do a task. The students could give back "facts" when asked, but did not demonstrate self-actualized recognition of the tasks needed to produce a design.

In the observed classes, the educators' goals were to provide students with an opportunity to obtain or practice many of the previously identified "design skills" focused upon a topic of interest to the students (e.g. an aircraft design for aerospace engineering students). The instructors attempt to provide an experience as much like an industry design setting as possible, while also providing a curriculum "capstone" that calls upon students to apply the technical knowledge obtained in previous courses to make design decisions. This often presents a dichotomy - students have been practicing well-formulated problem solving and analysis skills to gain technical knowledge, yet they are now being asked to use this on a problem that is poorly formulated. In fact, many of the design skills listed above speak to the abilities that a student needs to correctly formulate problems, whose solutions can be used to make design decisions.

With a consistent set of design skills identified, engineering educators may be able to assess which skills are being introduced to students for the first time during a senior capstone design course. Many of the design skills have been identified as important by the academic educator and the industry practitioner groups, yet they are only found in a small handful of courses. With well-defined, measurable design skills, it may be possible to interject these skills into other traditional courses (and there have been several efforts to do this). The skills can also provide a means to help balance the desire to provide a "near-real-world environment" for the design course with the idea that new design skills may also need to be taught and practiced for the first time during a senior design course.

## Recommendations

With the specific skills identified, educators can now identify what they expect a student to do. For example as part of the ability to design, the student can be expected to sketch a three view of a system, and to know what knowledge is necessary to do the task. For example the student is asked to sketch an outer mold line. The student must know what are the major components (wings, fuselage, empennage, landing gear), where the components generally go and why. The measures for the student are: did the student provide a sketch in a manner that is generally accepted, yes or no. Did the student include all the major components generally accepted as part of this sketch, yes or no. Did the student have the components placed in generally accepted positions or was able to provide a defendable reason for non-traditional placement, yes or no. The student can then be assessed on demonstrating (doing) a specific skill which has been connected to a specific outcome goal (demonstrating the ability to design) and selecting the knowledge and facts necessary to demonstrate the skill.

This exercise can be done using the identified skills from this research, or by performing a similar activity with local industry practitioners. The key is specificity.

*Identify specific metrics with which to assess student performance*. The faculty typically teaches knowledge and desires to assess ability but has few or no metrics for the student to respond. Currently academic educators and curriculum administrators are actively working to identify the specific abilities that satisfy their industry partners. However, in most cases observed in practice and in the literature, the activity encounters difficulty in assessment. This is because the abilities are generally broad and in most cases are not directly measurable.

The goal of possessing each ability must be specifically defined. From the goal, skills demonstrating the possession of the ability can be developed. The skills must be specific enough to use as assessment, i.e. did the student provide three sketches showing placement of all major components as defined in the course text? Yes or no. Figure 5 shows an example of the process and should not be considered complete.

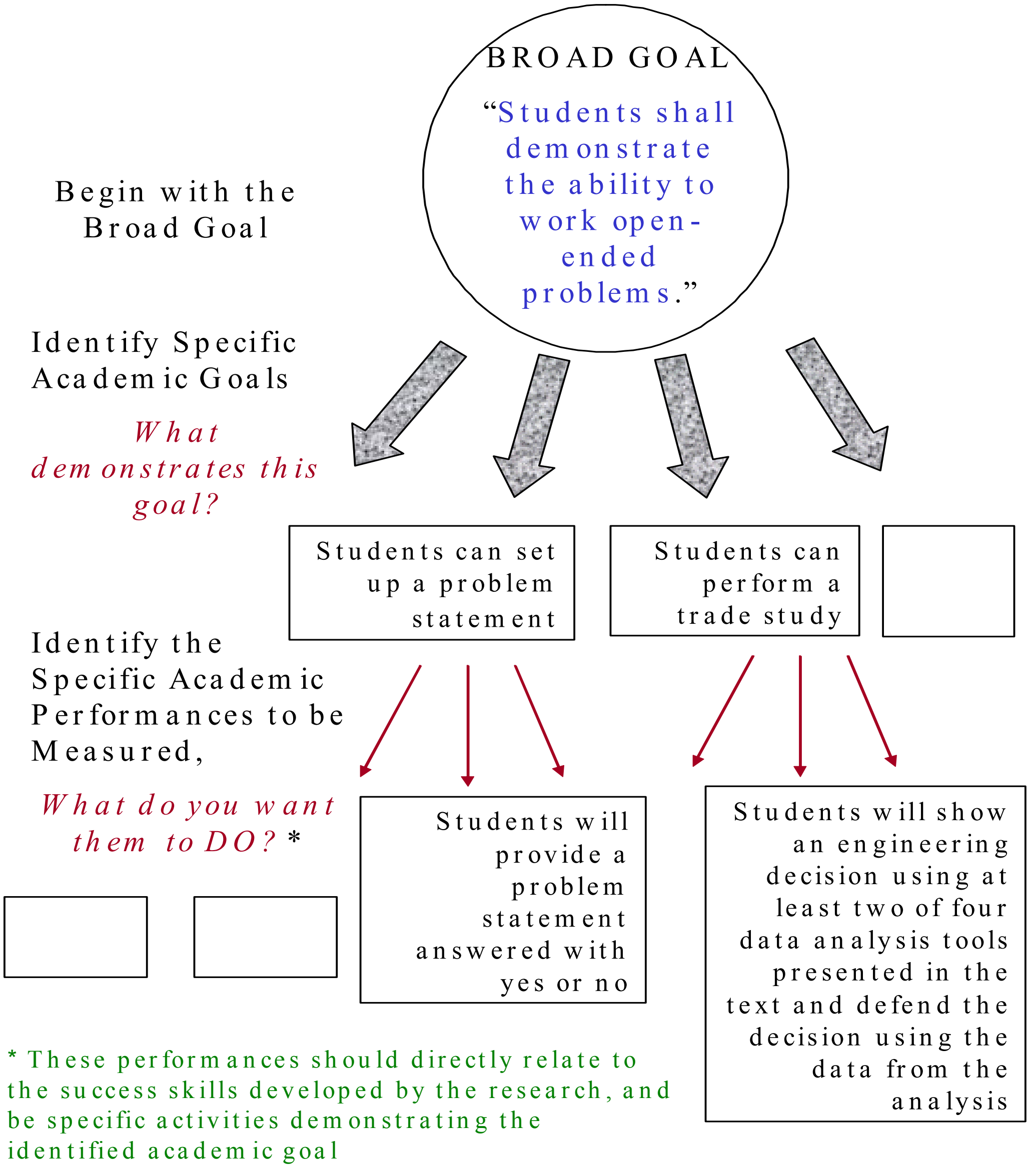

Figure 5: Example of the process of converting general goals to specific metrics

In the majority of the literature cases, academics were attempting to work with their industry partners to better identify what was expected from the graduates. However, in general the input from industry practitioners regarding desired skills was too vague. In the literature and anecdotally from advisory committee meetings, the discussions were allowed to remain very broad and esoteric. As a result the discussions hindered the development of goals and assessments.

For example, the concept "global visualization" does not provide educators with a specific goal or metrics with which to assess possession of a concept. The discussions need to result in specific skills that can be very clearly measured. "Students need to sketch their ideas more than once." "Students need to list the limitations and assumptions of computer code used to develop the output they use in their design project."

The challenge in these discussions was described by participants as those concepts which seem very specific but which are actually very vague because they can not be directly assessed. "Students should be able to demonstrate an ability to visualize the artifact." While at first glance this seems very specific, the broad interpretation is encountered when trying to assess a student's ability. What does visualize mean? Draw a cad model? Describe its behavior with a formulaic model? Build it out of foam and balsa? By identifying the specific goals, skills which utilize the students' knowledge and can be applied to an activity can also be identified. These activities can then be directly assessed.

*Connect the knowledge learned to the skills which apply the knowledge.* Based on the student observations and the literature survey, engineering students were predominately presented with isolated knowledge (facts) but the relationships to the skills that used the knowledge were not well presented. The students were taught theory in the absence of observation and then expected to make observations and recognize the applicable theory. In both the classroom observations and in literature reports, the students were observed to become frustrated by the lack of clear expectation from their performance in their senior design courses. There was a radical shift from the traditional knowledge garnering paradigm (tell me a fact, test whether I can give back the fact) to an expectation of demonstrating abilities.

The students need to be shown by demonstration of a behavior and then allowed to imitate the behaviors. The student should then demonstrate the behaviors as a decision in subsequent iterations. To be able to do this, it is necessary to have clear, measurable goals first (see recommendation one.)

In some of the case studies the projects were selected to permit multiple iterations, but the students did not have the behaviors specifically demonstrated to them once, then mimicked with the presenter before being expected to demonstrate the behavior on their own. In other cases, the lack of defined expectations left the students without a clear understanding of what they were expected to demonstrate. In other case studies the projects selected for the classes were so large or allowed to become so complex there was no opportunity for multiple iterations, eliminating the opportunity for the student to see, mimic and then demonstrate behaviors. By the time the student determined what the behaviors might need to be, there was no further opportunity to attempt the behavior.

*Keep design activities very specific.* A review of the case studies and the classroom observations indicated that the design projects were too large to permit students adequate time to iterate through a design process. This not only did not reinforce desired behaviors, i.e. obtaining input, dealing with poorly understood areas, networking and collaboration, but it also reinforced undesirable behaviors, i.e. isolationism, lack of dealing with interactions, lack of appropriate fidelity in analyses, lack of trade studies. Furthermore, the complexity of the project resulted in students having insufficient time to develop an in depth understanding of any one topic at the expense of a very esoteric exposure to a breadth of concepts.

*Specifically identify and publish academic goals for the class.* Ironically, recent articles on assessment, for example papers from session F1B and F4B of the Proceedings of the 32nd ASEE/IEEE Frontiers in Education conference, November, 2002, go into great detail on the importance of having well communicated goals and expectations, and clearly laid out metrics and grading requirements. These same articles do not provide insight into what the metrics should be, even through the generally expressed goals and objectives are reasonably consistent across authors and researchers. The authors stress the use of the ABET criteria in developing the goals but the goals leave development of performance standards and metrics to the discretion of an institution. Specific requirements should be those whose execution can be measured (did the student give all four examples, yes or no? Could the student provide and defend a prediction based on the input using generally accepted principles, yes or no?) and which demonstrate meeting the specified goal. To have clear measurable metrics, it is also necessary to be clear on what specific behaviors demonstrate the goal. From these metrics, educators can also assess shortcomings and improvements in the classroom which were not possible with the broad, non-specific metrics. Specific requirements facilitate reducing student frustration with educational inconsistencies, and it facilitates grading by the educators.

“Design a remote control aircraft that can carry a camera” is an insufficient academic expectation for the students. The course should have a published syllabus with specific academic expectations at specific points in the semester. For example “provide a three view sketch at week one, five and nine. A grade will be given based on inclusion of all appropriate information as demonstrated in example 1 in the class notes” “Analyze the airflow over a 3-D airfoil, fully documenting the assumptions and limitations of the analysis tool and explaining how difference in input effect airfoil performance. A grade will be given based on the clarity of the explanation and inclusion of all requested concepts. See the class notes, page 5 for an example of a sufficient analysis.” The assignments should be succinct enough to demonstrate a specific goal without excessive time commitments by the instructor. By having the specific goals of the each assignment connected to the desired outcomes of the course, students can be asked to use very specific skills in very brief assignments.

*Have professional expectations of the students.* Instructors should demonstrate and expect professional behavior from the students. Students should be expected to show up on time, stay through the period, turn in assignments on time and show respect for visitors, professors and each other. Based on the literature survey and observations, a desire to treat students as adults has had the result of not requiring professional behavior. Students in turn did not know how to behave professionally when they interfaced with customers during design activities [3].

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[1] Thom, M.A. (2004). Perceptions *of practitioners and engineering educators and students regarding requisite skills for effective design of complex systems.* (Master's Thesis, Purdue University, 2004).

[2] Sekaran, U. (2000). *Research Methods for Business* (3rd ed.) (p 250), New York: John Wiley and Sons, Inc.

[3] Horenstein, M., Ruane, M. (2002, Nov.) Teaching social awareness through the senior capstone experience, Session S3D. *Presented at 32nd ASEE/IEEE Frontiers in Education Conference, Nov. 6-9, 2002, Boston, MA.*

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