Session 2530

Measuring Student's Confidence with Problem Solving in the Engineering Design Classroom

by
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Abstract

The study presented in this paper focuses on the confidence component of problem solving in the undergraduate engineering design classroom. The Problem Solving Inventory was given to students participating in NAU's *Design4Practice* sequence of multi-disciplinary design courses. Two semesters of data were collected and analyzed. Year-in-school data compared closely to published trends. Differences in confidence were identified for students that had or hadn't declared a major within engineering. Of particular interest was the occurrence of team differences in confidence, influenced to some extent, by instructor style.

Introduction

The teaching of engineering is the teaching of problem solving in its broadest sense. To be an accomplished practitioner, however, students must be able to move beyond solving well-structured, algorithmic-type problems with easily identifiable solution steps. We believe that professional success requires skill and confidence with ambiguous, ill-defined, multi-dimensional problems that are characteristic of engineering design.

Northern Arizona University's (NAU) College of Engineering and Technology (CET) has developed and implemented a sequence of novel design courses. This through-the-curriculum program, formerly known as the *Path to Synthesis*, was renamed the *Design4Practice* program when the freshman level course was fully developed and added in the Spring of 1997. The through-the-four-year courses, as shown in Figure 1, were expressly created to strengthen and expand our students' design and problem solving skills. Teaching and learning relies on hands-on, mentoring-type experiences and the use of ill-defined, unstructured design projects to build technical, managerial, professional skills, as well as problem solving competency.

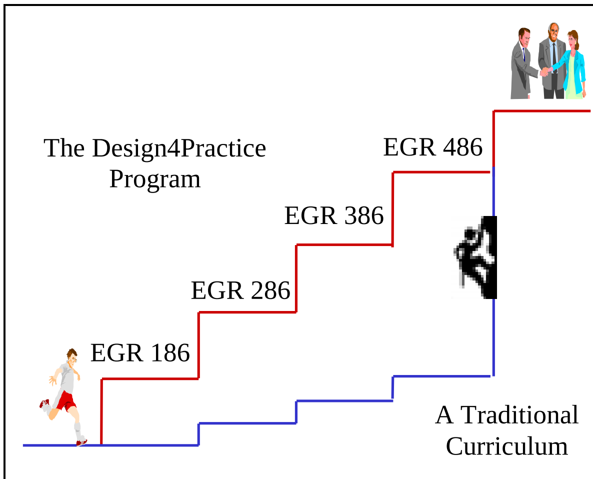

Figure 1. *Design4Practice* Program at Northern Arizona University

The *Design4Practice* program, which took approximately five years to create and fully develop, represents a serious investment of time and resources by NAU. The program's teaching demands are high; two to five instructors are needed for each course, as all of CET's[1] students participate in the sequence. Each design class is hands-on which places a tremendous demand for materials, computers, software, tools, and physical space. Given these unusual requirements, we are compelled to begin evaluating the effectiveness of the *Design4Practice* program. This paper documents our first attempts to assess student growth in a particular aspect, the confidence component, of engineering problem solving as CET's students move through the *Design4Practice* curriculum.

Two semesters of student data were collected using the Problem Solving Inventory (PSI), which is a validated measure that rates one's perception of approach and confidence with general problem solving. The relationship between confidence and problem solving is discussed, population trends are revealed, and the influence of instructor style is considered.

Why Examine Confidence in Engineering Problem Solving?

There is a growing body of education and childhood development literature that examines the relationship of personal confidence to problem solving. The general consensus is that successful problem solving relies not only on cognitive skills, (i.e. applying facts and rules), and meta-cognitive abilities, (i.e. understanding how and when to use knowledge), but also on affective thinking (i.e. confidence and personal control) and social processes. In fact, some researchers suggest that confidence may be more important than skill in determining problem solving success (Thornton, 1995).

Limited published information exists with respect to problem solving abilities and processes within the engineering environment. There is, however, substantial work in the companion field of mathematics education. This related work has shown that differences in achievement and participation parallel the differences in belief and attitude (Boekaerts, 1994). As compared to their peers of equal skill, students with higher expectations, self-confidence, and good control perform better in mathematics. Positive beliefs about their problem solving ability turn math problems into interesting activities worthy of their effort. Students with unfavorable personal beliefs view math problems as threatening and non-interesting experiences. These beliefs are coupled to low math performance (Seegers and Boekaerts, 1995). In addition, Boekaerts (1994) hypothesizes that ambiguous math problems requiring re-framing, modeling, experimentation, and/or reflection can promote insecurities and disturbed task solving processes; particularly when the teaching and learning environment does not explicitly support these types of problems. Bandura (1986) notes that an individual's belief about his or her problem solving ability strongly influences their success with ambiguous situations. Perception does not play such an important role in solution success when problems are clearly defined and well structured.

It is our – the authors – hypothesis that these same relationships between confidence and successful problem solving hold true within the engineering environment. In fact, the dependency may be even stronger or more critical upon consideration of the type of problems practicing engineers regularly face – unstructured, ill-defined, complex design issues.

[1] The Computer Science and Engineering students do not take EGR 186, but do take the remaining three design courses.

Confidence in design may contribute to student participation and success in the engineering classroom and beyond.

The Problem Solving Inventory

The instrument that we used to measure and collect confidence data was the Problem Solving Inventory (PSI) (Heppner, 1988). Our decision to use this particular assessment strategy was influenced by Woods, et al (1997), who have collected PSI data from their undergraduate engineering students. In addition, other university population PSI statistics exists as referenced by Heppner (1988). The thirty-two question PSI test appears to be applicable to our *Design4Practice* goal of strengthening student problem solving skills, since it is a proven measure that can differentiate between groups that have and have not received problem solving training. On the down side, the PSI test does not evaluate skill with technical problem solving, but is a "general appraisal (of perception) without reference to particular problems" (Heppner, 1988).

Generic confidence with problem solving involves many behaviors that include not only belief in one's ability, but also one's approach, (e.g. the capacity to motivate), and self-control, (e.g. pre-occupation with failure, the ability to regulate negative feelings, and anxiety). The PSI instrument examines these major factors through eleven personal confidence questions, sixteen approach-avoidance style items, and five personal control queries. Low scores mean that students trust their problem solving abilities, are willing to attempt difficult problems, and are in control of their feelings and behaviors during the problem solving process.

Summary of Collected Data

Student PSI data, collected at the end of the Spring and Fall semesters of 1997 from all students participating in the *Design4Practice* program, is summarized and presented in Tables 1 through 5. When possible, we also gathered information on grade point averages and performance in design classes.

Only the total PSI results, not category data, are reported herein. The total PSI score is a summation of the personal control, approach-avoidance, and confidence subtotals. Even though the sub-total results can be quite useful on an individual-by-individual basis, for purposes of comparing various populations, total PSI scores are sufficient. This is because changes in total scores generally represent a proportional change in category scores. The total PSI scores can range from a low of 32 to a high of 192.

	Total PSI Scores					
	Spring 1997[1]			**Fall 1997[4]**		
	No.	**Average**	**Std. Dev.**	**No.**	**Average**	**Std. Dev.**
Total in Freshman Classes[1]	51	81.1	20.5	71	86.6	19.6
Students w/ Declared Major	39	77.8	19.9	[3]	[3]	[3]
Students w/o a Major	12	92.7	20.9	[3]	[3]	[3]
Female Students	9[2]	85.1	25.2	11	81.4	15.4
Male Students	39[2]	79.1	18.3	60	87.5	20.1

(1) The Spring 1997 results include data from three Engineering Graphics courses plus an experimental version of EGR 186. Prior to EGR 186 coming fully on line in the Fall of 1997, design content was provided in Engineering Graphics. (2) Three students did not self-identify. (3) 2 out of the 71 students had not declared their major of study. (4) The Fall data was collected from only EGR 186 students.

Table 1. PSI Results for Students in Freshman Design Courses
Spring 1997 and Fall 1997

	Total PSI Scores[1]					
	Spring 1997			**Fall 1997**		
	No.	**Average**	**Std. Dev.**	**No.**	**Average**	**Std. Dev.**
Total Sophomore Class[2]	52	83.7	19.1	60	72	20.4
Female Students	5	99	19.8	5	84.8	17.5
Male Students	47	82.1	18.3	55	70.9	20.2
Division A[3]	17	73.6	17.6	20	77.4	17.6
Division B[3]	20	87.3	16.6	22	67.4	20.6
Division C[3]	15	90.5	19.3	18	71.8	21.5

(1) Overall grade point average data was also collected. Class average GPA with its corresponding standard deviation for the respective Spring and Fall semesters were 3.07 & .601 and 3.00 & .531. (2) EGR 286 is one large multi-disciplinary problem-based design class that is team-taught.

Table 2. PSI Results for Students in Sophomore Design, EGR 286
Spring 1997 and Fall 1997

		Total PSI		Grade Point	
	#	**Average**	**Std. Dev.**	**Average**	**Std. Dev.**
Total Junior[1] Class	42	80.2	25.7	3.07	.50
CSE[2] & EE[3] Majors	5	65.8	20.3	3.09	.48
CE[4] & EnV[5] Majors	24	84.2	25.2	3.07	.48
ME[6] Majors	13	78.5	26.3	3.06	.56
Female Students	8	77	20.6	3.27	.42
Males Students	34	81	26.7	3.02	.51

(1) EGR 386 is also a multi-disciplinary project-based team-taught course. Its student divisions are grouped by discipline with each division managed by the respective discipline-specific faculty member. EGR 386 is only offered once a year. (2) CSE = Computer Science and Engineering. (3) EE = Electrical Engineering. (4) CE = Civil Engineering. (5) EnV = Enviromental Engineering. (6) ME = Mechanical Engineering

Table 3. PSI and GPA Results for Students in Junior Design, EGR 386
Fall 1997

	#	Total PSI Average	Total PSI Std. Dev.	Grade Point Average	Grade Point Std. Dev.
Total Senior(1) Class	77	80.1	19.05	2.93	.5
CSE(2) Class	18	82.8	17.2	2.99	.48
EE(3) Class	16	74.2	19.4	3.06	.62
CE(4) Class	9	91	8.6	2.8	.5
EnV(5) Class	14	83.2	13.6	3.0	.42
ME(6) Class	20	75.2	23.5	2.8	.42
Female Students(7)	15	76.1	14.7	3.11	.53
Males Students(7)	61	80.7	19.8	2.89	.49
Students w/ X86 Courses(8)	26	77.9	19.4	3.15	.46

(1) EGR 486 is senior capstone design course. It is offered once a year and each discipline has its own separate course. (2) CSE = Computer Science and Engineering. (3) EE = Electrical Engineering. (4) CE = Civil Engineering. (5) EnV = Environmental Engineering. (6) ME = Mechanical Engineering. (7) One student did not self-identify. (8) Students that had previously taken one or more of the earlier *Design4Practice* courses. Of these 26 students, 16 had taken both EGR 286 and 386, 10 had taken only EGR 286. None of the students had taken EGR 186.

Table 4. PSI and GPA Results for Students in Senior Design, EGR 486 Spring 1997

	Total PSI Scores											
	U.S. University Students (1)			NAU Engineering Students in *Design4Practice*			Canadian Engineering Students w/o MPS(2)			Canadian Engineering Students w/ MPS(3)		
Year (4)	**No.**	**Aver.**	**Std. Dev.**	**No.**	**Aver.**	**Std. Dev.**	**No.**	**Aver.**	**Std. Dev.**	**No.**	**Aver.**	**Std. Dev.**
1	90	86.4	22.8	122	84	20						
2	100	87.9	22.2	112	77.5	20.7	256	91.3	18.5	238	92.0	18.6
3	73	83.7	18.4	42	80.2	25.7						
4	43	80.7	19.2	63	80.1	19.1	32	90.4	16.3	202	71.0	14.0

(1) U.S. University students from across all disciplines (Heppner, 1988). (2) Canadian university students specializing in engineering that have not received specialized training in problem solving through the McMaster Problem Solving Program (Woods, et al., 1997). (3) Canadian university students specializing in engineering that have received specialized training in problem solving through the McMaster Problem Solving Program (Woods, et al., 1997). (4) Year in college or level of course with 1 = freshman, 2 = sophomore, 3 = junior, and 4 = senior.

Table 5. Comparative Total PSI Data for University Students

Analysis of Data

Comparing University Populations

Except for the sophomore grouping, the NAU PSI overall student data compares closely to the norm data for U.S. University students.

At the sophomore and senior levels, the NAU engineering students have more confidence than their peer Canadian students that have not received specialized problem solving training, (77.5

versus 91.3 and 80.1 versus 90.4). In contrast, those Canadian engineering students that completed the McMaster Problem Solving Program demonstrated an improvement in confidence with respect to both the Canadian sophomore students (71.0 versus 92) and the NAU senior *Design4Practice* students (71.0 and 80.1). It was not possible, however, to test for statistical significance between the NAU and other university populations, as only average and standard deviation data for the other university students were published, and not the full population results.

Changes in Scores through the *Design4Practice* Program

At first glance, the lack of any significant change in PSI scores through the four years for NAU design students is discouraging. Upon further analysis, however, the senior population represents a control group without previous *Design4Practice* experiences. This is true because only a fraction, (26 /63), of the seniors participated in one or more of the earlier *Design4Practice* courses. In addition, their participation in the lower-level courses occurred when these courses were under development; suggesting that the experience was less than optimal. A homoscedastic t-test comparing the senior groups with and without prior design course work confirms this hypothesis. There is no statistical significance between the two populations at the 95% confidence level.

NAU Freshman Scores

At the freshman level, homoscedastic t-testing revealed a significant difference, (at the 95% confidence level), in problem solving confidence between the two student populations differentiated by whether or not their study major was declared. The group composed of declared engineering majors had a lower average total PSI score, (77.8), than the group composed of students without a major (92.7).

Correlating GPA and PSI

Overall grade point average (GPA) is a poor indicator of a NAU student's confidence with problem solving. Statistical testing at the sophomore and junior levels showed that there was no correlation between GPA and PSI results. The two metrics, however, were weakly correlated (21%) at the senior level.

This lack of correlation is logical because traditional coursework, that often emphasizes well-defined and well-structured problem solving strategies, dominate the undergraduate curriculum. As a consequence, GPA data is strongly weighted by traditional classroom performance; providing little insight into the broader aspects of problem solving abilities including the important affective issue of confidence.

NAU Sophomore Scores

T-testing of the Spring semester data shows that the confidence of the Division A students is significantly better, at the 95% confidence level, than the students of either Division B or C. There was no statistical PSI difference, however, between Divisions B and C.

EGR 286 is a very unique course. Each semester the students in each engineering discipline are randomly divided into three multi-disciplinary divisions of approximately 20 students. Each division is managed by one of the four course instructors. Each division manager stays with his or her group for the entire semester; managing their efforts to complete a semester-long, hands-on, complex project like an automated robot or a computer-controlled assembly operation. The fourth instructor acts as the company president and does not take on teaming responsibilities. Course content, however, is delivered within the company context ensuring that every student, regardless of division association, receives exactly the same quality of content instruction and material. While the overall class environment and project demands were the same for each division, and group composition was similar with respect to both discipline distribution and overall GPA; division manager style varied greatly. We believe that style, during the Spring semester, impacted the team's perception of problem solving ability. This style element is further discussed below in the section titled Sophomore Design Instructor Styles.

Even though the division managers and president remained the same over the reported two semesters, the Fall PSI data did not support this instructor style hypothesis. There were no statistically significant differences in division PSI scores. The Fall version of EGR 286, however, was different than the Spring class. The EGR 286 faculty were well aware of the Spring PSI results and its implications prior to the start of the Fall semester. As a result, this faculty team made a conscientious effort, during the Fall semester, to bring elements of division manger A's knowledge and management techniques to the other two teams. Most notable was the sharing of design "tricks" and guiding principles to the entire company.

It is also important to note that project performance per division for <u>both</u> semesters paralleled the Spring PSI data. Consistently, Division A produced elegant, well-documented paper designs that were built with few problems. Division A's projects performed smoothly and always did more than required. The students of Division A typically performed well within the teaming framework. Division B and C, however, struggled with the design phase; producing complex designs with little supporting details. In turn, design re-dos and many late nights were characteristic of Divisions B and C implementation phases. Their robots or assembly lines often had trouble completing the full set of required demonstration tasks. Both divisions also exhibited teaming problems that contributed to project failings.

Sophomore Design Instructor Styles

Division Manager A brings enthusiasm for and knowledge of the creative problem solving process called engineering design to his student divisions. This manager is the product development cheerleader and coach. There is no question – his students are going to be successful. In addition, this manager possesses two important characteristics or skills that differentiate his style from that of the other sophomore managers. These characteristics are:

1. Organization of the Team's Work – Division Manager A proactively shows his team how to organize themselves and their work. Manager A provides clear direction on how to break-down the various tasks, helps the students assign appropriate roles and responsibilities, supplies key sub-task deadlines, and demands professional behavior.

2. A Well-Defined Personal Philosophy about Design – Division Manager A actively conveys his personalized approach to design which provided structure and purpose in the ambiguous project environment. Division A students were focused by key phrases like:
   - Keep it Simple Stupid,
   - Fail Simple First,
   - Follow the Part,
   - Paper Design is Cheap,
   - Task Rules, and
   - Work the Plan.

The style of Division Manager B is probably best described as "warm and fuzzy" and understands the importance of guidance within a realistically structured format. Manager B feels, however, that this guidance needs to be tempered; providing the freedom to make mistakes as part of the student experience. Through the hands-on team design experience, Manager B expects his/her students to gain a feeling for the significance of their contributions and those of their fellow teammates who came from other disciplines. In addition, this manager expects his/her students to perform with technical competence within the context of cooperation, altruism (i.e. more than willing to do their part), and anticipation (i.e. work according to a schedule).

Manager C strives to give his team as much freedom as possible in terms of their organization, decisions, meeting times and leadership; encouraging the students to find their own best way of doing things, instead of specifying what to do. Manager C does provide suggested courses of action for the group and indicates priorities relative to project demands. In addition, Manager C attempts to quietly position himself as course facilitator and team advocate. He is not afraid of letting the students make mistakes in order to learn. This learning by doing, however, is coupled with a reflective approach. Manager C tries to nudge student awareness about what they are doing, why they are doing it, and how this relates to project successes or failures.

The results of this two-semester study suggest that a proactive, success-orientated management style is an important differentiating factor in determining student performance within the design classroom, (as measured by project success), and, possibly, student confidence with problem solving. The more typical academic hands-off approach of learning from mistakes coupled with minimal guidance is not as successful for the student design engineer.

Finally, What Does This All Mean?

This paper is our first look at the confidence and problem solving issue within the undergraduate engineering design classroom. The issue is indeed complex and one that will require many years of extensive data collection and observation to better understand. Even though the work presented here is not conclusive; some important trends and implications are revealed that are worthy of noting as we strive to improve the quality and effectiveness of engineering education. These relationships include:

- Grade point average, a performance measure that is dominated by traditional classroom scores, does not correlate well to confidence.
- Student design performance in the non-traditional classroom is influenced by instructor style.
- There is the suggestion that instructors affect student problem solving confidence.
- Explicit instruction in problem solving skills and/or proactive management of the problem solving process can enhance confidence.

- Confidence with problem solving may affect academic study choices as indicated by the declared and undeclared freshman population statistics.

A key premise, however, has yet to be explored. Does enhanced academic confidence with problem solving and multiple, phased undergraduate design experiences affect professional engineering career success? We believe that there could be a strong correlation, but those relationships will be difficult to prove. As engineering educators institute programmatic assessment strategies in response to the recently revised accreditation process, known as ABET 2000, long-term studies on the professional careers of engineering graduates may provide more insight into these questions.

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