Participation in a Freshman Design Sequence and its Influence on Students' Attitudes towards Engineering†

Qaiser Malik, Mathew J. Koehler, Punya Mishra, Neeraj Buch, Michael Shanblatt, and Steven J. Pierce
Michigan State University, malikqai@msu.edu, mkoehler@msu.edu, punya@msu.edu, buch@msu.edu, mas@msu.edu, pierces1@msu.edu

Abstract - **This study focuses on freshman attitudes and beliefs about engineering in a newly introduced engineering curriculum that emphasizes holistic design experiences to portray the discipline of engineering. To precisely measure these constructs, a well documented survey instrument (PFEAS) was employed. The two comparison groups were: the new design-based sequence (DS) and the previous traditional sequence (TS). The study was conducted at a time when both the sequences were available for direct comparison. Data were collected twice (pre- and post-), and changes in groups' attitudes were examined with repeated measures analysis of covariance models. We have found that freshmen join the program with positive perceptions about engineering. Students in the DS group have higher ACT scores, enjoy math and science the most, do not believe engineering to be an exact science, and have stronger parental influence in selecting engineering as a major. We did not observe appreciable group differences in how attitudes changed over time; perhaps one semester of engineering experience was not enough to effect an appreciable change in freshman attitudes. Our study forms the foundation for a longitudinal study to track attitudinal changes for the complete cycle of the design sequence. This formative evaluation will help to further understand and improve the curriculum design efforts.**

Index Terms – Design sequence, formative evaluation, freshman attitude, group differences over time, repeated measures analysis of covariance.

INTRODUCTION

Engineering education has been witnessing tough challenges during the past two decades[1]. Studies, based on the large national samples of freshmen at 2- and 4-year institutions, drew attention to a downtrend in the recruitment and retention of freshmen in engineering majors[2, 3]. It has been found that initial attitudes of students and changes in these attitudes during the freshman year play a vital role in student motivation, performance and resulting retention in the engineering programs[4]. Students who choose engineering majors and complete degree requirements are most likely those who hold positive perceptions toward engineering and have significant interest in science and technology[5]. Based on these findings engineering programs at several institutions have introduced design oriented courses (also called cornerstone or freshman design sequences) in an effort to attract students and retain them in the freshman year. Significant improvements in retention rates have been reported by some of these institutions[6].

Faced with similar challenges in recruitment and retention, and to present engineering as a profession early in the program, the engineering college at Michigan State University introduced its cornerstone design sequence in Fall 2008. The sequence provides freshmen with a broad introduction to engineering design, the engineering profession and engineering ethics, engineering problem-solving skills and teamwork skills. The new required (as of Fall 2008) sequence is composed of two freshman courses: EGR 100 (Introduction to Engineering Design); and EGR 102 (Introduction to Engineering Modeling). EGR 100 is an addition to the existing core course requirement for admission to an engineering program and is also a prerequisite to EGR 102.

The broad goals of the new initiative are: 1) attracting top students to engineering programs and retaining them; 2) better preparing graduates to adapt to a quickly and constantly changing global engineering workforce by appreciating the importance of teamwork, project management, innovation, hands-on experience, ethics, career preparation and professionalism; 3) see engineering as a broad field with many opportunities; 4) positioning engineering as a favored choice for prospective students and parents; and most importantly, 5) to effect an appreciable and positive change in the freshmen attitude towards engineering. The cornerstone design sequence is aimed at achieving these objectives by raising the sense of community and interaction centered on design projects to reap the benefit of long, strong and integrated technical education, and social and professional development[7].

This research study aims to examine the effects of the cornerstone design sequence on freshman attitudes and beliefs about engineering and to establish whether the new sequence is meeting some of its defined goals. Such a study can be best performed if two cohorts are available for a direct comparison. In this respect, Fall 2008 was a unique semester. Students in both streams, the older traditional sequence (TS) and the new design sequence (DS), were available to form a control group and a treatment group respectively for multiple comparisons, i.e.:

- Comparison of changes in student attitudes *within* each cohort through pre-, post- design i.e., in the beginning and towards the end of a semester to appreciate if group changes are significant over time.
- Comparison of the attitudes *between* the two groups in the beginning and towards the end of a semester, and examine if the two groups are significantly different (averaging the time effect).
- Comparison of the delta change in attitude over time, *between* the two groups to determine if the groups experience different amounts of change in their attitudes over time (group*time interaction).

The key research question for this study is: "*Does the cornerstone design sequence influence freshman attitude about engineering?*" This leads to the Null Hypothesis: *"There is no treatment affect of the new design sequence."*

$$H_{01}: \ \Delta\mu_{TS} = \Delta\mu_{DS} \qquad (1)$$

Where,

$\Delta\mu_{TS}$ ≡ pre- post- difference in TS population means, and,

$\Delta\mu_{DS}$ ≡ pre- post- difference in DS population means.

Assessment Measures

I. Valid and Reliable Measures

Review of the literature revealed several assessment tools commonly used by engineering educators: closed form questionnaires, focus groups, one-on-one interviews, open-ended surveys, essay questions, ethnographic studies, portfolios, student journals, and verbal protocols. For our study we selected a closed form questionnaire because: 1) it provides a reliable assessment of student attitudes[8]; 2) it is commonly used to measure impressions of engineering, enjoyment of working in groups and self-assessed competencies; 3) it is easier to administer; 4) it can be given to a large number of subjects with minimal cost[9]; 5) the responses to the questionnaire can be given with a check list, rating, Likert scale or semantic differentials; and, 6) repeated use of instrument can measure changes in attitudes over time or the effect of a particular intervention.

II. Instrument Selection

Development of a survey instrument and its subsequent validation is a tedious and time consuming process. To save on time in construction and validation, experts strongly recommend the use of available instruments[10]. We undertook a literature search for valid and reliable survey instrument that could measure attitudes and beliefs among student cohorts and, particularly, how they are impacted by the cornerstone design sequence. We found a general scarcity of standardized instruments, though some need-based instruments have been developed by a few engineering institutions. For example, Astin has developed a closed form survey to measure the attitudes and perceptions of entering freshmen[11]. His instrument however does not have the post- or follow-up component to determine if the differences among the cohorts persist over the course of a semester. Four commonly used instruments were examined: 1) Pittsburgh Freshman Engineering Attitudes Survey (PFEAS), developed at the University of Pittsburgh[12]; 2) Freshman Engineering Attitude Survey, developed at Texas A&M University[13]; 3) Entering Freshman Engineering Survey, developed at Arizona State University[14]; and, 4) Cooperative Institutional Research Program Survey developed at the UCLA Higher Education Research Institute[15].

We selected PFEAS as the base line instrument for this study because: 1) it was the most relevant since it was originally developed for a similar study; 2) the student attitude is measured by grouping the items under thirteen measures (factors) that are of interest in this study; 3) it had been extensively used by various institutions and cited in a number of refereed publications[16]; and, 4) it has an established high degree of validity and reliability[5]. The pre-version, comprised of fifty items, is designed to measure four facets of student attitudes: 1) student definition of engineering; 2) student attitude about engineering; 3) student self-assessed confidence; and, 4) student self-assessed skills including working in groups. The post-version has twenty additional items that capture student perceptions of their attainment of the eleven Engineering Criteria (EC) 2000 outcomes[17] as defined by ABET (Accreditation Board for Engineering and Technology). We preferred to use the pre-version since data mapping for EC2000 outcomes was not the scope of the study. The survey items are rated on either a five point Likert scale or an ordinal self-assessed confidence scale. Fifty items statistically cluster into thirteen attitudinal measures or sub-scales, as listed in Table I[18]. Sub-scales define the domain of the instrument's main construct, i.e., freshman attitude about engineering.

TABLE I
PFEAS SUB-SCALES

	Sub-scale Items	Sub-scale	Definition of Sub-scales
1	1-3,4*,5,6*,7,8*,9*	Career	General impression of engg@.
2	10,14,21,23	Jobs	Fin. influences for studying engg.
3	11, 20	Society	How engrs% contribute to society.
4	12,17,18,22,25,27,28	Perception	Work engrs. do & engg. profession.
5	13,19*	Math	Enjoyment of math & science.
6	15,26	Exact	Engg. perceived as exact science.
7	16,24	Family	Family influence to studying engg.
8	29,30,31,32,35	Basic	Confd# basic engg knowledge, skills.
9	33,34,35	Comm.^	Confd. in comm., computer skills.
10	39*,46	Study	Adequate study habits.
11	37,43*,45*	Groups	Working in groups.
12	38,40,42,49,50	Ability	Problem solving abilities.
13	36,44,47,48	Compatibility	Engg. abilities.

*reverse scored. @engineering. %engineers. #confidence. ^communication.

PERFORMANCE PARAMETERS

The cornerstone design sequence emphasizes a collaborative, open-ended, iterative, innovative, and creative design process. To assess the effectiveness of the sequence, we surveyed students' understanding, attitude, and beliefs about thirteen key issues in engineering both before and after they took the DS and TS courses. Our objective was to accurately measure student attitudes and then model change over time in each of these thirteen sub-scales for each group. The instrument has good validity and reliability and is expected to measure these attributes with precision. The performance parameters for this study are briefly explained below.

III. Dependent Variables (DVs)

Thirteen sub-scales of PFEAS (Table I) are the dependent variables or the outcomes. PFEAS sub-scales are the proven outcomes of factor analysis of a large sum of data from multiple longitudinal studies[19]. We normalized these outcomes with PFEAS factor loadings for ease of reference and standardization. With statistical modeling, the outcomes were examined for treatment effects (cornerstone design sequence) while controlling for the confounding effects of other variables.

IV. Independent Variable (IV)

"Group," a dichotomous variable, distinguishes between the two groups of freshmen; the DS (treatment) group and the TS (control) group. The DS group is comprised of freshmen registered in one or both of the new freshman courses; EGR 100 and EGR 102 (We dropped EGR 102 from analysis, as will be explained later). The TS group is comprised of freshmen not registered in the two new courses.

V. Other Variables

The sixteen variables available for this study could be grouped into three broad categories: background (age, gender, ethnicity, citizenship, resident state, resident county, high school attended); past performance (ACT composite., ACT math, SAT math, SAT verbal, high school GPA, Math competency); and present performance (FS07 GPA, SS08 GPA, SS08 CGPA). Some of these variables were not useful because of excessive missing data (SAT math, SAT verbal), low variability (age, citizenship, resident state), non standardized nature (high school GPA) and little relevance to the research question (resident county, high school attended).

- **ACT vs. SAT**: The ACT and SAT scores are highly correlated (r=0.854) and interchangeable[20]. We selected ACT since most of the applicants in the Midwestern region take the ACT. SAT scores were converted to equivalent ACT scores wherever the latter were not available or missing. ACT is comprised of two components; ACT composite. and ACT math. The two are known to be highly correlated. We preferred ACT composite. since it is broad based and commonly used for admission screening.
- **Math Competency**: This variable categorizes the freshmen into three groups: under-qualified, qualified and over-qualified. These groups are formed on the basis of students' math proficiency requirement for cornerstone courses. It is important to select variables that are reliable and pertinent predictors of the outcomes. Math competency was considered a good predictor but was dropped from the final analysis due: 1) high correlation with ACT comp. (Pearson Correlation=.560); 2) low cell count (n<10); and, 3) missing data (more on this later).

DATA COLLECTION

Data collection was done twice: at the beginning and towards the end of the semester. For maximum participation, the survey for the DS group was conducted during laboratory sessions using laboratory computers. Students were sent a link to the survey from SurveyMonkey®, a commercial provider for on-line surveys. EGR100 involved 450 students distributed in thirteen laboratory sections while EGR 102 had 45 students in two sections. The participation rate for DS group was approximately 85%. Freshmen in the TS group comprised of 227 students spread all over the campus; hence an on-line survey was the best option. TS group students were approached via the university's secure web mail and urged to respond. The participation rate for TS group was 21%. The data collection was affected for two reasons: 1) only subjects with both, pre- and post-responses could be considered for the study; 2) as per the federal regulations subjects under the age of 18 years could not take the survey. The sample size was further affected by control variables that were added to the model (more on this later). A data summary is given in Table II.

TABLE II
PRE-, POST-DATA COLLECTION

Survey Participants	TS Group		DS Group			
	Pre	Post	EGR 100		EGR 102	
			Pre	Post	Pre	Post
Total students	227	227	450	450	45	45
Participants	71	47	381	367*	43	38
Percent participation	31	21	85	83	95	84

*9 incomplete surveys dropped.

DATA ANALYSIS

Selection of Variables: An overview of the collected sample gives a description of freshman population. Major conclusions about the sample are given below.

- There was a large difference between the two sample sizes: 405 in the Post-DS group (EGR 100 and EGR 102); and, 47 in the Post-TS group (Table II). Large differences in sample sizes may affect the robustness of the model[21]. We dropped EGR 102 data from our analysis because: 1) it reduced the absolute difference in sample sizes without affecting the TS group; 2) it simplified the DS group dynamics, now belonging to one course, i.e., EGR 100. The sample sizes for DS and TS groups were now 368 and 46 respectively.

- The sample included 83% males, 17% females. The ethnic distribution was: 80% Caucasian, 5% Asian/Pacific Islander (PI), 8% African-American (AA), 3% other and 4% Not Reported (NR) as given in Table III.

TABLE III
GENDER AND ETHNICITY

Group	Gender			Ethnicity					
	M	F	Total	Caucasian	Asian/PI	AA	Other	NR	Total
DS	307	61	368	322	19	11	9	7	368
TS	35	11	46	10	3	22	3	8	46
Total	342	72	414	332	22	33	12	15	414
Percentage	83	17		80	5	8	3	4	

- In accordance with the DS course prerequisites for Math competency, 66% met the criteria (qualified), while 25% exceeded (over qualified) and 9% were below (under qualified) the criteria (Table IV).

TABLE IV
MATH COMPETENCY

Group	Under qualified	Qualified	Over qualified	Total
DS	6	255	95	356
TS	29	10	5	44
Total	35	265	100	400*
Percentage	9	66	25	

*14 missing values

- Low cell counts (n<10) in the two variables; "Ethnicity" and "Math competency," render them unfit for realistic analysis (see Tables 3 and 4). We therefore dropped these variables from data analysis.
- The two demographic variables, "Gender" and "ACT comp." could be effectively used in statistical modeling. An independent-samples t-test showed a significant difference between the two group means on "ACT comp." score (Table V): on average, the DS group had higher ACT scores than the TS group. It should work as an important covariate and be watched for any collinearity issues. "Gender" was, on the contrary, uniformly distributed between the two groups (χ^2 (1) = 1.399, p = .226).

TABLE V
INDEPENDENT SAMPLES T-TEST - GROUP VS. ACT COMP.

	Group Statistics			t-Test for Equality of Means					
	Group	N	Mean	t	df	Sig. 2-tail	Mean Diff.	99.9% Confd. Lower	99.9% Confd. Upper
ACT comp.	TS group	38	20.71						
	DS group	351	26.27	-9.395	387	.000	-5.560	-6.724	-4.397

Test Assumptions: Parametric tests are robust and powerful, and obviously more suited to our study if the underlying assumptions are not violated. Some of the key assumptions are linearity, normality, and homoscedasticity. Moreover outliers sometimes play an influential role in determining the most suitable approach for data analysis. We found SPSS diagnostic tools helpful in validating the parametric test assumptions.

- **Linearity:** Linearity is fundamental to multivariate statistics because solutions are based on the general linear model (GLM)[22]. General linearity of the relationship of variables was examined with scatter plots of raw residuals vs. predicted values superimposed with lowess smoothing line. Also, scatter plots of the covariate vs. outcomes were examined for specific nonlinearity between the two. We found no evidence of gross non linearity between the pre-, post- measures and the predictors.
- **Normality:** If there is normality, the residuals are normally and independently distributed[22]. We examined histograms and Q-Q plots of studentized residuals and found the outcomes normally distributed except for the evidence of few outliers in the data. The Central Limit Theorem supports the normality assumption (n>30).
- **Homoscedasticity:** The pattern of data spread was examined with scatter plots of studentized residuals vs. predicted values. The data were found to be homogeneous except for eight (out of twenty six) measures where evidence of heteroscedasticity was found. Box's tests of equality of covariance matrices[23] support the above pattern.
- **Influential Data:** Highly influential data points can change the fit of the model. On examination of Bubble plots of studentized residuals[23, 24], we found four data points highly influential in most of the outcomes (seventeen out of twenty six measures). The data points were highly influential due to large Cook's distance paired with large residuals and large leverage. A bubble plot of F5 (Pre- Math Enjoyment) is shown in Figure 1 with three influential data points duly highlighted.

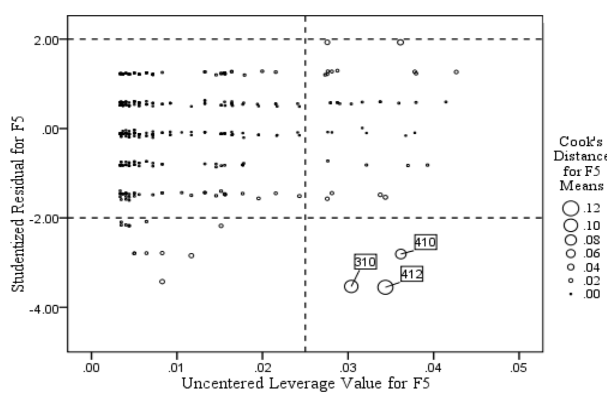

FIGURE 1
BUBBLE PLOT - PRE-MATH ENJOYMENT.

- **Data Transformation:** Removal of influential data points (all four belonged to the TS group) is neither justified nor recommended for a relatively small sized group. Rank transformation reduces the effects of influential data and reduces the importance of normality or homoscedasticity assumptions[21, 25]. It has the properties of robustness and power in the analysis of covariance[25]. We rank transformed the data and checked for the assumptions. While linearity remained unaffected (rank transformation has little affect on linearity), normality and homoscedasticity improved remarkably. Box's test confirmed equality of covariance matrices for all the thirteen outcomes. Bubble plots of rank transformed data show no influential observation (for example see Figure 2 for RF5; Rank Transformed Pre- Math Enjoyment).

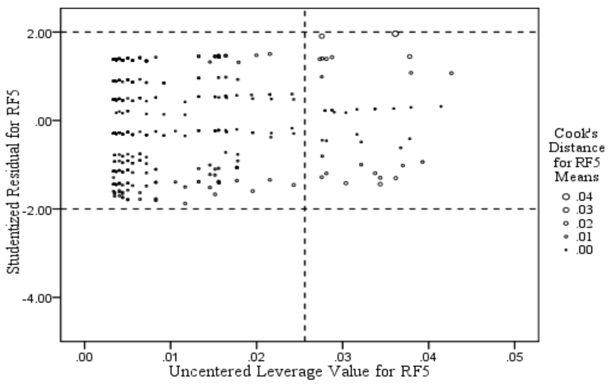

FIGURE 2
BUBBLE PLOT-RANK TRANSFORMED PRE-MATH ENJOYMENT.

Hypothesis Testing: A general linear model was selected with repeated measures analysis of covariance, to test the null hypothesis. Thirteen models were developed in SPSS 16.0 with "Gender" and "Group" as categorical predictors and "ACT comp." as a continuous covariate. The data was examined with and without rank transformation. We found similar results from both the approaches which supports the earlier findings about parametric ANCOVA being robust to violations of normality or homoscedasticity[21]. Table VI provides p-values for DVs.

TABLE VI
WITHIN- AND BETWEEN-SUBJECTS TESTS.

Pre-Post	Within-Subjects Effects	Between-Subjects Effects		
Measure	Time*Group	Group	Gender	ACT comp.
F1-M1	.222	.236	.676	.005
F2-M2	.515	.141	.569	.035
F3-M3	.879	.110	.239	.000
F4-M4	.081	.469	.659	.019
F5-M5	.740	.001	.529	.332
F6-M6	.176	.025	.036	.000
F7-M7	.391	.005	.242	.098
F8-M8	.058	.163	.000	.000
F9-M9	.895	.351	.445	.306
F10-M10	.712	.762	.594	.016
F11-M11	.221	.133	.323	.000
F12-M12	.400	.902	.019	.535
F13-M13	.127	.203	.000	.319

A summary of the analysis is presented below.

- Estimated marginal means indicate that students generally join the engineering programs with positive attitudes about engineering (Table VII). Two of the measures namely F7-M7 and F10-M10 show marginal results (M=2.490 and 2.566 respectively) implying marginal family influences on studying engineering and adequate study habits.

TABLE VII
ESTIMATED MARGINAL MEANS* OF OUTCOME MEASURES

Pre-, Post-Outcome	**Mean**	**Pre-, Post-Outcome**	**Mean**
F1-M1=Career	4.101	F8-M8= Basic	3.703
F2-M2= Jobs	3.573	F9-M9= Communication	3.668
F3-M3= Society	3.467	F10-M10= Study	2.566
F4-M4= Perception	4.215	F11-M11= Groups	3.138
F5-M5= Math	3.765	F12-M12= Ability	3.870
F6-M6= Exact	3.199	F13-M13= Compatibility	3.561
F7-M7= Family	2.490		

*Ranges 1 to 5, with high numbers meaning more positive perceptions.

- The "Time * Group" interaction (within-subjects effects Table VI) was not statistically significant for any of the thirteen outcome measures. It is hypothesized that a time frame of eleven weeks of engineering experience may not be enough to affect an appreciable change in the freshmen attitude towards engineering.
- Attitude scales, "Math Enjoyment" (F5-M5; p=.001) and "Family Influence" (F7-M7; p=.005) were significantly higher for the DS group while "Exact Science" (F6-M6; p=.025) was significantly higher for the TS group. These between-subjects effects (Table VI) mean that the DS group enjoys math and science subjects more, have higher family influences towards engineering and stronger belief that engineering is not an exact science. These attitudes could be due to a stronger background in math and science, higher ACT scores and stronger parental influence.
- The covariate, "ACT comp." significantly affects eight out of thirteen models (between-subjects effects Table VI). The variable has high correlation with the outcomes and is strongly related to the explanatory variable (Group) that exemplifies it as a good covariate.
- The variable, "Gender" significantly affects four measures (between-subjects effects Table VI), i.e., "Exact Science" (F6-M6; p=.036), "Basic Knowledge" (F8-M8; p=.000), "Problem Solving Ability" (F12-M12; p=.019), and "Engineering Ability" (F13-M13; p=.000). Females have lower scores than males in all these measures implying that females perceive engineering as an exact science more than males do; they have lower confidence levels in basic engineering knowledge and skills, problem solving abilities, and engineering abilities than their male counterparts.

LIMITATIONS

The study has three inherent limitations:

- Unequal sample sizes: 46 vs. 368, the size were further reduced to 38 vs. 351 when the ACT covariate (with 25 missing values) was added to the model. This reduces the ability (power) to detect differences.
- Short time duration between pre-, post- surveys conducted in the second and thirteenth week respectively. Eleven weeks of cornerstone design experience may not be enough for a significant treatment effect to manifest.
- Data collection methods for the two groups were different. Moreover, incentives for participation were not similar. The large differences in participation rates (see Table I: 85% for DS group vs. 21% for TS group), could have been due to selection bias.

CONCLUSION

The research study has helped us understand the cornerstone design sequence and its impacts on student attitudes about engineering. It has also contributed towards formative evaluation of the sequence indicating areas that need further development in the new freshman initiative that will help to further understand and improve the curriculum design efforts. We intend to continue the study in the coming semesters to gain more insight into the learning that takes place in the freshman courses with larger and similar sample sizes and preferably the same data collection methods. We also plan to substantiate our study by adding a qualitative component to include one-on-one interviews with randomly selected students, classroom observations, and a study of student artifacts, to make it more encompassing and useful for the formative evaluation of the new initiative. This exercise has set the foundation for a longitudinal study to track the two groups, examine their performance in the junior and senior years, and determine a relationship to the issue of retention in the engineering programs.

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† The study has been duly approved by the university's Institutional Review Board responsible for reviewing and approving research involving human subjects.