

**AC 2009-2283: A DEGREE-PROJECT APPROACH TO ENGINEERING
EDUCATION**

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A Degree-Project Approach to Engineering Education

Abstract

Chemical engineering education is facing a growing disconnect between a *curriculum* focused primarily on “unit operations” (e.g., heat exchangers and distillation columns) and *faculty research* that has increasingly emphasized nano- and bio-technology. This discrepancy was recognized by an NSF-sponsored *Frontiers in Chemical Engineering Education* initiative, recommending a move from the macroscopic, unit-operations educational approach to instead teach from the molecular point of view in a bottom-up fashion. The challenge, however, is to continue to serve the more conventional chemical and petroleum industries while instituting this change. At USC we have developed the two-pronged approach of utilizing (1) a recently-created nanotechnology course-work emphasis within the Department of Chemical Engineering and Materials Science, and (2) vertically- and horizontally-integrated “degree projects” consisting of nano or bio laboratory modules in successive chemical engineering courses that build upon a student’s growing knowledge in their chosen emphasis, while at the same time relating the degree project to traditional areas of chemical engineering. Students in the nanotechnology emphasis, for example, synthesize nanoparticles in the *Mass Balance* course, examine the interaction strength between these nanoparticles in *Thermodynamics*, size-fractionate these nanoparticles in *Separations*, investigate nanoparticle catalyst in *Kinetics*, and examine the thermal conductivity of nanocolloids in *Heat Transfer*, all culminating with an independent research project in the senior year.

A comprehensive assessment strategy is utilized to study these changes to the chemical engineering curriculum in collaboration with faculty in Engineering and Education. Three assessment measures are utilized, including an observational rubric, a chemical engineering efficacy scale, and a chemical engineering multidisciplinary scale. This allows robust evaluation of how the merger of traditional chemical engineering subjects with advanced nanotechnology and biotechnology topics using a degree-project approach may better prepare students for today’s increasingly molecular-oriented workplace.

Introduction

Education in Chemical Engineering (ChE) education is currently facing a crossroads. There is a disconnect between the *curriculum* (which is largely focused on unit operations, e.g., heat exchangers, distillation columns, etc., and heavily geared towards commodity chemicals) and *faculty research* (which has recently emphasized nano- and bio-technology). Furthermore, there is a disparity between the courses students take and the diversity of industries they will serve (approximately 25% of graduates go to work in the chemical industry, while the biotech, food, fuels, and electronics industries continue to aggressively hire ChE graduates). Indeed, the large amount of academic and industrial research in the nano and bio areas will likely result in new technologies, which will lead to an even greater number of graduates working in nontraditional enterprises. This challenge substantiates the need to engage undergraduates in project-based, inquiry learning that requires higher order thinking.

An NSF-sponsored, cross-departmental *Frontiers in Chemical Engineering Education* initiative,¹ recommends a paradigm shift in the way Chemical Engineering be taught with an intent of moving away from a macroscopic, unit-operations educational approach toward a molecular point of view. While this allows students to be uniquely prepared for 21st century jobs in emerging microelectronics and biotechnology fields, the challenge becomes to continue serving conventional chemical and petroleum industries.

Accordingly, we developed a two-pronged approach to this challenge. The first approach involves formal *coursework emphases* in key areas of science and technology: bioengineering, polymer science, petroleum engineering, and environmental engineering, along with a recently-created nanotechnology option, as seen in Figure 1. Each emphasis allows our undergraduate students to tailor their education by augmenting their core ChE courses with five to six targeted courses in a particular area; thus, each emphasis acts as a “mini-minor”.

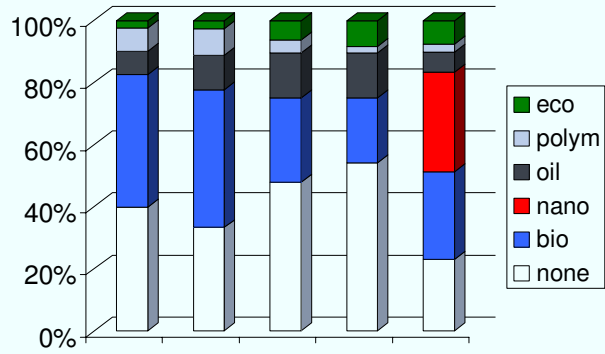


Figure 1. Percentage of students selecting each emphasis in Chemical Engineering.

The second approach uses laboratory research experiences as an integral part of the undergraduate education process. We have recently begun modernizing our curriculum by including emphasis-specific laboratory experiments associated with each ChE course, using a hands-on integrated approach of “*degree projects.*” Accordingly, students pursuing a nano emphasis will have a degree project entitled “Nanoparticles,” as illustrated in Figure 2. To augment the traditional approach utilized in the *Material Balance* course, the nano students perform a mass balance as they synthesize nanoparticles during the first stage of their degree projects. Sequentially, in their *Thermodynamics* course, in parallel with learning about molecular interactions of ideal gases and solutions in the classroom, the students examine nanoparticle interactions in the laboratory via nanoparticle packing at a surface as the second stage of their degree project. Similarly, while learning about chemical purifications in their *Separations* course, the students fractionate nanoparticles based on size in their degree-project

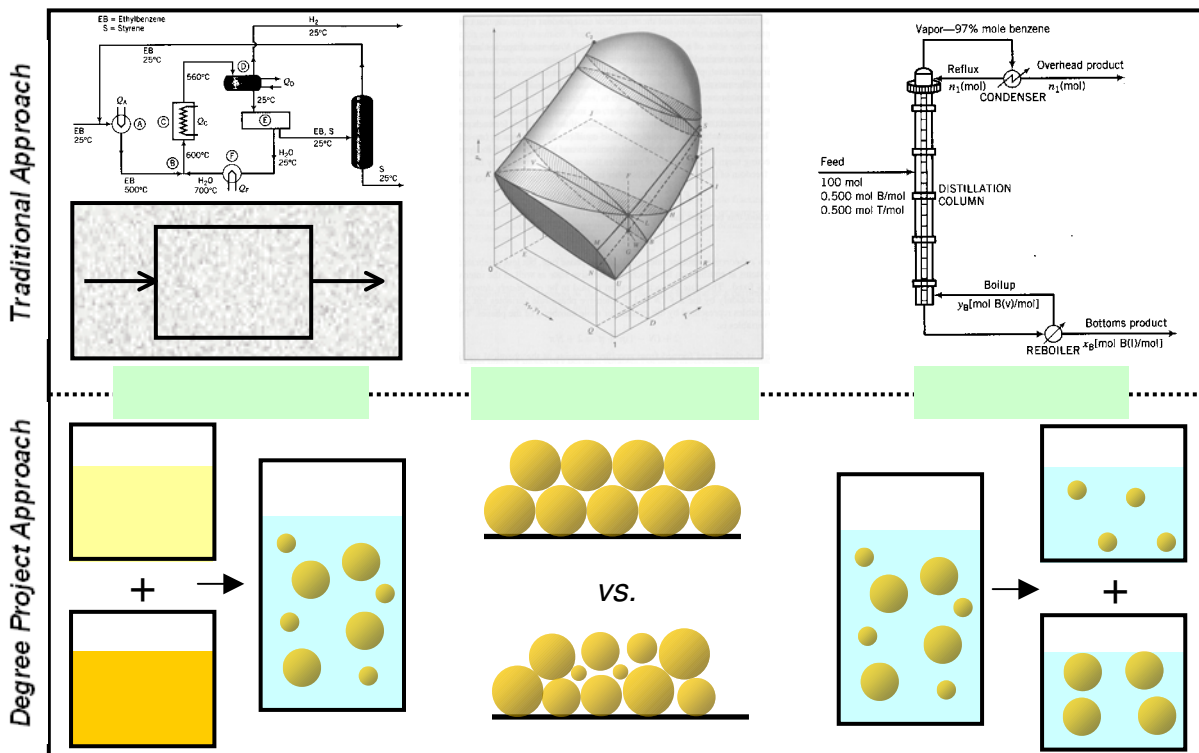


Figure 2. Illustration of the degree project approach to modernize ChE education.

laboratory module. Continuing with this theme, subsequent classes lead to additional modules of the degree project (fully described in Table 1), which culminates with the students performing an independent research thesis in their senior year. These degree projects allow students to experience first-hand how their emphasis (in this case nanotechnology) can be directly related to traditional chemical engineering courses.

Challenges in Chemical Engineering Curriculum

While the goal is clear, achieving this goal presents unique challenges. The Chemical Engineering curriculum is already quite demanding both in terms of the total number of courses students complete and the material that must be covered in each core course. As it relates to the emerging nano- and bio-technology areas, the solution is not simply to add a few nano/bio courses to the existing curriculum, or a few related lectures to each course. The latter option may be a quick fix, it is doubtful that simply applying a nano or bio “coat of paint” to existing courses will serve the students well. Given the wide differences between the macroscopic and molecular approaches to teaching the students may end viewing nanotech and biotech as unrelated, rather than integral parts of their ChE education.

We have chosen to address these curricular and pedagogical challenges by bringing undergraduate research and laboratory experiences into the classroom. This has been accomplished through the creation of *degree projects*: projects that will span the entire four years of a student’s undergraduate education. For example, students pursuing a nano-emphasis have a degree project entitled “Nanoparticles”, while the degree project for bio-emphasis students is “Cellular Processes” (see Table 1). Similar to the nano degree project illustrated in Figure 2, the bio students grow *E. coli* cells in the *Mass Balance* course, investigate protein-protein and protein-ligand interactions in the *Thermodynamics* course, recover active enzymes that have been overexpressed in *E. coli* in the *Separations* course, study enzymatic catalyst in the *Kinetics* course, and examine thermal denaturation of proteins in the *Heat Transfer* course. In the senior year, the students perform an independent research project under the guidance of a faculty member, which expands upon the knowledge gained in these degree project modules. In this way, students build upon the focused knowledge gained in their respective emphasis (e.g., nano- or bio-technology), and see how the traditional subjects of Chemical Engineering can be applied to these areas. This experimental-learning strategy has several advantages over the “coat-of-paint” approach mentioned above, particularly in the context of the four “essential elements of a new curriculum” recommended in *Frontiers in Chemical Engineering Education*:¹

1. Relevant and topical – nanoparticles in various forms (inorganic, biological macromolecular, etc.) and cellular processes are finding increased industrial use.
2. Horizontal (over-time) and vertical (cross-course) integration – the degree project last four years, connecting each core course with a central theme.
3. Real-world context and challenges (open-ended, complex, etc.) – the independent research project in the senior year is open-ended, as opposed to a typical well-defined/structured lab.
4. Reopen the flow of ideas from graduate research to the undergraduate curriculum – the laboratory component of the degree project exposes students to modern research.

By addressing these four essential elements with our new curriculum, we serve as a model for other engineering departments throughout the country.

The ChE Degree Project Design

This curricular reform effort had two primary objectives: (1) to add a nanotechnology course-work emphasis to the existing emphases within the Chemical Engineering Department and (2) to develop degree projects consisting of emphasis-specific laboratory modules associated with each core Chemical Engineering course, culminating with an independent senior thesis. Each of these efforts are discussed below.

Nanotechnology Emphasis. In order to graduate with a Chemical Engineering-Nanotechnology degree, students take five carefully selected courses in the nano area, which range from *fundamental* (theoretical) to *technical* (hands-on) to *engineering science* (a mixture of fundamental and technical). These courses, and particularly the “signature” course for this emphasis (CHE 487), have been selected with the question in mind of “where do our students go to work after graduation?” This was done because it does not serve the students well to prepare them for generic nanotechnology jobs that may not exist; instead, we have designed this emphasis based on jobs that have already been offered and occupied by our recent graduates in the materials, microelectronics, bio-nano (e.g., proteins and enzymes), and complex fluids (i.e., colloids) areas. The courses selected for the nano emphasis are described below:

CHE 487 Nanotechnology and Nanoscale Engineering Through Chemical Processes

Focus: Chemical engineering fundamentals and engineering science

Topics: Properties of materials on the nanometer scale, probes capable of visualizing matter on these length scales, techniques of processing nanoscale materials.

CHE 491 Nanotechnology Research for Undergraduates

Focus: Experimental learning

Topics: Individual research for the completion of the degree project, to be taken during both semesters in the senior year.

MASC 350 Design, Synthesis and Processing of Engineering Materials

Focus: Engineering science (top-down approach to nanotechnology)

Topics: Structure, properties, synthesis, and design of metallic, ceramic, polymeric, electronic, composite, nanostructured and biomaterials; microfabrication.

CHEM 453 Advanced Inorganic Chemistry

Focus: Fundamental (bottom-up approach to nanotechnology)

Topics: Atomic and molecular structure, bonding, coordination compounds, transition and nontransition metals, magnetic and optical properties, crystal field theory.

Nanotechnical Electives

EE/MASC 438L Processing for Microelectronics

Focus: Technical (microelectronics)

Topics: Applications and electrical evaluation of selected processes used in electronic microfabrication.

-or- ***CHE 489 Biochemical Engineering***

Focus: Technical (bionanotechnology)

Topics: Biological and biochemical processes and materials, separation/purification of biological products; proteins, enzymes, and nucleic acids.

-or- ***CHE 463L Introduction to Transport Processes in Porous Media***

Focus: Technical (nanomaterials)

Topics: Properties of porous materials, single- and multi-phase flow through porous media; diffusion, dispersion, and heat transfer.

Beginning in the first semester of the junior year, the nano-emphasis students take MASC 350, an overview course that introduces students to material properties at the nanoscale in a (top-down approach to nanotech). Then in the following semester, the students take two nano-emphasis courses. CHE 487 builds upon MASC 350, but from the point of view of chemical processing and detailing the specifics of how Chemical Engineering can be applied to nanotechnology. Simultaneously, students take CHEM 453 Inorganic Chemistry, where they learn the fundamentals of chemistry at atomistic length scales (bottom-up).

Armed with an introduction to nanotechnology, and seeing how nanotechnology fundamentals can be applied through Chemical Engineering, the students take two additional courses in their senior year. The first is CHE 491, the senior research/laboratory project, described below. The second is a *nanotechnical* elective. Given the richness and multifaceted nature of nanotechnology, this allows students to tailor their nanoemphasis based on their particular interest (and degree project): EE/MASC 438L for microelectronics, CHE 489 for “bionanotechnology”, and CHE 463L for nanomaterials.

Degree Projects. The experimental learning approach offered by the degree projects represent the central and most important aspect of this curricular reform. As the name implies, the degree projects span the entire four years of a student’s undergraduate education, where students in the various coursework options have *a corresponding research/laboratory module associated with each undergraduate course*, as illustrated in Table 1.

Table 1. The Degree Project Course vs. Experiment Matrix.

Core ChE Course	<i>Nanotechnology</i>	<i>Biochemical Engineering</i>	<i>Polymer Science</i>	<i>Petroleum Engineering</i>	<i>Environmental Engineering</i>
<i>CHE 120: Mass Balance</i>	Synthesize nanoparticles	Grow <i>E. coli</i> cells	Perform polymerizations	Fractionate <i>n</i> -component feeds	Investigate side-reactions of contaminants
<i>CHE 330: Thermodynamics</i>	Examine nanoparticle interactions	Protein-protein, protein-ligand interactions	Determination of the θ -solvent conditions	Aliphatic and aromatic interactions	Partitioning of contaminants from org. to aq.
<i>CHE 350: Separations</i>	Fractionate nanoparticles based on size	Recover viable proteins from cells	Separation of monomer from polymer	Separations based on volatility (GC)	Ultra-separation of contaminants (~ ppm, ppb)
<i>CHE 442: Chemical Kinetics</i>	Investigate nanoparticle catalyst	Examine enzymatic catalyst	Study emulsion polymerization reactions	Using petro chems. in rxns (combustion)	Rxn rates in VOC vs. eco-solvents
<i>CHE 445: Heat Transfer</i>	Thermal conductivity of nanocolloids	Thermal denaturation of proteins	Thermal conductivity of polymer sols	Heat transfer in fuels combustion	“Micro” global warming, UV and O ₃ removal

offered Spring 2005, implemented Spring 2006, remainder online 2007 (other options)

A key characteristic of these degree project modules is that they utilize very sophisticated, contemporary scientific equipment as a means of using experiential learning to connect modern Chemical Engineering education with traditional Chemical Engineering approaches.

As illustrated in Table 1, the nano-emphasis students have a degree project entitled “Nanoparticles”. Beginning in their freshman year *CHE 120 Introduction to Chemical Engineering* course (i.e., mass & energy balances), the students synthesize nanoparticles, and investigate whether a mass balance indeed holds, namely if “mass of raw materials in” = “mass of nanoparticles out” + “by-products, if any”. While the students perform many “on paper” mass balances in class, they will likely remember this lab long after graduation. In the sophomore year *CHE 330 Thermodynamics* course, the students work with nanoparticles similar to those

that they produced in *CHE 120* to investigate nanoparticle interactions via packing of a monolayer of nanoparticles on a surface. Here the students find that the polydisperse size distribution of the nanoparticles they created prevent regular packing. This leads them to *CHE 350 Separations*, where they fractionate nanoparticles based on size in order to obtain monodisperse samples. Then in *CHE 442 Kinetics*, the student use these fractions of monodisperse samples as nanoparticle catalyst in order to investigate the effect of particle size on surface reaction rate (surface area = $4\pi R^2$, where R is the nanoparticle radius). The final application is in *CHE 443 Heat Transfer*, where students add metal nanoparticles to antifreeze (i.e., ethylene glycol) as a means of increasing the thermal conductivity and with this antifreeze efficiency, while not clogging engine parts since nanoparticles are incredibly small.

The culmination of the degree projects occurs in the senior year, where the students engage in independent research based on what they have learned in the experimental modules and coursework emphasis. The students are presented the task to *develop* a hypothesis, *devise* an experimental approach based on the techniques previously employed, *design* an appropriate system to study their hypothesis, and to *re-engineer* effective solutions as problems arise.

Impact on the Undergraduate Curriculum

In the Department of Chemical Engineering and Material Science we have changed the way Chemical Engineering is taught, and the work discussed in this paper represents an integral part of this effort. To continue to teach traditional Chemical Engineering topics, while at the same time adopting a molecular framework for education, represents a significant challenge. To accomplish this, we utilize a two-fold approach, combining the recent creation of a ChE-N coursework emphasis, as well as utilizing the “degree project” approach within this. The combined effort of specialized course-work in tandem with a degree project represents a dramatic and ambitious overhaul of the ChE program. By providing coordinated undergraduate research opportunities *beginning in the freshman year*, we are able to demonstrate how traditional ChE courses and approaches can be applied to nanotechnology.

It is hoped that our efforts will serve as a model for other STEM departments. Indeed, the flexible nature of the “plug-in” laboratory modules is ideally suited for this transferability. Clearly, the nano-lab module(s) that we utilize in the Chemical Engineering *Thermodynamics* course may need anywhere from a minor adjustment to a total redesign in order to be applied. It is not the specific lab modules that are the “selling point” here. Instead, it is the mechanism by which degree projects can be incorporated into an existing curriculum that is the key and novel concept. Once the framework allowing for this incorporation has been established, it becomes relatively easy for other STEM departments to apply the same methodology by selection (or creation) of lab modules that mesh with the traditional courses of each individual major, and better match the scientific instruments available to a given department. The model of a continuous four-year, experiment-driven degree project that builds upon each consecutive course and relates nanotechnology, biotechnology, etc. to traditional science and engineering is a general one that has widespread applicability.

Project Implementation and Impact on Existing Courses. One of the advantages of the degree-project approach is that the impact on the existing curriculum is minimal. Each degree-project module functions as a course project, and typically will require only about 5 hours of student time or less to perform. In this manner the traditional material covered in these courses does not need to be cut at the expense of modernizing the curriculum. However, as will be

shown below, the impact of these small individual class modules, when are summed over the entire four years, can be quite large.

Efficacy Behind the Degree Projects Approach

As stated by Feisel and Rosa,² in order to evaluate the success of an undergraduate educational program that involves a laboratory component, a set of clear student learning objectives is required. In spite of this, however, generic and often amorphous “course goals” are used in lieu of precise student learning objectives to assess the success of instruction. This was recently addressed by ABET, a body very concerned with the use of objectives as a means of accreditation, and in 2002 a colloquium amongst the top minds in engineering was convened to help answer this question of the fundamental objectives of instructional laboratories in engineering education, and a list of 13 objectives were defined.³

Broadly, these 13 objectives can be broken down into three areas of learning: the *cognitive domain* (intellect and attaining knowledge), the *psychomotor domain* (physical development), and the *affective domain* (emotions, feelings, and values). While a typical lab covers the cognitive domain, the psychomotor and affective domains often receive less attention; however, stimulating all three domains is necessary for the development of effective engineers.² Furthermore, standard undergraduate laboratories, which utilize existing equipment and consist of well-structured procedures,⁴ fall short of meeting many of the individual objectives: *Experiment* (devise an experimental approach), *Design* (design an appropriate system), *Learn from Failure* (re-engineer effective outcomes), and *Creativity* (independent thought).

Within the time constraints of a typical three-hour block for lab, students are simply unable to design, re-engineer, think (for themselves), or select as they follow a step-by-step procedure. The independent research in the senior year of the degree project serves to address many of these shortcomings. Further, experimental results are by their very nature contextual – depending on the experimental conditions, sample preparations, and a host of other factors. Thus, this research-based approach serves to teach students a valuable lesson: knowledge is not certain, and instead must be viewed from the context of the problem at hand. This transition from a certain to a questioning view of knowledge is a key milestone in the developmental progression of students,⁵ as they transition from high school to functioning, critically-thinking engineers.

Participants in the Program

Over the course of the two years of implementation, a total of fifty-seven students in chemical engineering participated in the project. Fifty-four percent of the students were male and the remaining forty-six percent of the student participants were women. Interestingly, this gender breakdown is somewhat atypical in traditional engineering programs, making us curious about the effect that gender had on program results. Accordingly, as we analyzed the data collected for the project, we analyzed the results by gender in some incidences.

Degree Project Preliminary Results

To measure the impact of the degree project approach to chemical engineering education, we collected a variety of data, looking both at the students’ knowledge gained in the degree project courses, the degree of multidisciplinary that they had resulting from the experiences and their engineering efficacy (an indicator of their confidence as chemical engineering students that is highly correlated to their ability to be successful practicing engineers).

This paper provides results from the inaugural and second year of offering the degree projects approach to our chemical engineering students. Accordingly, we have preliminary results of the program's impact, as the program has not yet achieved four years of implementation (the typical time required to complete the bachelor's degree in chemical engineering.) Preliminary results are presented as follows.

Firstly, we have tracked the students' grades by project and overall course grade. We have also compared the grades resulting from the two years of implementation to the mean GPA of students in ChE prior to implementing the degree projects. Table 2 provides a grade comparison by year (pre and post degree project implementation).

Table 2: GPA Comparison Pre Degree Projects and After Implementation

	2001-2006 Pre-implementation	2007-2008 Implementation
Overall GPA	3.25	3.26

We are pleased that the students' grade point average did not decrease as a result of the curricular reform through the degree projects. This provided necessary evidence the students are academically able to perform with the curricular reform. While the difference in overall grade point overall is only slightly higher since the degree projects have been implemented, the students' satisfaction with the degree project approach provides a qualitative metric for the projects' successes. The following student statements are illustrative of this success. The table that follows (Table 3) provides quotes from students resulting from the experience. These quotes depict the true benefit that the participating students' gained from the degree project experience. Interestingly, their experiences align to the research in engineering education related to the importance of providing hands on engaging experiences for students to retain them in engineering fields. Additionally, the students recognized the importance teamwork and meaningful results to their experimentation. Finally, the students expressed a keen interest in the equipment that they were exposed to through the degree projects. We suspect that this will have a positive effect on their retention in the program beyond year two and their interest in the ChE field and look forward to our longitudinal results accordingly.

Table 3: Qualitative Metric of Degree Project Success

Student	Quote
Chelsea M.	"It was great to get some experience with the techniques and apparatuses in the laboratory. Thank you for preparing this part of the class, it was great and really fun."
Erin D.	"This lab was a unique and interesting experience for me. I feel as though I learned a lot, and this new knowledge stretches beyond simply knowing [lab protocols] ...I found just how valuable teamwork and cooperation can be."
Alëna M.	"To produce meaningful results we needed creative methods to analyze the experiment...I was impressed by the equipment we were trusted to use!"

To test the skills that were demonstrated in the laboratory, we designed a three subscale laboratory rubric that we utilized during observation in the lab experiences. This rubric utilized a 4 point rating scale that judged students in three areas: multidisciplinary, experimentation, and analysis and data interpretation. The rubric was scored by a faculty

observer to judge the lab experience process in action. Figure 3 that follows illustrates the mean scores on this laboratory rubric by area. Results reveal that the students mean laboratory skill

was 3.12 on a 4 point scale, with highest scores in the areas of data analyses and interpretation with a mean score of 3.4. We correlated the laboratory rubric score with grades in the course accompanying each degree project element for which the rubric was utilized and found highly positive correlations ($r = .66, p < .001$).

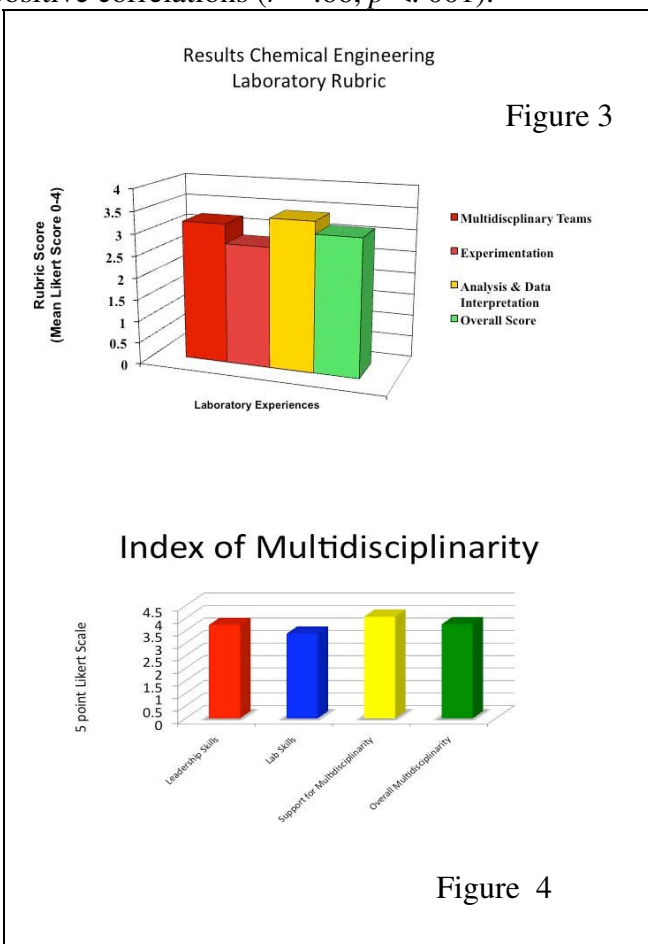


Figure 3

Index of Multidisciplinary

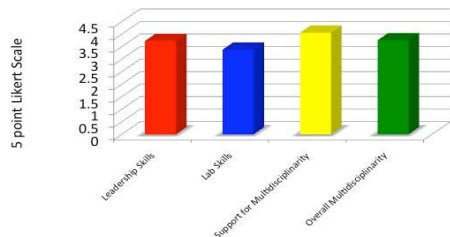


Figure 4

An additional significant factor associated with the degree projects identified by the students and the field is teamwork and associated multidisciplinary. To measure this construct, we designed an inventory of multidisciplinary to test the students' propensity for multidisciplinary research. We designed a three-subscale inventory that measured students' reported leadership skills, reported lab skills and support for multidisciplinary associated with the lab experiences. Figure 4 illustrates the results of this inventory by skill area. This inventory indicates that the students rated themselves relatively highly across areas of potential multidisciplinary. It is important to note that the items on this inventory were designed with the theories of multidisciplinary in mind. Accordingly, we posit that a high overall score on the inventory indicates that the students would have relatively high levels of multidisciplinary research skills. The mean score of overall multidisciplinary was 3.76 with students ranking highest in their

support for multidisciplinary approaches to experimentation of ($m=4.06$) on a five-point scale. While this measure was based on students' reported rating, because of the alignment of the subscales and individual inventory items to multidisciplinary research theory, we found this information of value as one of several metrics of overall success of the degree project program. This is particularly important when the ratings are compared to the qualitative information (Table 3 above) in which the students recognized the value of teamwork in experimentation.

One final metric that we applied to our degree project program is one of engineering efficacy. For this metric, we adapted a computer science efficacy scale to meet the needs of our chemical engineering students. This efficacy scale includes six subscales, has 25 total items, and utilizes a 6 point Likert type scale of student self-rating. The six subscales included are: problem solving confidence ($\alpha = 0.79$ - based on adaptation; $\alpha > 0.70$ indicates reliable measure), trouble shooting confidence ($\alpha = 0.84$), career encouragement ($\alpha = 0.71$), career exploration ($\alpha = 0.72$), satisfaction with college, ($\alpha = 0.78$), and course anxiety ($\alpha = 0.78$). Reliability statistics for each of the subscales were obtained by computing inter-item correlations.

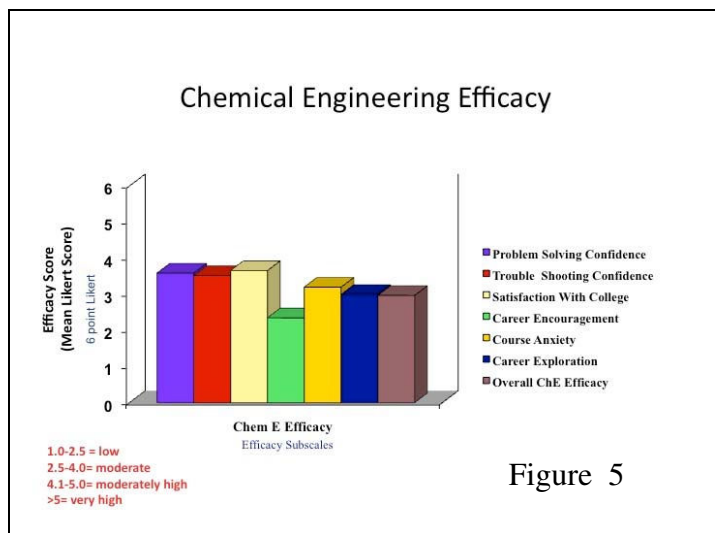


Figure 5

Results of this efficacy scale are reported in Figure 5. This efficacy scale revealed moderate results. Overall efficacy of the students was 2.97 on a 6-point Likert type scale. It is important to note that much of the low score obtained could be attributed to the career encouragement scale with an overall mean score of 2.35. This scale measures how much encouragement students reported receiving from their teachers in high school and their parents to choose chemical engineering as a major. This important result indicates that outreach and education to K-12

programs and parents is necessary to increase students' encouragement to go into the field. To explore the variability of chemical engineering efficacy by gender, we compared overall efficacy amongst the male and female students. Women ($m=3.13$) in our sample scored a higher mean score of efficacy than males ($m=2.86$). Additionally, males GPA was 3.29 while the females mean GPA was 3.23 suggesting that the males' lower chemical engineering efficacy did not effect their course grades dramatically. Correlational analyses between course grades and engineering efficacy were not significant in our sample. We utilized correlational analyses in our study of the effect of the degree projects with caution because our study sample size was only 57 students limiting statistical power in our study beyond descriptive statistics.

Results of these diverse metrics provide an interesting profile of our chemical engineering students who experienced the first two years of the degree projects program. Our students achieve as high and slightly higher GPAs than pre degree project students. Our students have propensities for multidisciplinary research and are moderately efficacious in chemical engineering. Our reported results are preliminary as the program has only been in operation for two years. We look forward to measuring students' multidisciplinary, research skills, chemical engineering knowledge and engineering efficacy annually to document changes in cognitive and affective factors resulting from our degree projects curricular reform.

Discussion

Our ultimate goal for the degree projects program is to spread the degree-project model to other science and engineering departments nationwide; thus, in the future we will develop laboratory modules where students from different academic departments are grouped together. The combinations could be tuned year-to-year to match scientific trends. Establishing an infrastructure where students can interact with other disciplines will better prepare these students to meet the challenges of the modern day workplace. Furthermore, evidence suggests that an integrated curriculum can increase the graduation rates of engineers,⁶ and can be particularly helpful in the study of nanotechnology.⁷

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