Faculty Roles in Student Learning, Confidence, and Skills Development

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Abstract *– Previous studies have investigated and identified a number of ways in which faculty can affect students' gains in learning outcomes and course satisfaction. This study focused on the relationships between engineering faculty teaching practices and students' gains in communication skills, problem-solving skills, occupational awareness, and engineering competence in a curriculum emphasizing engineering design activities. The study was based on data gathered from 1555 students taking the first-year design course offered at 19 campuses of The Pennsylvania State University system over a period of two years. The results suggest that faculty interacting with and providing constructive feedback to students was significantly and positively related to student gains in developing problem solving and communication skills, understanding what it is practicing engineers do, and improving students' motivation and confidence to become engineers. These relationships remained after controlling for student demographic characteristics and campus location. The focus of this paper is to provide engineering instructors with insights about their roles in fostering selected student gains. Recommendations regarding specific teaching practices are provided*.

INTRODUCTION

Over the last several years, engineering colleges in the United States have placed greater emphasis on integrating engineering design into the four- or five-year curriculum, emphasizing hands-on projects, teamwork, and greater student-student and student-faculty collaboration. At the first-year level, these efforts were targeted to interest students in engineering as a profession and subsequently retain the students in their majors.

Penn State's College of Engineering developed the Introduction to Engineering Design (ED&G 100) course as a part of a National Science Foundation sponsored coalition project, ECSEL. ECSEL was a coalition of engineering colleges of seven universities, funded between 1990 and 2000, and focused on the goals of increasing the recruitment and retention of historically underrepresented students in American engineering colleges and infusing design throughout the four-year curriculum. ED&G 100, a required course for engineering majors, is offered at 19 Penn State campus locations and promotes a design-driven curriculum with emphasis placed on skills such as: teamwork, communication skills (graphical, verbal, and written), and computer-aided analysis tools. The curriculum introduces students to the engineering approach to problem solving, emphasizing the use of basic science and math skills to test and evaluate design ideas by building working prototypes. The design projects require students to work in teams, and their course grades reflect their ability to function effectively as team members. These enhancements were intended to enhance students' confidence in their ability and motivation to become engineers and to increase the value of the course within the curriculum.

Generally, curricula incorporating collaborative learning aim to develop students' problem-solving skills, their abilities to apply theories to "real-world" problems, and their functioning as effective team members [1]. In working in teams to solve ill-structured design problems and construct working prototypes, engineering students also cultivate their communication and conflict management skills [2]. A meta-analysis of the effects of small-group learning on undergraduates in engineering, science, technology, and math indicated that working in small groups promotes academic achievement and college persistence [3]. Likewise, a recent study of 718 students found that active learning experiences (e.g., team design projects) had positive direct and indirect effects on college student persistence [4].

While the body of research on the relationships between collaborative learning techniques, student achievement, persistence, and affective outcomes is growing, few studies have investigated engineering faculty's role in fostering student gains through students' participation in design projects that foster teamwork. Previous studies have found that student-faculty interaction promotes educational attainment, and is significantly and positively related to college grade point average, degree attainment, graduating with honors, and enrollment in graduate school [5]. Since engineering faculty decide upon and use certain teaching methods or learning activities in their classroom and lab courses, "the impact of faculty upon student involvement and persistence is likely to arise indirectly via their impact on ethos and educational activity structure of the classroom…. It can therefore be argued that at least part of the often-observed relationship between persistence and student-faculty contact outside the classroom is a reflection of faculty actions" [6, p. 90]. A number of studies have found that student-faculty interaction both in and outside the classroom is critical to a number of the aforementioned outcomes [5, 6, 7]. However, this study specifically

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examines *engineering* faculty roles in fostering student learning gains in confidence and skills development in first-year students participating in a design-driven course.

The purpose of this study was to investigate the effects of faculty roles on students' self-perceptions of gains made in problem-solving skills, communication skills, awareness of what practicing engineers do, and confidence in becoming engineers.

TABLE I
DEMOGRAPHICS OF THE DATA SAMPLE

Item		n	%
Gender	Female	289	18.6
	Male	1266	81.4
Race/ Ethnicity	African American/Black	51	3.3
	Latino/Hispanic	38	2.5
	Asian/Pacific Islander	83	5.4
	American Indian/Native Alaskan	10	.7
	White/Caucasian	1321	85.9
	Other	34	2.2
Class Year	First Year	1220	79.1
	Sophomore	220	14.3
	Junior	72	4.7
	Senior	21	1.4
	Other	10	.6

N = 1555

DATA SOURCE

The Introduction to Engineering Design course (ED&G 100) is offered at 19 campuses of the Penn State system with a total enrollment of 1800 students per year. Approximately, 50 percent of the students attend the University Park campus, and the rest are distributed among 18 campuses statewide. Approximately, 25 faculty teach the course at the various campuses in any one year. Although the course content is the same at all campuses, the design projects vary from campus to campus. ED&G 100 is a three-credit course that involves 6 hours of in-class work (two hours per session, three times a week).

Characteristics of the Sample

One thousand five hundred fifty-five students participated in the study by completing a questionnaire at the end of the fall 1999, spring 2000, or fall 2000 semesters. Eight hundred eight (808) University Park students and 747 students from 18 other Penn State campus locations participated in the study. The respondents' mean SAT Verbal score was 576; the mean Math score was 634. See Table I for more information about the demographics of the sample.

THE SURVEY

This study was conducted using Classroom Activities and Outcomes questionnaire developed by the Penn State's Center for the Study of Higher Education (CSHE). This instrument was developed as part of the assessment of curricular innovations of the ECSEL project. The questionnaire was used to investigate students' experiences in a particular engineering course, how much the course affected their engineering-related skills, and background and demographic characteristics [8]. Terenzini et. al. [9] describe in detail the theoretical underpinnings of the Classroom Activities and Outcomes questionnaire. This paper, therefore, provides only a brief description of the variables included in this study.

The instrument gathered data on students' perceptions of the course characteristics and the extent to which those characteristics had an effect on students' learning. Terenzini et. al. examined self-perceptions because "Previous research shows that students' motivational beliefs and self-perceptions influence their academic performance, choice of careers, and intent to persist in science and engineering. Although much prior research has demonstrated that positive self-perceptions and motivation contribute to college students' success, relatively little research has been conducted about the extent to which classroom instructional practices enhance students' self-perceptions and motivation" [10, p. 1].

Faculty Instructional Activities

Students responded to 26 items asking about the kinds of instructional activities used by faculty and the characteristics of the ED&G 100 course by circling the number on a four-point scale that best reflected their perceptions. The scale included "1 = never," "2 = occasionally," "3 = often," "4 = very often/almost always." A principal components factor analysis with varimax rotation generated four constructs related to faculty classroom or instructional activities: Instructor Interaction and Feedback, Collaborative Learning Activities, Instructor Climate, and Peer Climate. However, in this paper we are examining two of the four constructs: Instructor Interaction and Feedback and Collaborative Learning (see Table II). The internal consistency reliability was high for both factors, with Cronbach's alphas of .88 and .80, respectively. The adjusted R^2 of 0.411 indicates that these variables can explain 41 percent of any changes in the students' learning outcomes (the dependent variables).

The Skills Students Gained

A principal components factor analysis with varimax rotation of 27 outcome variables produced four factors: Group Communication Skills, Problem-Solving Skills, Occupational Awareness, and Engineering Competence (see Table III). Again, internal consistency reliability of the factors was quite high (Cronbach's alphas between .80 and .93). The adjusted R^2 accounted for 61.5 percent of the variance of the correlation matrix.

TABLE II

FACTOR LOADINGS FOR INSTRUCTIONAL ACTIVITIES

Item	*Instructor Interaction & Feedback*	*Collaborative Learning*
Instructor Interaction and Feedback		
The instructor makes clear what is expected of students, activities, and effort.	.759	
The instructor gives me detailed feedback.	.751	
The instructor gives me frequent feedback.	.732	
Assignments and activities are clearly explained.	.685	
I interact with the instructor as part of this course.	.660	
The instructor guides students' learning activities, rather than lecturing or demonstrating.	.639	
Assignments, presentations, and activities are clearly related.	.597	
The instructor encourages students to listen, to evaluate, and to learn from others' ideas.	.586	
I have opportunities to practice skills.	.546	
I am encouraged to challenge instructor's and students' ideas.	.541	
The instructor emphasizes the design process and activities.	.539	
I interact with the instructor outside of class.	.438	
Collaborative Learning		
I discuss ideas with classmates.		.768
I get feedback from classmates.		.686
There are opportunities to work in groups.		.684
Students teach and learn from one another.		.633
I work cooperatively with other students.		.632
We do things that require students to be active participants.		.567
I interact with other students in this course outside of class.		.411
Internal consistency reliability (alpha)	.88	.80
% of Variance Explained 41.07		

METHODS

Multiple regression analyses were run to identify the significant predictors of students' perceptions of the progress they made in Problem Solving Skills, Occupational Awareness, Group Communication Skills, and Engineering Competence. Listwise selection of variables was used to eliminate any variables with missing values. Then, the 8 selected independent or control variables were regressed on each of the four dependent (outcome) variables. Eliminating the most non-significant variables produced four significant reduced models.

RESULTS

Table IV identifies the variables significant in predicting the four outcome variables, and their beta weights. Beta weights help assess the relative importance of the independent variables relative to the given model of a regression equation.

Instructor Interaction and Feedback was the only variable significantly associated with each of the four learning outcomes. Furthermore, the magnitude of the instructor interaction variables' beta weights indicates that instructor interaction and feedback was the strongest contributor to the model for these learning outcomes. Table V shows that students reported the greatest gains in all four learning outcomes when they interacted with and received feedback from the instructor "almost always."

Expected grade ($p<.05$), participation in collaborative learning activities ($p<.001$), and instructor interaction and feedback ($p<.001$) were significantly and positively related to students' self-reported gains in problem solving skills. Year in school was significantly and negatively related to gains in problem solving abilities ($p<.05$).

Collaborative learning and instructor interaction and feedback were significantly ($p<.001$) and positively related to students' perceptions of gains in occupational awareness (understanding what practicing engineers do). Year in school ($p<.05$) was significantly and negatively related to occupational awareness. This finding suggests the further along in their collegiate careers, the less likely students were to believe the ED&G 100 course boosted their occupational awareness. Consequently, first-year students reported higher gains in occupational awareness than did more advanced students as a result of taking ED&G 100.

TABLE III
FACTOR LOADINGS FOR LEARNING OUTCOMES VARIABLES

Item	*Group Skills*	*Problem Solving Skills*	*Occupational Awareness*	*Engineering Competence*
Group Skills				
Pay attention to all group members' feelings.	.793			
Listen to the ideas of others with an open mind,	.782			
Works on collaborative projects as a member of a team.	.724			
Develop ways to resolve conflict and reach agreement in a group.	.673			
Problem Solving Skills				
Identify the tasks needed to solve an unstructured problem.		.732		
Develop several methods that might be used to solve an unstructured problem.		.722		
Divide problems into manageable components.		.702		
Clearly describe a problem in writing..		.690		
Identify the knowledge, resources, and people needed to solve an unstructured problem.		.685		
Evaluate arguments and evidence so that strengths and weaknesses of competing alternatives can be judged.		.677		
Clearly describe a problem orally.		.673		
Solve an unstructured problem.		.669		
Apply an abstract concept or idea to a real problem.		.660		
Weigh the pros and cons of possible solutions to a problem.		.650		
Visualize what the product of a design project would look like.		.567		
Figure out what changes are needed in prototypes so that the final engineering project meets design specifications.		.488		
Occupational Awareness				
Knowledge and understanding of the process of design.			.693	
Knowledge and understanding of the language of design.			.669	
Understanding of what engineers so in industry or as faculty.			.655	
Understanding of the non-technical dimensions of engineering.			.582	
Engineering Competence				
Likelihood that you will continue in engineering.				.868
Likelihood that you will become a practicing engineer.				.855
Confidence that majoring in engineering was the right choice.				.833
Likelihood that you will go on to graduate school in engineering.				.830
Motivation to become an engineer.				.839
Confidence in your ability to become an engineer.				.760
Likelihood that you will pursue a teaching career in engineering.				.591
Internal consistency reliability (alpha)	.87	.93	.80	.92
% of Variance Explained 61.49				

Participation in collaborative learning activities and instructor interaction and feedback were significant predictors ($p<.01$) of students' developing group communication skills. This finding makes sense since group projects require students to interact with each other and with the instructor, thereby increasing the chances that students will develop more advanced communication skills. SAT math and verbal scores and year in school ($p<.05$) were negatively associated with students' perceived gains in communication skills.

Four variables were associated with students' development of Engineering Competence (motivation to continue in engineering and confidence in achieving that goal). Gender was positively related to Engineering Competence at the .05 significance level, suggesting men had more confidence than did women that engineering was the right major for them and that they will continue in engineering. SAT verbal score was negatively associated with this learning outcome ($p<.01$). Expected grade and instructor interaction and feedback were significantly and

TABLE IV

BETAS FOR THE REDUCED MODELS, CONTROLLING FOR ALL OTHER INDEPENDENT VARIABLES.

	Learning Outcomes			
	Group Skills	**Problem Solving Skills**	**Occupational Awareness**	**Engineering Competence**
Gender				.069 *
SAT Math	-.074 *			
SAT Verbal	-.060 *			-.124 **
Year in School	-.072 *	-.061 *	-.065 *	
Expected Grade		.067 *		.207 **
Collaborative Learning	.271 **	.149 **	.076 *	
Instructor Interaction and Feedback	.296 **	.481 **	.523 **	.373 **
R^2	.262 **	.356 **	.329 **	.226 **

* p<.05, **p<.01

positively related to self-reported student gains in Engineering Competence at the .01 level of significance. Students who expected higher grades were more confident than their peers with lower grades in their motivation to and confidence in becoming engineers.

FACULTY ROLES IN THE CLASSROOM TO ENCOURAGE GREATER STUDENT GAINS

The results of this study suggest that instructor interaction and feedback – even more than assigning group or ill-structured design projects – is the greatest contributor to student gains in communication skills, problem-solving skills, and group skills, and confidence in becoming an engineer. Thus, this section further explores instructors' roles in student learning and then offers some recommendations for improving the ways in which faculty interact with and offer feedback to their students.

Instructor-student interaction can take on many forms and many degrees of intensity. Faculty interact with students both in and out of the classroom, discuss course-related topics, and offer academic advice.

Vines and Rowland [12] applied the concept of feedback mechanisms in electrical engineering applications to create their Instructional Feedback model. The model suggests that faculty implement many sensors (e.g., homework, group projects, exams) to gauge students' progress. Vines and Rowland compare instructors to "actuators" that provide correction to the system (i.e., student progress) by providing frequent and detailed feedback. They also suggest faculty apprise students of their progress or shortcomings several times during a course, giving students the opportunity to change their approach or study habits to learn more successfully. The findings of another recent study suggest "immediate feedback intervention is more effective when automatic processing occurs while delayed feedback produces greater change with tasks involving deliberative and effortful processing" [11, p. 365]. Therefore, instructors are advised to provide immediate feedback for modifying psychomotor skills and to wait to give feedback (until the next class period, for example) to instill changes in students' long-term memory. In all cases, instructors ought to re-examine a student's behavior or progress after the student has had the opportunity to make adjustments based on faculty feedback.

Student-faculty interaction can transpire in a number of ways, some of which occur in the classroom, during office hours, when a student works on a faculty's research project, or at departmental functions. Out of class conversations on substantive matter, and faculty-supervised internships or research opportunities provide excellent opportunities to interact with students [14].

While instructors may know the processes by which interaction can occur, respectful and open attitudes pave the way for greater student involvement. Ways to foster student-instructor interaction include transmitting an attitude that values students' opinions and contributions, by verbal or non-verbal communication. For example, faculty might solicit student views in class, and be willing to discuss divergent points of view that may arise. Success in creating an environment conducive to faculty-student interaction depends largely on the personality of the instructor and to what extent the students think the instructor is accessible [12, 13].

Features in ED&G 100 that may have contributed to these findings:

- Design projects by nature require significant amount of class time to problem-solve. By providing in-class time to engage in the design activity there are greater opportunities for faculty-student interaction.
- The ED&G 100 class includes 6 contact hours per week and is a three credit course, which provides greater opportunity for faculty-student interactions.
- Small class size (maximum 32 per section), and students working in team of four (8 teams per section) is a manageable size for one faculty.
- Design projects have multiple deliverables including weekly presentations, written reports, and building and testing prototypes. These activities require students to work closely with their team members with constant guidance from faculty.

CONCLUSIONS

Discussions of course enhancement regularly include only changes to the course content, which is often the case when adapting a lecture-based course curriculum to a design or project based curriculum. The success of the new course is

TABLE V
PREDICTED MEAN SCORES FOR LEARNING OUTCOMES BY INSTRUCTOR INTERACTION AND FEEDBACK

		Instructor Interaction and Feedback			
Learning Outcome	*Progress/gains made as a result of ED&G 100*	*Never*	*Occasionally*	*Often*	*Almost Always*
Group Communication Skills	1=None 2=Slight 3=Moderate 4=A great deal	2.50	2.86	3.20	3.56
Problem Solving Skills	1=None 2=Slight 3=Moderate 4=A great deal	1.90	2.42	2.94	3.46
Occupational Awareness	1=None 2=Slight 3=Moderate 4=A great deal	1.77	2.34	2.91	3.47
Engineering Competence	1=Decreased greatly 2=Decreased slightly 3=Not changed 4=Increased Slightly 5=Increased greatly	2.43	2.96	3.48	4.01

frequently measured by the impact the course content on student grades. By integrating design projects and collaborative learning opportunities in the classroom, faculty are far more likely than their lecturing peers to be engaged with students and their learning. This study illustrated that greater faculty-student involvement, in addition to its contribution to student retention and academic success, is also the strongest contributor to student gains in "soft skills" outcomes.

ACKNOWLEDGMENTS

The authors are grateful for the contributions provided by Professors Patrick Terenzini, Carol Colbeck, and Alberto Cabrera. The authors thank Dr. Kathleen Silva for leading the initial phase of this study. The study was funded in part by a grant from the National Science Foundation (Grant No. 634066D) to Engineering Coalition of Schools for Excellence in Education and Leadership (ECSEL).

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