AC 2009-797: FORMING A CULTURE OF ENGINEERING: UNDERGRADUATE RESEARCH PROJECTS IN A DEVELOPING COUNTRY

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FORMING A CULTURE OF ENGINEERING: UNDERGRADUATE RESEARCH PROJECTS IN A DEVELOPING COUNTRY

Introduction

A one-hour class in an undergraduate research program called Creative Inquiry (CI) at a public university was designed to introduce engineering students to design work for projects in a developing country. The projects are under the aegis of Engineers Without Borders, a non-profit humanitarian group that is focused on water, sanitation, energy, and environmental issues. The purpose of this concurrent mixed methods pilot study was to better understand the efficacy of the course by comparing responses of active students to those of a control group. In this study, a five-choice, closed-ended survey using a Likert scale was used to quantitatively measure the relationship between student participation in the class and their understanding of engineering as being part of a community of practice. At the same time, two additional open-ended questions allowed students to give their primary and secondary reasons for becoming an engineer.

The value of this research was two-fold. First, we wished to gather knowledge with which to make systematic improvements to the CI class's structure and setting. Often called action research, this kind of research is quickly assimilated and implementable, and has the potential for bearing much immediate fruit[1]. The goal of the class is in creating an atmosphere of professionalism that is characteristic of a consulting engineer's office and work structure. Secondly, the findings may point to the need for a more in-depth study that will utilize student profiles and perceptions generated here.

Two educational theories are used to form the initial theoretical constructs or bases for the survey questionnaire. These are motivation theory and situated cognition, and both are described below.

No less than with elementary and middle-school students, educational success with college-age engineering students is hampered or enhanced by the motivations of immediate or future goals, and the usefulness of required behavior towards attaining those goals. Exit surveys reveal a variety of initial motivations for students to choose engineering as a major field of study, from the strong influence of parents or a teacher to the desire for a financially-rewarding career[2]. For understanding continued motivation within the program, the VIE (Valence-Instrumentality-Expectancy) theory is a useful tool. Put simply, the motivation to perform is based on the value of a behavior and its related goals (valence), the perceived probability that the behavior will lead to the goals (instrumentality), and the perceived likelihood of successfully performing the task or behavior (expectancy) [3]. Within a one-hour undergraduate research course, the goals tend to reach beyond intermediate goals, such as a good grade, and are focused on larger goals such as learning how to become an engineer and the desire to participate in a humanitarian endeavor.

Situated cognition is a theory of education which asserts that learning and cognition are fundamentally situated in a community of practice. In this community, learning is embedded in activity, and a kind of cognitive apprenticeship develops between a student(s) and a mentor.

Similar to constructivism, our construction of knowledge is only our interpretation and is based on our own cultural background and frames of reference. Furthermore, this community of practice has developed its own set of symbols, methodologies, rules and language, and successful apprenticeship involves a good grasp of each of these professional implements. Figure 1 demonstrates how this theory redefines pedagogy from a traditional to a critical mode.

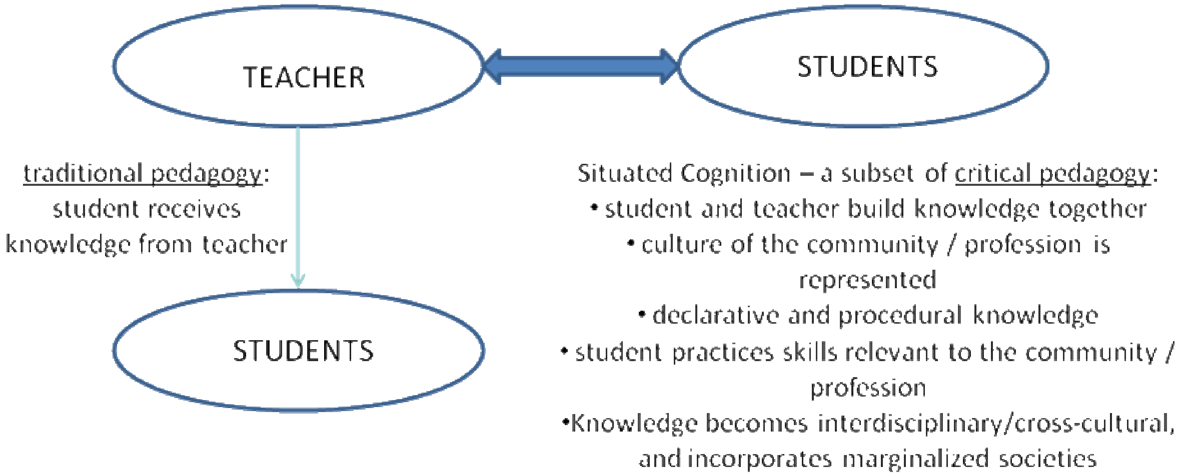

Figure 1. Graphical representation of the factors involved with learning based on the theory of situated cognition.

The tools of a trade can only be fully understood through usage, and people who use tools actively are building a rich comprehension of the world, or context, in which the tools will be used[4]. By learning and practicing simultaneously the tools of engineering – algorithms, equations, concepts – students are entering into a community of practice that has its own culture, stories, and language, one that they will later help to shape themselves. The community's domain, or shared agenda, is its *raison d'etre* that provides a level of focus and purpose that sustains the community through changes in leadership and membership, as well as through shifting emphases[5]. The structure of an undergraduate research project offers an ideal setting for forming such a community of practice.

Creative Inquiry Class with Engineers Without Borders

Our institution has an undergraduate research program called Creative Inquiry (CI) which promotes and supports small, focused classes that utilize discovery-oriented approaches to learning. Projects are chosen with the goal of nurturing students' capacities to find, analyze and evaluate information. In doing so, students will likewise develop reasoning and critical thinking skills, teamwork experience and communication skills. Engineering classes in this program are not only well sought-after by students, but also directly address many of ABET, Inc.'s accreditation program outcomes listed in criterion 3, subsections (a) through (k)[6].

A CI class was designed to complement an ongoing Engineers Without Borders (EWB) project in El Salvador with critical design components in the field of environmental engineering. Students choose to work on one of various project modules, including the design of gravity-flow water distribution, a playground mechanical pump for the filling of an elevated water tank, the usage of solar power for water pumping and low-load office equipment, and evaluating various options for plastic waste collection and recycling. Older graduate students and several practicing engineers act as mentors and resources to younger students who are being introduced to such methodologies as Bernoulli's equation, solar design, and pump sizing principles in the project sometimes even before they ever study these in a classroom setting. These students are then asked to give presentations to a wider student audience in the EWB general chapter meetings as well as to Rotary Club luncheons as part of an initiative to acquire project funding.

In an effort to establish a kind of "consulting engineer" environment, students were asked to keep a timesheet, modeled after an actual consultant's timesheet, that was used to record "billable" and "non-billable" hours, as these pertained to the project, and to itemize these hours with brief descriptions as to how the hours were used. The "client" in El Salvador was contacted on an as-needed basis using conventional e-mail or SKYPE via the Internet. Each module group was given a "deliverable" to produce, either in the form of a written paper, poster or presentation, to be delivered either to the Salvadoran client, EWB chapter, or the larger EWB community at a conference. Students were exposed to the fluidity and changeability of the project's focus, lack of needed data to complete a design, and all the frustrations and surprises that come from working with a client, typical of a consulting engineering firm.

Methods

The constraints on this study were primarily the limited time available before the end of the semester and limited time with the students themselves. Thus, data was collected at one cross-section in time (at the end of the course) using a survey instrument. The survey included both close-ended and open-ended items in order to extract not only quantitative profiles of students regarding their beliefs and motivations associated to engineering but also qualitative descriptions of what motivated them to choose an engineering profession. The open-ended questions were used only to provide supporting evidence, where appropriate, of the results of analysis of the rest of the survey.

For the survey, the students in the class were asked to personally invite one or more of their peers who were at exactly or about the same stage in the core curriculum of their particular discipline. In other words, the only difference between the two groups was that the invited students were not in the CI class or involved with EWB in any way. Both CI and non-CI invited students took the survey together and shared complimentary pizza during a special evening session. The two groups used in this study were all undergraduate engineers and are profiled in Table 1 below. There were no first year engineering students included, but 39% (11/28) were sophomores, or the first year in their respective disciplines. The remainder (61%) were juniors and seniors.

Table 1. Profile of two student populations for the current study.

	In Class (treatment, n=13)	Not in Class (control, n=15)	Total
Male	9	12	21
Female	4	3	7

Civil Engineering	4	0	4
Mechanical Engineering	4	7	11
Industrial Engineering	2	4	6
Bioengineering	1	1	2
Electrical Engineering	2	3	5
Industrial career aspirations	4	11	15
Non-industrial career aspirations (teaching, government, consulting, self-employment)	9	4	13

A survey had been developed and used to assess the motivation and attitudes of undergraduate engineering students using VIE (Valence – Expectancy – Instrumentality) theory as a theoretical basis[7]. Additional questions were added to this survey to test assumptions regarding situated cognition as a working theory for engineering education. For example, these questions asked the students whether engineering as a profession involved working on a team, working with mentors or older engineers, possessing its own tools, methods and language, and included being a part of a community of like-minded people working on a common problem or project. The internal consistency reliability for the 47 close-ended items (rated on a 5 point Likert scale) measured by Cronbach's Alpha is 0.90. In addition to the close-ended items, two open-ended questions were asked in the survey – "What is your primary reason for wanting to become an engineer?" and "What is your secondary reason for wanting to become an engineer?"

Results were analyzed in the following three ways:

(1) Factor Analysis: Responses to the 47 closed-ended questions were analyzed using factor analysis with SPSS 16.0 statistical software. As a result of the analysis, the questions were grouped together into seven conceptually meaningful factors, or groupings of responses with strong correlations, partly based on the VIE and situated cognition (SC) theoretical frameworks. Several questions remained as stand-alone items because they did not load heavily into any one factor. These items may need to be revised for future administrations of this survey. The results of the factor analysis are presented in the results section below.

(2) Group Comparisons: The stand-alone items and eight factor groupings were then examined to see if the two groups – in class and not in class – showed significant differences in how they responded. This analysis was done using independent sample t-tests. In addition, we also compared the difference in likelihood between the groups in choosing an industrial career using a Mann-Whitney U test. These results were compared with the findings from the open-response questions.

(3) Factor Comparisons: Although not the focus of this work, we also compared the factors and stand alone items across all the students to examine the strength of the relationship between them for this sample.

Results

The seven factors that resulted from the factor analysis are summarized in Table 2. In addition, we mapped the factors to our initial constructs (Valence, Instrumentality, Expectancy, and Situated Cognition) and listed the program outcomes from ABET Criterion 3 (a) through (k) that were assessed by the survey.

Table 2. Factor Labels, component items, and theoretical mappings.

Factors	Component Items [ABET Criterion 3 outcome]	Theoretical Mappings
Program Satisfaction (F1)	My overall attitude about my engineering department is positive. I am struggling with my college courses. I am struggling with my engineering courses. I am having to work harder than many of the other students in my classes. The university is preparing me well to become an engineer. I am dissatisfied with my educational progress.	V, I, & E
Engineering Career Aspiration (F2)	I want to be an engineer. I enjoy applying what I know in my classes. The field of engineering is interesting. I am considering switching majors. I am confident about my choice of major.	V
Confidence in Technical Skills (F3)	I can analyze and interpret data. [3(b)] I can use the techniques, skills, and modern engineering tools necessary for engineering practice. [3(k)] I can identify, formulate, and solve engineering problems. [3(e)] I can think critically. I can apply my knowledge of mathematics, science, and engineering. [3(a)]	E
Coursework Satisfaction (F4)	My course work gives me practical engineering skills. [3(k)] I get satisfaction from my coursework. In my engineering coursework I am able to practice engineering skills. [3(k)] My course work is preparing me for my first job. I have received the broad education necessary to understand the impact of engineering solutions in a global and societal context. [3(h)]	I
Engineering Interactions (F5)	Engineers often work as part of a team. [3(d)] I get satisfaction from my presentations in engineering classes. The practice of engineering typically involves working with a mentor or senior engineer.	SC
Engineering Practice (F6)	In the engineering profession, mentors and novices often learn together. I have an understanding of professional and ethical responsibility. [3(k)] I can design a system, component, or process to meet desired needs. [3(c)] I am committed to engaging in life-long learning. [3(i)]	SC
Confidence in Communication (F7)	I can articulate my ideas in front of my peers. [3(g)] I can speak effectively in front of an audience. [3(g)] I lack self-confidence.	E

Despite the small group sample sizes (n=13 in CI class and n=15 not in the CI class), there was one significant difference found from amongst the stand-alone items and one difference that was borderline significant (i.e., just above the 95% confidence level) from amongst the factors. The results of the group comparisons are illustrated in Figure 2. First, there was a significant difference regarding responses to the question: “The engineering profession has great humanitarian potential,” with in-class students being significantly more in agreement (p = 0.028). One CI student wrote as a response to the open-ended question: “I want to help improve the standard of living for people all over the world.” Another wrote: “I want to do fulfilling work that matters.”

One possible explanation for these results is that the CI class group was self-selected as a community that, in general, sought a concrete application to their classroom instruction and who saw the engineering profession as having an important humanitarian aspect. Another possibility is that the CI class led students to be more aware of the humanitarian potential in engineering professions. Unfortunately, we are unable to rule out either of these possibilities since time limitations restricted us from collecting survey data at the start of the class to measure students' starting states.

The second difference found indicated that the CI class group showed lower satisfaction with their engineering program (F1) than the non-CI class group (p = 0.054, not significant at the 95% confidence level). This finding is consistent with anecdotal evidence from members of the class who feel like they are not getting enough practical applications of theory in their engineering classes. Clearly, for students who opted into taking the CI class, there was more of a mismatch between their expectations and their engineering program.

Finally, we found a significant difference in the career paths of the two groups. Students who were not enrolled in the CI class were significantly more likely to choose a career in industry than those who were in the CI class (p = 0.027). The CI class students wished to pursue non-industrial careers, such as academia, consulting, government and self-employment . This is an important finding because the students who were bound for non-industrial careers also had a significantly higher rating of their confidence in their technical skills (F3) (p=0.043). Perhaps those students bound for industrial careers, who have less confidence in their technical skills, *believe* that a job in industry will limit their problem-solving challenges to designs that are easily solved with structured, algorithmic solutions. Thus, they may not have to "think outside the box" or use technical/critical thinking skills as extensively. One CI class student wrote: "I want to become an engineer (because I have an) interest in complex problem-solving." However, we note that this hypothesis is one that concerns "perception" of engineering in industry rather than reality, and should be tested with further research. Indeed, many engineering innovations arise from the industrial sector where engineers are required to develop solutions within constraints unique to their industry.

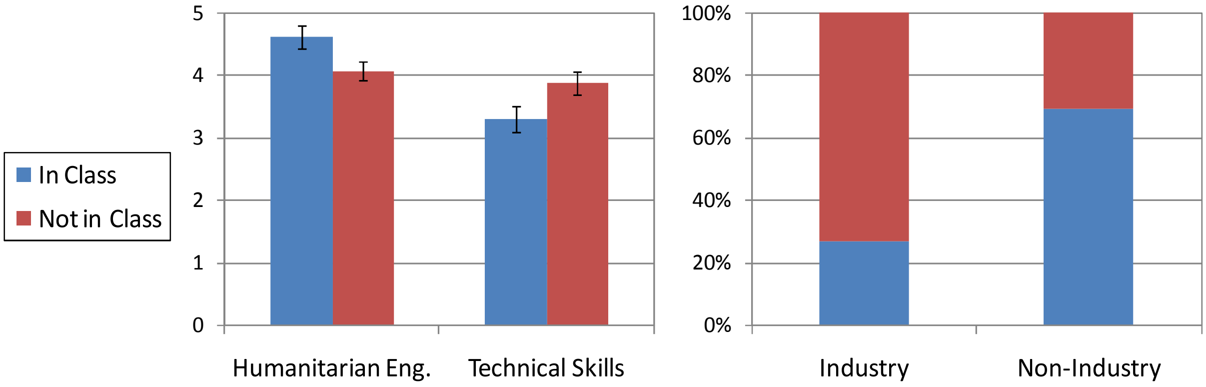

Figure 2. Differences between preferences as indicated on survey responses for students in CI class and not in CI class.

The final analysis was concerned with grouping the seven factors. These seven factor groupings and stand-alone items were correlated to each other, and the results are shown in Table 3 below. Results from this analysis suggest that, in this sample population at least, those who aspire strongly to an engineering career also understand the profession to have a community component. In addition, satisfaction in project design comes at least partly from confidence in technical and communication abilities. For example, satisfaction in project design was highly correlated with positive responses to “I can speak effectively in front of an audience” and “I can articulate my ideas in front of my peers”.

Table 3. Correlation chart for seven response factor groupings across select stand-alone items and other factors.

	Program Satisfaction (F1)	Eng. Career Aspiration (F2)	Confidence in Tech. (F3)	Coursework Satisfaction (F4)	Eng. Interactions (F5)	Eng. Practice (F6)	Confidence in Comm. (F7)
I am having fun in my major.	0.46*	0.55**	ns	0.47*	ns	ns	ns
I am encouraged and supported in my studies by the engineering faculty.	0.45*	ns	ns	ns	ns	ns	ns
I have developed a knowledge of contemporary issues through my engineering courses.	ns	0.46*	ns	ns	ns	0.40*	ns
Being an engineer is being part of a community of like-minded people working on a common problem or project.	ns	0.51**	ns	ns	ns	ns	ns
Engineering is a profession with its own methods / tools / language.	ns	ns	0.38*	ns	ns	ns	ns
I get satisfaction from my design projects.	ns	ns	0.61**	ns	ns	ns	0.49**
Engineers are respected by society.	ns	ns	ns	0.50**	ns	ns	ns
I feel pride when I tell others that I am an engineering major.	ns	ns	ns	ns	ns	0.40*	ns
Eng. Practice (F6)	ns	ns	0.46*	ns	ns	ns	ns

* Correlation is significant at the 0.05 level (2-tailed).
** Correlation is significant at the 0.01 level (2-tailed).
ns - not significant

Conclusions and Future Work

This pilot study has provided baseline data upon which a more thorough investigation can be conducted into measuring the effect of the CI class on students’ perceptions of engineering as a profession. Analysis of the reliability and validity for the seven factors elucidated in the factor analysis, as well as the survey as a whole for this population, will be performed. In order for the survey to be a truly effective instrument in this case, a pre- and post-class survey should be given. The CI course is not required as part of the engineering curriculum, nor is any other CI course required. Thus, the motivation to take the course is purely individual, something which a follow-up survey could specifically address. Because many students will choose to take the class more than one semester, the post-class survey could be implemented after several consecutive semesters of in-class participation, or during each semester of participation. Such a set of tests would provide a clearer answer to the question of whether the CI students are self-selecting in regards to the issue of engineering's humanitarian potential or if the class is raising discrete awareness of such. A pre/post survey could also address whether or not the students were self-selecting on the basis of wanting to hone more of their technical skills, in contrast to many of their peers who feel more confidence in this area a confidence that is postulated on the latter's choice of an industrial career.

The authors plan on using this initial survey to form a basis for a qualitative instrument that more pointedly asks the respondents to give their perceptions about what an engineer does and how she/he works in a typical setting. The instrument would also gauge perceptions about how this image is being supported by the curriculum in general, and by the CI class in particular.

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