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Engineering Design Education - Core Competencies

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In the past, it was very common for students to come to the university to study engineering with basic design and build skills acquired through hands-on experiences acquired through play with friends, work on farms, work on cars and general tinkering. Engineering students were predominantly white males and eager to dive into design projects that could call upon skills in spatial reasoning, problem solving, working with others, and more. Currently, students who enter the university to study engineering are more diverse in race, gender, and background. The pervasiveness of computers, computer gaming, and social networking has also shifted the competencies of most incoming students. Many incoming students do not have the background and skills required to succeed in the design of solutions to engineering problems. This paper suggests there is a need to identify and better understand the basic set of core competencies that, if possessed by the student, would assure their success in the engineering education environment as well as in industry upon graduation. This paper identifies industry lists and critiques and academic efforts to catalogue core competencies and gives an example of one core competency, after being identified as being weak and remediated, showed dramatically improved student performance.

Nomenclature

ABET = Accreditation Board for Engineering and Technology (ABET, Inc.)
ENGAGE = Engaging Students in Engineering
PSVT:R = Purdue Spatial Visualization Test:Rotations (diagnostics test)
WEPAN = Women in Engineering Program Advocates Network

I. Introduction

IN In the past, students have come to the university to study engineering with basic design skills acquired through play with friends, work on farms, and general tinkering. Engineering students were predominantly white males and had backgrounds conducive to diving into engineering design education. Currently, students who enter the university to study engineering are more diverse in race, gender, and background. The pervasiveness of computers, computer gaming, and social networking has also shifted the competencies of most incoming students. At this point in time, many incoming students do not have the core competencies required to be successful in their engineering design education. How to remedy this situation has been the focus of discussion for some time. One must wonder … are there several core competencies, if possessed by the student, that would assure success in a design education environment and ultimately as a practicing engineer?

Consider spatial visualization for example. Research[1] has shown roughly 10% of entering engineering students taking a basic spatial visualization skill test[2] do not have a minimal level of competency which is crucial to success in engineering design. It has also been shown that with a semester long once a week course to teach students basic spatial visualization skills, students can acquire this core competency. At the conclusion of this course, students' skills have improved to the point where they score close to the average of the general population of engineering students. Research has also noted that women who initially scored the lowest on the pre-test show the most gain in

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the post-test after taking the course. Addressing this area of weakness early has saved countless hours of special help sessions, long hours and frustration for students, and unfortunate departures from engineering by students who felt they simply did not have the ability to succeed.

This example points to just one core competency. We conjecture, there are likely several core competencies that form a foundation that are needed for success and if assessed prior to starting an engineering design curriculum to discover deficiencies, can be addressed with simple interventions. This paper attempts to catalogue and illuminate the core competencies needed for success in engineering design at the university and in industry practice. It also reveals disconnects between industry needs and current engineering education discovered in the research in engineering education literature and in industry observations. It also discusses, through an example, assessment methods as well as corrective actions to assure engineering students have these core competencies critical to being successful in engineering design.

II. Background

* What differentiates the expert practicing engineer from the novice? There are a number of factors that can contribute to this difference but many of these can be tied to a single item: experience. The experiences of going through multiple iterations of a technical solution to a problem, making compromises, working with customers and colleagues, and a host of other events lead to the advances and setbacks that help shape the effectiveness of a practicing professional engineer. As C.S. Lewis once noted, “experience is a brutal teacher, but you learn. My God, do you learn.” Employers of engineering graduates, both in industry and the government, have made claims that though the engineers being produced in the present engineering education system are strong in technical skill, they are still lacking in certain professional skills that make them not fully ready to practice engineering in the current fast paced, interconnected world. Addressing this disconnect in student preparation is of near term concern as the Baby Boom generation of engineers retires, leaving a void in experience and knowledge that must be filled in part by new engineering graduates. How did this come about and what is the gap between those that produce engineering graduates (the university system) and those that hire the great majority of engineers (industry and the government)? The following discussion explores this disconnect.

Engineering, as it is with many professions, is a profession that is in a constant state of flux as it responds the constantly changing and evolving demands of the society in which it functions. This constant evolution is in part manifested in the way engineers are trained. In the United States, this change has led to substantial shifts in the focus areas of the engineering curricula over the decades.

A review of the literature indicates a cultural difference between industry and academia with students/graduates caught in the middle having to negotiate both ends of the spectrum. The following section discusses in detail the specifics of the gap.

A. Specifics of the industry and academia gap in student preparation needs

In order to best understand why industry feels engineers being produced today are not fully meeting their needs, a discussion of the traits desired by industry is in order. Various entities in academia, industry, the government and other organizations have developed and published “desired traits/attributes of a graduating engineer” lists. In this discussion, lists from non-academic entities will be examined in order to best represent the desires of government and industry for their new hires. Tables 1 and 2 are engineer desired traits/skills lists from the National Association of Colleges and Employers (NACE), the Boeing Corporation, the International Engineering Alliance, former Boeing CEO Phil Condit, National Academy of Engineering and Leland Nicolai and Eric Schrock of Lockheed Martin Aeronautics Company[5-9]. Though most of these entities have dealings with aerospace engineering, all but the necessary skills suggested by Nicolai and Schrock[10] are generic traits that could be applied in any field of engineering. Early versions of the Boeing Corporation traits influenced the ABET Criterion 3 Program Outcomes[11,12]. The Nicolai and Schrock skills in Table 2 are particular to design and represent the types of skills and design tasks that new engineers need to design on an industry level and should be familiar with before leaving the university.

An examination of each of these desired traits and attributes lists reveals that there a number of common entities among them. These include communication, teamwork and collaboration, understanding and applying knowledge, continuous learning, ethics, understanding the context of engineering practice, flexibility, and critical and creative thinking. Though a number of the traits could be considered technical skills such as computer and analytical skills, a

[*] Excerpted and slightly edited from a dissertation in progress[3]. The goal of the research is to alter how engineering design is taught so that designers emerge with core competencies more closely aligned with industry needs[4].

large number of the traits and attributes fall under the heading of professional skills that when combined with the technical skills make for an effective practicing engineer in today's world[13].

Table 1

National Association of Colleges and Employers	Boeing	Phil Condit (Boeing)	International Engineering Alliance	National Academy of Engineering
Qualities/Skills (In order)	*Attributes*	*Attributes*	*Competency*	*Attributes*
• Communication skills • Honesty/integrity • Interpersonal skills • Motivation/initiative • Strong work ethic • Teamwork skills • Analytical skills • Flexibility/adaptability • Computer skills • Detail oriented • Leadership skills • Organizational skills • Self-confidence • Friendly/outgoing personality • Tactfulness • Well mannered/polite • Creativity • GPA • Entrepreneurial skills/risk-taker • Sense of humor	• A good understanding of engineering science fundamentals. • A good understanding of design and manufacturing processes. • A multi-disciplinary, systems perspective. • A basic understanding of the context in which engineering is practiced. • Good communication skills. • High ethical standards. • An ability to think both critically and creatively - independently and cooperatively. • Flexibility. The ability and self-confidence to adapt to rapid or major change. • Curiosity and a desire to learn for life. • A profound understanding of the importance of teamwork.	• Collaboration • Communication • Cost Awareness • Continuous Learning	• Comprehend & apply universal knowledge • Comprehend & apply local knowledge • Problem Analysis • Design & development of solutions • Evaluation • Protection of Society • Legal and regulatory • Ethics • Manage engineering activities • Communication • Lifelong learning • Judgment • Responsibility for decisions	• Strong Analytical Skills • Practical Ingenuity • Creativity • Communication • Business and Management Skills • Leadership • High Ethical Standards • Professionalism • Dynamism, Agility, Resilience, Flexibility • Lifelong Learner

Table 2

Desired Skills of an Aerospace Aircraft Design Engineer

- Analyzing requirements
- Developing a strategy to address the requirements
- Executing initial sizing and developing preliminary sketches
- Making tough decisions among different configuration choices
- Substantiating the choices with engineering analysis
- Developing configuration drawings
- Executing vehicle sizing to constraints
- Performing trade studies
- Making design decisions and executing them
- Documenting and finalizing the design concept

Note. Adapted from *What would industry like to see covered in the senior capstone design course?*, by L. Nicolai, and E. Schrock, 2010, Paper presented at the 10th AIAA Aviation Technology, Integration, and Operations (ATIO) Conference. Copyright 2010 by AIAA.

A review of the literature also reveals a number of papers[14-26] where employers specifically state areas where engineering graduates could have improved preparation for real world practice and these are shown in Tables 3a through 3d. The table contains the article name and journal or proceedings title, the publication year of the article, the phrasing used to indicate an improvement is needed in the engineering graduate and the exact skill or attribute mentioned by the employer as needing improvement. The articles come from a review of engineering education literature examining specifically papers that discuss the desired traits for practicing engineers and papers mentioning shortcomings in engineering graduates. Most articles come from major journals in engineering education such as the *Journal of Engineering Education*, *the International Journal of Engineering Education* and the *Australasian Journal of Engineering Education*. The articles chosen for this table were limited to those published after 2001 in order to account for the changes enacted as a result of ABET EC2000.

Table 3a

Industry/Academia disconnect specifics found in the literature

Year	2011	2011	2011
Author	Charyton, Jagacinski, Merril, Clifton, DeDios	Korte	Tryggvason, Apelian
Article Title	Assessing Creative Engineering Design	How Newcomers Learn the Social Norms of an Organization: A Case Study of the Socialization of Newly Hired Engineers	Meeting New Challenges: Transforming Engineering Education
Source Title	Journal of Engineering Education	Human Resources Development Quarterly	*Shaping Our World: Engineering Education for the 21st Century*
Phrase Indicating Disconnect	"today's engineers need to be more ..."	"Preliminary investigation of the experiences of engineers starting a new job that the most troublesome experience was learning how to work within the social systems of the organization."	"...as skill becomes a commodity and routine engineering services are available from low cost providers that can be located anywhere in the world, engineering education has to add value beyond just teaching skills. It seems reasonably safe to expect that the added value will include an extensive exposure to..."
Listed Area of Disconnect	creativity, innovation	organizational socilization	innovation, entrepreurship, communication

Table 3b
Industry/Academia disconnect specifics found in the literature

Year	2011	2011	2011
Author	Yadav, Subedi, Lundberg, Bunting	Niewoehner	Dunsmore, Turns, Yellin
Article Title	Problem-based Learning in Electrical Engineering	CDIO Syllabus Survey: Systems Engineering an Engineering Education for Government	Looking Toward the Real World: Student Conceptions of Engineering
Source Title	Journal of Engineering Education	Proceedings of the 7th International CDIO Conference	Journal of Engineering Education
Phrase Indicating Disconnect	"...today's engineers lack these skills and have difficulty applying their fundamental knowledge to problems of practice"	"...accreditors charged U.S. engineering schools with re-orienting their programs to ensure student competency in traditional engineering science subjects...intended reforms largely stalled short of the original goal due in part to a lack of clear stakeholder direction and engagement..."	"Among the specific concerns voiced has been the need to prepare engineering students for the changing working world of engineering. Among the dimensions of preparation often mentioned are enhancing…"
Listed Area of Disconnect	dealing with uncertainty, teams, communication, problem solving	communications, teamwork	communications skills, dealing with the globalizing economy

Table 3c

Industry/Academia disconnect specifics found in the literature

Year	2011	2010	2010
Author	Borrego, Bernhard	Van Treuren	Dees
Article Title	Emergence of Engineering Education Research	Never too Old to Learn: A Report on the Experiences in Boeing's Welliver Faculty Fellowship Program	An Industry Perspective on Future Needs for Aircraft Design Education
Source Title	Journal of Engineering Education	ASEE 2010 Annual Conference and Exposition	10th AIAA Aviation Technology, Integration, and Operations (ATIO) Conference
Phrase Indicating Disconnect	"…survey of relevant literature on student learning outcomes shows that graduates from university courses lack important skills…", "…students do not have the requisite ability to…", "…workplace performances of engineering graduates have been a constant subject of criticism"	"Most engineering programs do not talk about topics such as…"	"Some of these attributes are covered in typical aerospace engineering undergraduate curricula, but many are not... several could be better emphasized in coursework"
Listed Area of Disconnect	communication, decision making, problem solving, leadership, emotional intelligence, social ethics, work with people from different backgrounds	global market, lean engineering	project management, aircraft design & integration, practical design knowledge, communication, presentation and teaming skills, systems integration, business basics

Table 3d

Industry/Academia disconnect specifics found in the literature

Year	2007	2007	2006	2001
Author	Boyette	Walther, Radcliffe	Lattuca, Strauss, Volkwein	Gorman et al
Article Title	Viewpoint-The Problems of Teaching Practical Design To Today's Engineering Students-the Agricultural Engineering Experience	The competence dilemma in engineering education:Moving beyond simple graduate attribute mapping	Getting in Sync: Faculty and Employer Perceptions from the EC200	Transforming the Engineering Curriculum: Lessons Learned from a Summer at Boeing
Source Title	International Journal of Engineering Education	Australasian Journal of Engineering Education	International Journal of Engineering Education	Journal of Engineering Education
Phrase Indicating Disconnect	"Employers complain bitterly that recent graduates …" are not able to...	"...engineering graduates have deficiencies with respect to crucial job skills such as…"	"… are assessed as least adequate by 3 out of 4 employers	"Each Welliver Fellow developed individual ideas about what improvements could be made based on their experience at Boeing ."
Listed Area of Disconnect	ability to apply engineering education to real world problems	problem-solving, communication, entrpreneurship, dealing with complex interactions	teamwork, commnucation skills, understanding of the organizational, cultural, and environmental contexts and constraints of one's work	engineering fundamentals, communication, design & manufacturing, continuous learning

As shown in the above tables, there are skills/traits/core competencies that reoccur across the literature from the 2001 time frame forward as well as shortcomings or disconnects identified in our educational approach to filling these competencies. We also find a fair amount of overlap with the employer desired traits and attributes identified in the literature. The skills needing improvement include communication, working in teams, lifelong learning, applying engineering knowledge to solve problems, decision making, organizational socialization, creativity and innovation, entrepreneurship, working in the global economy, understanding of design and manufacturing, ethics, leadership and emotional intelligence. The three most mentioned items are communication, working in teams, and applying engineering knowledge to solve problems.

III. Harvey Mudd Design Workshop Core Competencies

In addition to the areas of disconnect between industry desires and the educational experience of engineers they hire, there was a recent weigh in on this issue from engineering design education thought leaders from across the nation at the eighth Mudd Design Workshop (MDW VIII). This workshop is supported by Harvey Mudd College's Center for Design Education and the National Science Foundation, was held at Harvey Mudd College during 26-28 May 2011 and titled as "Design Education: Innovation and Entrepreneurship." The Workshop was organized in the same way as its prior implementations. Multiple sessions with four speakers presenting for 10 minutes each followed by a sufficiently long (75 min) panel discussion with the other workshop participants. Highlights of the conference along with the following discussion on core competencies are reported by *Altman, Dym, Hurwitz and*

Wesner [27] and Altman[28] at this conference. The discussion is repeated here with slight edits as it is an integral portion of the emphasis of this paper.

During one of the session discussions, Terpenny issued a challenge to the assembled participants to identify the core competencies necessary to performing design. This challenge was posed after an audience consensus emerged: students are, in general, ill prepared to do design when they start design classes. Also "What are the minimum design competencies students should learn from our programs?" to take into industry. As a direct response to the challenge, Agogino organized an impromptu activity designed to identify the core competencies that students needed to enjoy success in design. This workshop filled with engineering design professors and students from universities and industry across the country as well as international experts was an ideal environment to assemble such a framework of core design competencies. Just as technical skills and mechanical principles are important to design education, there are other, less-quantifiable core abilities that are vital to success in design. The purpose of this exercise was go one step further and to articulate these traits and capabilities with the aim of enabling proper assessment of them.

Agogino suggested a Post-It™ note affinity-type exercise to have Workshop participants write notes (and place them on a dedicated whiteboard) identifying the most important design competencies. The MDW VIII participants responded overwhelmingly, resulting in an abundance of notes that led to the list of design competencies presented below. The competencies were separated into affinity groups and then titled after multiple iterations as participants passed by the board throughout the Workshop refining their contributions. The final listings are divided into eight sections, and it is worth noting that the competencies are a mix of attributes— especially the first set of personal attributes—while the remaining seven are mixtures of attributes and of skills to be developed.

1. Personal Attributes
2. Evaluation and Testing
3. Creativity
4. Problem and Opportunity Identification
5. Communication and Teamwork
6. Knowledge Creation and Thinking Processes
7. Making Things
8. Technical Fundamentals

Greater detail is provided below. The competencies within each of these sections illustrate some, but not all, valuable aspects of an engineering design student.

Personal Attributes: Comfort with and tolerance for ambiguity, resourceful**,** persistent**,** open-minded, can relax and have fun, sense of humor, be willing to step aside and be willing to step up, be sufficiently self-confident to lead, able to take risks, confident in asking questions and coming up with ideas, can recover from failure, is proactive and fearless, gives credit where credit is due, collegial and trusting, can identify and actuate passion, has humility, knows when to get help, knows when too much time and resources have been exhausted on one design step, can accept failure gracefully, can let go of ideas, is curious.

Evaluation and Testing: Can compare and evaluate solutions**,** can demonstrate modeling and analytical skills**,** has ability to "listen to" tests, experiments with prototypes, exploits and interprets what is heard (for debugging).

Creativity: Can generate ideas and brainstorm, can offset decision-making tools to assess risk and potential failure, can generate a variety of solutions that are both novel and feasible, can think outside the box, has creative thinking skills, can create unexpected solutions that are innovative.

Problem and Opportunity Identification: Can discover or identify problems, can define the problem, can identify constraints, can identify a market and assess a market opportunity, can understand the context of the problem being solved, is optimistic and seeks opportunities (even among constraints), can identify customer needs and opportunities for innovation, making user centricity real.

Communication and Teamwork: Can communicate orally and in writing, can communicate with team and client and other stakeholders, can work on a team, can select the right kind of team members (i.e., can identify individual strengths), is able to listen to others and really hear what they have to say, can build collaboration instead of ownership.

Knowledge Creation and Thinking Processes: Realizes there are multiple repetitions of divergence and convergence in the process of idea generation, is able to abstract, is able to transfer knowledge from on area to another, asks good questions, can search the patent literature, knows how to recognize unknowns/assumptions/limitations, can abstract and detail (i.e., can roll up/down in representations), can think on multiple levels (e.g., what is in front of me, what was I doing before, what do I do next, what is this process about, how do I change this process), can gather information, can recognize her/his own cultural lens, knows what to record/save/document/share (when, why, who, how . . .), can troubleshoot a non-functioning device or prototype to identify the root cause of a failure, can think critically, can capture and maintain knowledge, for reuse, can learn to learn (i.e., can teach themselves), can self-assess their core competencies so as to seek out opportunities for improvements, be willing to unlearn defunct/obsolete knowledge, be able to search for information and critically analyze it and categorize it and determine its relevance, can make innovation tangible and digestible.

Making Things: Has prototyping skills, knows when to model or prototype, builds (i.e., less talk, more action), uses tools to build, builds to learn, does iterative prototyping (i.e., build/ test, change, rebuild), is able to build or provide required information to be able to manufacture a product, implement an idea that can be built and mass-produced, can sketch and do drafting (e.g., CAD, SolidWorks).

Technical Fundamentals: Know 2nd order ODE's, know Bernoulli, know control volumes and transport, can use engineering fundamentals to guide design and to model concepts to predict performance, can identify functions, must have technical competence—CORE to professional engineers—regardless of design or communication capability.

When comparing and contrasting this list of core competencies generated by faculty attending the MDW VIII workshop with the industry lists in the previous section, one finds that faculty and industry have similar views on the core competencies desired and required to be a successful engineering designer. The question remains … are students receiving the coaching they need to acquire, develop, and excel in these attributes/skills/core competencies at the university? Is academia assessing entering students to determine their level of proficiency in core competency areas? Are there means and methods for remediating deficiencies and developing learning environments that foster new and better competencies?

From the list of disconnects between academia and industry, desired skills, attributes and core competencies that industry and academia have identified, the next step is to review the list to identify individual core competencies that can be assessed, and then create learning environments such that students can improve the competency that will contribute to their being more successful engineering students and function more fully in design teams both in academia and in industry.

IV. Example Core Competency – Spatial Visualization

In this section, we offer an example of one core competency, spatial reasoning, and how it can be measured and that interventions can lead to significant benefits and long-term success of engineering students who would have otherwise been at risk. We argue that similar work and efforts need to be applied to other less well understood competencies. Spatial visualization is a core competency associated with design communication (sketching and CAD) and is paramount to success in engineering studies and design in particular. Can it be discerned whether the student can think in three dimensions, whether they can visually communicate ideas, and whether they can translate 2-D to 3-D and vice versa? Considerable research has been done in the areas of assessment of spatial visualization and course development to improve spatial visualization and subsequent success in engineering[1]. This work has found wide spread traction through promotion by the ENGAGE Project and WEPAN. The overarching goal of ENGAGE is to increase the capacity of engineering schools to retain undergraduate students by facilitating the implementation of three research-based strategies to improve student day-to-day classroom and educational experience. Spatial visualization is one of these research based strategies.

A. ENGAGE Background

As a university site for the ENGAGE Project, the team at Virginia Tech delivered the Purdue Spatial Visualization Test: Visualization of Rotations (PSVT:R)[2] during onsite summer orientation 2010 for incoming first-year engineering students. Paper versions of the tests were given in groups of 50 to 100 students over two weeks in July. A total of 1084 students took the test to assess the spatial visualization skills of incoming first-year engineering students. Those scoring below 18/30 on the spatial visualization skills test were enrolled in a one credit, A/F, elective, Spatial Visualization course offered in fall semester 2010 by the Department of Engineering Education using Sorby's text[29] *Introduction to 3D Spatial Visualization: An Active Approach*. As this course had been taught in the past for pilot research studies, the course had been approved by all appropriate curriculum committees and was in place be taught last fall by one of our Ph.D. students who was an experienced engineering graphics/CAD instructor. The team's goal for this past summer was to require the online version of the PSVT:R test for all incoming first-year students, identifying all first-year engineering students scoring below 18/30, and enrolling them in the course prior to their coming to summer orientation. This was a successful modification of approach as 1207 students took the online version of the test this past summer.

B. Approach in 2010

To identify high-risk students, incoming students were screened using the Purdue Spatial Visualization Test: Visualization of Rotations (PSVT:R) during onsite summer orientation. The test was announced during general engineering orientation sessions given by the interim department head. She described the opportunity and the importance of strong spatial visualization skills for success in both engineering courses and professional engineering practice. Students had time in their orientation schedule to take the test and students were strongly encouraged to do so. One thousand eighty five (1084) students took the test. Students who scored below the threshold were automatically enrolled in the course and could then drop if they chose to do so. One hundred and five (105) students were enrolled and due to dropping and schedule conflicts, seventy-one (71) students started the course.

C. Course Structure in 2010

The spatial visualization course consisted of consisted of a semester long weekly 75 minute class session consisting of modules in Sorby's text[29] *Introduction to 3D Spatial Visualization: An Active Approach* (number represents the module number in this text) plus additional modules on orthographic projection with inclined and curved surfaces. The sequence of the modules taught was 9-Combining Solids; 8-Surfaces and Solids of Revolution; 1-Isometric Sketching; 2-Orthographic Projection; 3-Flat Patterns; 4-Rotation about single axis; 5-Rotation about multiple axes; 6-Reflections and Symmetry; and 7-Cutting Planes and Cross Sections. All students met weekly in class in a single section of 71 students. The spatial visualization class was organized by an Engineering Education faculty member and was taught by and experienced Engineering Education Ph.D. student. The format of the course was interactive with some contextual examples to emphasize the importance of spatial visualization skills and then moving onto students working in the workbook with instructor available for assistance. Students were encouraged to work on more examples at home, but most could be completed during the class period.

D. Test Results and Outcomes of 2010

Pre-test PSVT:R scores of the 1085 students taking the test in 2010 averaged 23.8/30. The pre-test scores of the students falling below the 60% threshold and enrolled in the course was 16.3/30. Of the105 students who scored below 60%, 60 were male, 45 were female. Of the 71 students actually enrolled in the class, 33 were male and 38 were female. After participating in the course, the students again took the PSVT:R post-test and had an average score of 21.4. Five (5) males and nine (9) females fell below the 60% threshold after completing the course. The screening of the students was effective in identifying students who would benefit from the course (roughly 10%), but could improve to screen even more students. The course was effective in coaching 80% of the students to an improvement in their spatial visualization skills, but still 20% of those taking the course did not have their scores improve enough to exceed the 60% threshold.

E. Testing Approach, Results and Outcomes of 2011

Based on the smooth screening process and the response of the students to taking the test in 2010, the team in 2011 expanded the screening to reach more students by using the online PSVT:R. Students were informed and encouraged via e-mail to register and take the online PSVT:R as part of ongoing communications between Engineering Education academic advisors and incoming first-year engineering students during early summer. Students were then given a two week window to take the test, after which they were warned that a hold may be put on their enrollment if they did not complete the test. Once the test was taken and the scores were noted, students were enrolled in the Spatial Visualization course prior to their arrival at orientation so the course appeared with other courses on their fall academic schedule. The course was then taught in the fall in two sections because of increased enrollment. In this iteration, the course was taught by an instructor with a PhD in mechanical engineering.

Pre-test PSVT:R scores of the 1207 students taking the test in 2011 averaged 23.9/30 (almost identical to the previous year's scores). Of the106 students who scored below 60%, 58 were male, 48 were female. Of the 92 students actually enrolled in the class, 44 were male and 48 were female. Eleven (11) males and six (6) females dropped the course. After participating in the course, 75 students took the PSVT:R post-test and had an average score of 23.1. One (1) male and six (6) females fell below the 60% threshold after completing the course. The screening of the students was effective in identifying students who would benefit from the course (again roughly 10%). The course was effective in coaching over 90% of the students to an improvement in their spatial visualization skills, and this year less than 10% of those taking the course did not have their scores improve enough to exceed the 60% threshold.

V. Conclusion

As can be seen, there are many competencies that industry see as critical for success and other competencies that academia have identified for success in engineering design. Some do overlap, but at the same time industry identifies a gap between what is needed on the job and what engineering schools are teaching. In the example competency of spatial visualization discussed above, it is clear that an approach grounded in engineering educational research, that assesses preparedness, and then creates a path toward successful improvement of a competency, can have a major impact. The results of the assessment and intervention described here were predicted by Sorby's research[1]. The assessment was executed using paper versus electronic testing and two different instructors were used in two different class sizes with almost identical results. It is conclusive that this isolated core competency can be improved through systematic assessment and targeted instruction using tools vetted through research, development and testing. The results described here point to the promise that other core competencies, listed above, can be similarly targeted and addressed with the goal of all engineering graduates being assured of success in engineering design teams and ultimately success in industry.

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