2006-1354: THE CHEMICAL ENGINEERING ENVIRONMENT: CATALYST OR INHIBITOR TO STUDENTS' CONFIDENCE IN SUCCESS?

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The Chemical Engineering Environment: Catalyst or Inhibitor to Students' Confidence in Success?

Abstract

The achievement, retention, and interests of undergraduate engineering students have repeatedly been linked to their self-efficacy beliefs - their perceived confidence in their abilities to complete the tasks that they deem necessary to achieve a desired outcome. This study has employed a qualitative survey instrument to monitor undergraduate chemical engineering students' self-efficacy beliefs during their first year in a chemical engineering program. The survey was administered to all students enrolled in *Chemical Engineering Calculations* (CHE 205), a course required of all chemical engineering students at Purdue University. Open-ended survey questions prompted the students to list factors that affected their confidence in CHE 205 success. The results presented here examine beginning chemical engineering students' efficacy beliefs and their sources as they transitioned into the chemical engineering program. The findings suggest how the chemical engineering environment, curriculum, and classroom practices might influence students' self-efficacy, a significant factor to be considered in attempts to boost both the retention of capable students who are considering leaving the program and the performance, satisfaction, and enthusiasm of those who persist.

Introduction

The issue of poor retention in engineering programs has become the focus of increased attention across the U.S. The implications of declining retention rates are far reaching. In a three-year, cross-institutional study of 335 science, mathematics, and engineering (SME) students, Seymour and Hewitt[1] found many cases for which no significant difference could be identified in the academic performance and individual characteristics of students who decided to leave the SME fields and those who persisted. This finding suggests that able students, who might otherwise provide added perspectives to the field of engineering, are leaving in good academic standing. In a field centered on generating solutions for society, the absence of these students' perceptions may be particularly detrimental to the relevance of engineering solutions to society as a whole. A future engineering workforce lacking a diversity of perspectives may also be ill equipped to recognize the needs of a diverse society.

In attempts to better understand why the science, technology, engineering, and mathematics (STEM) fields are experiencing such a loss of able students, many researchers have turned their focus to the choices, achievement, and interests of students in the fields. As a result, many studies have emerged demonstrating a clear link between students' self-efficacy beliefs and their persistence,[1-8] achievement,[2, 8-13] and interest[2, 9-13] in the fields. Introduced by Bandura as a part of his social cognitive theory, self-efficacy beliefs describe people's confidence in their abilities to perform the tasks that they deem necessary to achieve success in a desired area.[14] Researchers across the STEM fields have repeatedly used statistical models to demonstrate that increased student confidence in their abilities in a given area (i.e. more positive efficacy beliefs), yields added persistence in that area when faced with challenges,[2, 7] higher student GPA's, [7, 10] and increased interest in course work[9] and STEM careers[2, 8].

Defined in self-efficacy theory are four sources from which efficacy beliefs are believed to be developed: mastery experiences, vicarious experiences, social persuasions, and physiological states.[14] *Mastery experiences*, suggested by both theory and research to be the most influential source of efficacy,[14, 15] occur when individuals base their confidence in success on the outcomes they have achieved from previously performed actions. Slightly less influential than mastery experiences, *vicarious experiences* have an increased affect on the development of efficacy beliefs when individuals are unsure of their abilities in a certain area or have no experience in an area and therefore must base their beliefs on the outcomes achieved by others. This influence is highly dependent on the extent to which individuals see similarities between themselves and those whom they observe. People who are *socially persuaded* that they have the necessary skills to succeed are likely to exhibit higher levels of persistence than those who are not encouraged[14] thereby causing them to base their efficacy beliefs on the social judgments of others. The anxiety, stress, fatigue, and other *physiological states* people associate with their actions can also have an affect on their self-efficacy beliefs.

Many of the studies that have previously addressed STEM students' efficacy beliefs have focused primarily on the development of statistical models correlating efficacy with student behavior and attitudes. Fewer studies have looked at the specific sources on which students base their efficacy beliefs, and those that have[16-18] did not focus on undergraduate students in the field of engineering. It is suggested by efficacy theorists that to best understand the sources and cognitive processing of students' self-efficacy beliefs, a discovery-oriented, qualitative approach is required. The previously demonstrated[1-13] power of efficacy beliefs over students' persistence, achievement, and interests serves as a building block for the current investigation. Here, a survey containing qualitative items is used to identify those factors cited by second-year chemical engineering students as influential on their efficacy beliefs.

Research Design

Theoretical Framework

In the design of a qualitative research study, the choice of an appropriate theoretical framework is a vital first step.[19] A selected framework guides the researcher for the remainder of the study, dictating the study's data collection and analysis methods. Phenomenography was chosen as the guiding framework for this investigation. Developed in large part by Marton and co-workers, phenomenography is a study of "…the limited number of qualitatively different ways in which we experience, conceptualize, understand, perceive, apprehend, etc., various phenomena in and aspects of the world around us".[20] These different ways of conceptualizing or understanding are then categorized by description and logically related to each other to form an outcome space for the ways in which the phenomenon under investigation is perceived. The present study was designed to identify factors affecting students' self-efficacy beliefs. It has been established that men and women have different self-efficacy beliefs and that these beliefs further vary among members of the same gender.[6, 7, 17] Therefore, it is apparent that how students perceive the CHE 205 experience will vary, falling into several categories of perception and lending this study to a phenomenographical focus.

Participants

Participants for this study were 68 chemical engineering students enrolled in CHE 205, *Chemical Engineering Calculations*, at Purdue University in the fall of 2005. A prerequisite for all upper-level chemical engineering courses, this three-credit course covers applications of steady-state mass and energy balances to solve problems involving multi-component and multi-unit chemical processes. A response rate of 85% was achieved from the survey, yielding responses from 19 women and 39 men. At a 95% confidence level, this response rate corresponds to no more than 4.9% error in the data collected.

Procedure

The engineering efficacy survey was administered to all students enrolled in CHE 205 as a required, on-line homework assignment. As part of the survey, students were informed that their responses were completely confidential and would not be linked to their individual identities. The survey was administered during the same week as the students' third of four course exams. This timeframe was used to ensure that students had been given ample exposure to both material and energy balances, the two main focuses of CHE 205. At this point in the semester, students had significant experience with the CHE 205 environment, assignments, and exams, however, the semester had not progressed far enough that students were able to make concrete predictions concerning their final course grades.

Instrument

Students' perceptions of the learning environment and their efficacy beliefs based on their experiences in CHE 205 were probed using a modified survey based on one previously used[21, 22] to investigate the perceptions of first-year engineering students. The first-year survey was adapted by replacing references to other courses with reference to CHE 205. Items asking students to consider their efficacy beliefs based on their computing skills and teamwork skills were also removed as these skills are not required in CHE 205. After assessing students' efficacy beliefs, the factors they attributed to influencing their beliefs were probed using a cognitive thought-listing technique patterned after Lent et al.[16] This technique allowed students to discuss the factors in their own words. Specifically, students were asked to think about CHE 205 and rank the extent to which they agreed with the statement: "I am confident I can succeed in CHE 205." Following this item, students were told to "think about the factors you considered in the previous question. Describe briefly all of the factors on which you based your confidence rating to this particular question. Write everything that comes to mind. When possible, indicate whether the factor positively or negatively influences your confidence in CHE 205 success." The instrument was designed to allow students to list up to 10 separate factors.

Analysis

Guided by a phenomenographical methodology,[20] the analysis of survey data aimed to identify components of the CHE 205 environment that influenced students' confidence in course success. Based on the findings of a similar previous study[22] and reviews of the students' survey responses, eighteen categories of influential factors and corresponding codes were created. The responses provided by each student were then independently coded by two researchers using the qualitative data management program, ATLAS.ti version 5.0[23]. This process included coding both the category to which each factor was assigned and whether it was indicated as a positive, varying, or negative influence by the student. Initially, researchers achieved 83% agreement on the placement of factors, a reasonable level of agreement for this type of research[20]. Factors not initially agreed upon were discussed until agreement was reached. The existence of statistical differences in the responses given by men and women were investigated using z-tests ($\alpha = 0.05$).

Open-ended instruments such as the survey employed in this study allow for variation in how students record their responses. As such, care must be taken to address these variations during data analysis. One instance of this included students listing more than one factor belonging to a single category (e.g. "My exam grades," "My homework grades," and "My grade in the class."). Because analysis was based on the percentage of *students* citing each factor, such cases were only counted once in the corresponding category (i.e. the student was counted once in the category of 'Grades'). Conversely, other instances arose in which one student response fit more than one category (e.g. "I understand more than 90% of the homework by the time I turn it in, *and* I have done most of the problems completely on my own."). In these cases, the student was counted in all applicable categories.

Results

The analysis of CHE 205 students' survey responses yielded eighteen factors that students cited as influential on their efficacy beliefs. Z-tests for statistically different responses based on gender showed no significant difference in the factors reported by men and women. The results presented here remain differentiated by gender to allow for the discussion of minor, yet interesting gender trends.

Many of the categories created during data analysis were found to be cited by only a minimal number (< 10) of CHE 205 students. These categories, including the number of men and women who described related factors, are briefly summarized in Table 1 to illustrate the breadth of student responses.

Table 1: Influential factors cited by less than ten CHE 205 students.

Category	Example	Men	Women
Instructional Methods	"Lecture structure [positively affects my confidence in success]; showing worked out examples in class helps demonstrate the application of concepts."	5 (13%)	3 (16%)
Comparison to Others	"I am best with economical problems, so when we talk about a process and what affects it will have on the company's economical situation I can almost always have an educated answer before most people in my class."	4 (10%)	3 (16%)
Difficulty of the Material	"The material presented in this course is very challenging."	4 (10%)	1 (5%)
Physiological Responses	"A feeling of accomplishment and satisfaction could come from either of the two aforementioned factors [understanding and grades], as well as failure and sorrow."	4 (10%)	3 (16%)
Instructor / TA	"…my relationship with the professor. This factor has positively impacted my confidence as he has expressed his confidence in me and has been very readily available to meet with me and help me through the learning curve in this class."	4 (10%)	3 (16%)
Attendance	"Attending lecture regularly."	3 (8%)	1 (5%)
Previous Experiences	"Freshmen engineering experience and skills learned in ENGR 116 [positively affect my confidence in success because] several skills [are] used in CHE 205."	3 (8%)	0 (0%)
Correct Answers	"Getting correct answers consistently."	2 (5%)	0 (0%)
Outside Support	"My parents' support in my work…I know that no matter what I do they are going to support me and thus I feel like I have more confidence because I have such a strong support system."	2 (5%)	1 (5%)
Working with Others	"Study group of classmates help to explain difficult concepts and work together to solve homework problems [positively affects my confidence in CHE 205 success]."	2 (5%)	1 (5%)
Time Management	"Proper time budgeting: CHE 205 problems require lots of time and it is important that you leave enough time to complete the work."	1 (3%)	0 (0%)

The results presented here will focus on those seven components of the CHE 205 experience listed by at least ten (17%) students as affecting their confidence in success: understanding or learning the material, grade related aspects of the course, issues surrounding doing assignments, student problem-solving abilities, drive or motivation toward success, the availability of help and the ability to access it, and student performances on exams. Figure 1 summarizes the percentages of the men and women who cited each of these factors.

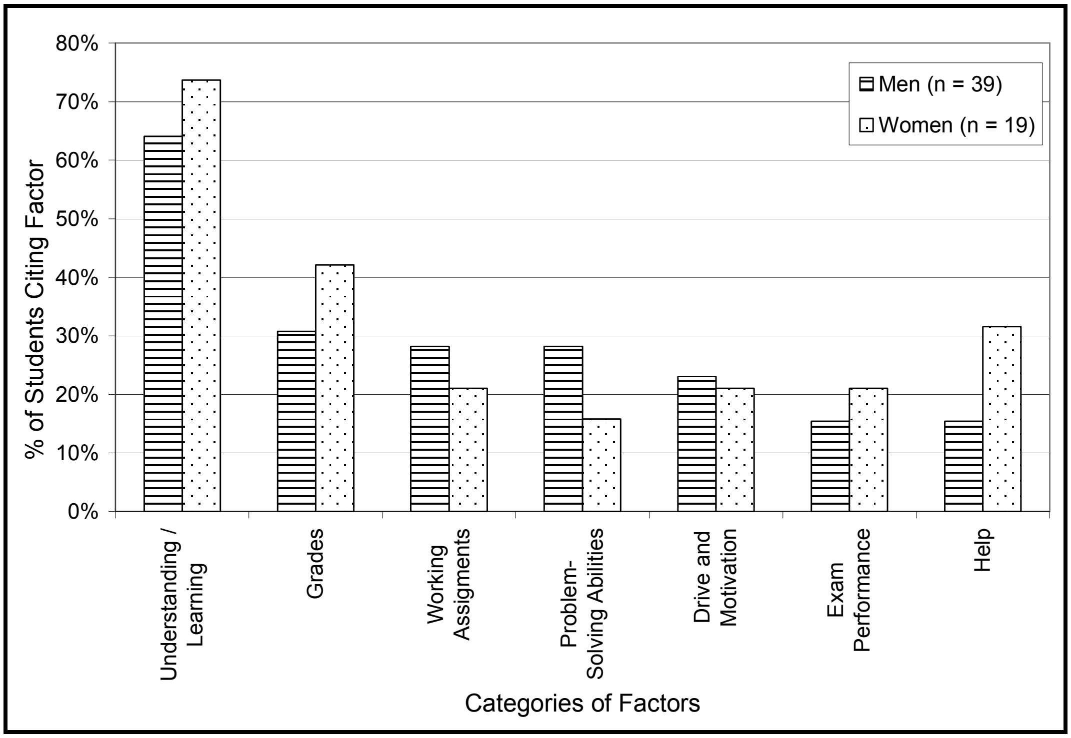

Figure 1. Factors indicated by at least ten students as influential on their confidence in CHE 205 success.

The categories presented in Figure 1 are discussed in more detail below.

Understanding/Learning: Perceptions of their abilities to understand or learn the material were cited most frequently by both men and women. Most often, students either reported this factor to be a positive ("A lot of the material in the course seems very intuitive. Prof. [Smith] explains something, and I think 'Yeah, that makes sense.' I find it fairly easy to then manipulate these ideas to fit the situations presented in the problems.") or fluctuating ("My level of understanding of the material, meaning how well I can look at a problem and see a way to find the solution and not feel in the dark. This factor at first very negatively affected my confidence, but my confidence in this area is beginning to slowly increase.") influence on their confidence in success. Few students specifically indicated a lack of understanding as detrimental to their efficacy.

*Grade*s: Scores on graded course materials including homework assignments, projects, quizzes, and exams and CHE 205 grading policies were frequently considered by students when assessing their confidence in success. In indicating how grades and grading policies influenced their efficacy, CHE 205 men were more likely to describe a positive influence ("I have a good average on the tests and should get a decent grade.") while women were more likely to indicate a negative influence ("Another factor that influenced my decision was how my grades stand in the class. As of right now I am doing about average, which also negatively impacts my confidence because it is hard for me to be doing average when in high school I always succeeded at things I worked hard at."). Students also often made neutral comments about their grades such as, "My grades on exams, homework and quizzes."

Working Assignments: Students' experiences while working assignments were also cited as influential on their efficacy beliefs. For both men and women, these experiences were most commonly reported to positively affect their confidence in CHE 205 success: "I can get most of the homework done." and "[My] ability to apply knowledge and equations to solve homework/quiz problems is usually a positive [influence]."

Problem-Solving Abilities: CHE 205 students never indicated that their problem-solving abilities negatively influenced their confidence in success. When cited, students most frequently discussed their abilities as increasing their confidence in success ("I can perform mass balances. I can perform energy balances. Positive [influences].").

Drive and Motivation: Nearly equal percentages of men and women cited significant determination or a strong desire to succeed in CHE 205 as a source of confidence in success. For women, this factor was always a positive influence ("I study long and hard for the exams, and therefore I do well."). Men, however, were equally split as to whether the influence of this factor was positive or negative ("Will I really use these concepts outside of CHE 205? [No], negative [influence]."). Student comments that fell into this category illustrated an internal locus of control mentality. Theories describing possessors of this mentality include the mindset that with enough persistence, determination, and hard work, success can be achieved, regardless of the challenges they may encounter, or, that due to a lack of these characteristics, they were unlikely to achieve success.[5]

Exam Performances: While men most frequently discussed their abilities to perform well on exams and quizzes as a positive influence on their efficacy, women nearly always described these abilities as a negative influence. Students citing this factor made statements such as: "I do not do that well on the quizzes in recitation because I never have enough time." and "I perform well on tests." Rather than focusing on exam and quiz *grades*, these students indicated being influenced by their personal performance while actually taking the exam or quiz.

Help: Although it was not statistically significant, the largest gender difference in the identified sources of CHE 205 efficacy was found in men and women's discussions of the influence help seeking had on their confidence in success. Never indicated as a negative influence, students who sought help reported finding it through many avenues: "TA's are readily available for help if I do not understand, and they are a good resource for positive [influence].", "The last factor I considered was my relationship with the professor. This factor has positively impacted my confidence as he has expressed his confidence in me and has been very readily available to meet with me and help me through the learning curve in this class.", and "A lot of help is available for this course, and I feel that if I am struggling that I will be able to find help."

Discussion

Due to the nature of the survey data, our understanding of student efficacy sources is limited to the statements provided by students. Interviews with CHE 205 students are currently being analyzed to gain a more in-depth understanding of how these sources influence students' efficacy beliefs, and thus inform the development of practices and interventions to promote student self-efficacy. Nevertheless, the survey results presented here offer preliminary implications for practice, as outlined below.

The importance CHE 205 students appear to place on their level of understanding in a course, a finding that supports the results of a similar study with first-year engineering students,[22] suggests that instructors should go to significant lengths to provide students with ample opportunities to confirm their understanding. There are a number of ways in which such opportunities could be implemented into the engineering curriculum. It is important, however, that two key components are incorporated: students are provided with the means necessary to (1) test their understanding and (2) make any necessary adjustments or clarifications. In other words, when assessing their own understanding, students require swift instructor feedback if learning is to occur.[25]

The teaching literature provides suggestions as to how instructors can assist students in refining their understanding. Davis[26], for example, advocates using a simple "check-for-understanding" question during a lecture. An instructor might pose a question designed to probe students' understanding, provide the students with sufficient time to generate a response, poll the class for the various responses generated, and then provide the students with the correct answer. In this case, discussing why the alternative responses are incorrect is as important as discussing the correct answer. This approach provides students with the opportunity to check for personal mastery of the material. Asking follow-up questions offers repeated opportunity for students to build their efficacy through mastery experiences, a component that Bandura[14] sites as important in the development of efficacy in new situations. Moreover, such activities that involve the instructor polling the class to check for understanding provide students the chance to compare their understanding to that of the rest of the class (a vicarious experience). Research and efficacy theory[14,24] alike suggest that when put in unfamiliar situations, students draw heavily on how they compare to their classmates. For example, first-year engineering students compare their understanding of course material to that of their classmates when assessing their efficacy.[24] Enabling the realization that other students also struggle with course concepts is thus likely to help prevent the development of inaccurately low efficacy beliefs.

Graded materials such as assignments, tests, and quizzes can also assist students in assessing their understanding in a course; the success of this strategy, however, requires significant effort on the part of the instructor. Graded materials rarely contain detailed comments to students about why their solution is incorrect, and instructor solution keys frequently lack an exhaustive list of potential solution errors and why they are incorrect. Assignments, exams, and quizzes therefore often provide only the opportunity to confirm complete understanding and usually prove difficult for use in assessing understanding that is less than perfect. To aid students in the assessment of their understanding based on graded materials, instructors might have teaching assistants or groups of students re-solve problems in a recitation section [27] or provide written comments that point out where errors occurred and direct the student as to how the problem might be alternatively approached[25].

Instruction should also be informed by CHE 205 students' discussion of the positive influence their successes with assignments, problem-solving, and exam performances had on their efficacy beliefs. Because these actions are all primarily mastery experiences, beginning students may require many repeated opportunities to develop their skills in the areas. According to Bandura, while mastery experiences act to build a robust sense of efficacy when actions are successful, failures can quickly undermine it, especially if they occur before a strong sense of efficacy is established.[14] As such, if educators do not provide students with the opportunity to overcome initial failures in these areas, their engineering efficacy beliefs may never reach levels sufficient for maintaining persistence in the field. Consistent with efficacy theory, the teaching literature suggests that first- and second-year students be given frequent homework assignments and tested or quizzed often [25, 27, 28]. This frequency could be as much as assigning homework sets due each lecture period and giving shorter, weekly exams. A course design such as this provides students with ample opportunity to adjust to assignments and exams and makes initial failures on several of these less significant to their overall achievement outcome in the course.

The significant boosts in efficacy students report based on the availability of help and the experiences they associate with seeking it justify educators taking measures to ensure that students have many avenues from which they can receive help. This factor has previously been shown to be significantly more influential in the case of women,[22] a finding suggested here as well. Recognizing the current push in the field of engineering to retain a diverse student population encourages the development of resources for help in courses where they may not currently exist.

Conclusions

The findings from this study suggest that students in their first discipline-specific chemical engineering course draw on seven prominent factors when assessing their confidence in CHE 205 success: understanding or learning the material, grade related aspects of the course, issues surrounding working assignments, problem-solving abilities, drive or motivation toward success, the availability of help and the ability to access it, and performances on exams and quizzes. This information can inform instruction in similar courses by focusing the attention of educators on the components of their courses that most significantly influence their students' efficacy beliefs. In addressing the factors upon which efficacy is built, educators have the power to promote the development of accurate, positive efficacy beliefs among their students, an important measure to consider in attempts to boost both the retention of capable students and the performance, satisfaction, and enthusiasm of those who persist.

Acknowledgments

The authors would like to extend their thanks to Dr. Nicholas Delgass for his cooperation and support in this study, Jason R. Green for his assistance in computerizing survey materials, and the ChE Division reviewers for their useful suggestions.

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