The I-C-D-M Methodology

Improving Undergraduate Engineering Student Motivation, Satisfaction, and Performance

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Abstract*—This paper combines two bodies of engineering education work aimed at improving the undergraduate engineering classroom experience for industrial and mechanical engineering students. The integration of these two bodies of work has led researchers to propose a framework for maximizing undergraduate engineering student motivation, satisfaction, and performance. The "Interact, Cultivate, Deliver" or I-C-D methodology has been shown to significantly increase undergraduate industrial engineering student ratings of teaching effectiveness when compared to industrial engineering courses where the I-C-D methodology is not formally implemented. Decreasing student anxiety while improving student self-recognition, cognitive value, and intrinsic value have been shown to be the driving factors behind student motivation among undergraduate mechanical engineering students. Along with discussing the results of both studies, an optimal teaching methodology dubbed "Interact, Cultivate, Deliver, Motivate" or I-C-D-M methodology is proposed to maximize student motivation and satisfaction leading to increased engineering student retention and performance.

Keywords— Industrial Engineering; Mechanical Engineering; Design; Teaching; Motivation

I. Background and Motivation

Engineering education is looked at as a vital area of research as colleges and universities are trying to find creative ways to both attract students into STEM degree programs and retain students within these degree programs. This has led to engineering educators being forced to recreate the methodologies for delivering undergraduate engineering courses. Recently, special emphasis has been put on increasing active learning with special emphasis on engineering course projects in an effort to maximize student engagement in their work in an effort to retain and motivate students to stay within their engineering degree programs.

The authors of this paper were motivated to both retain students in their respective engineering degree programs and to develop a holistic approach for teaching undergraduate engineering courses that can be taught to existing and incoming faculty members in an effort to optimize the undergraduate engineering course experience by improving student motivation, satisfaction, and performance.

The industrial engineering program at this campus is only in its fourth year but is growing rapidly. The mechanical engineering program at this campus has doubled in size in just the past 10 years. In Fall 2016, a new $15.6 million Advanced Manufacturing and Innovation Center (AMIC) covering 60,000 square feet of space opened to house the industrial and mechanical engineering departments along with corporate tenants, Figure 1. The industrial and mechanical engineering faculty work together with corporate tenants on industry projects as part of the college's commitment to an "open lab" initiative.

Fig. 1. Advanced Manufacturing and Innovation Center (AMIC)

II. Introduction

An innovative approach is being taken by faculty members from both industrial and mechanical engineering to develop a teaching methodology that seeks to optimize undergraduate engineering student motivation, satisfaction, and performance as industrial and mechanical engineering faculty and students collaborate with companies on industry projects all under one roof in the AMIC on campus.

Ongoing studies in industrial engineering found the general driving factors of student satisfaction which were used to develop the I-C-D teaching methodology. This methodology incorporates eleven significant factors in the areas of Instructor Interaction and Feedback, Classroom Environment, and Modes of Teaching to improve overall student satisfaction with their engineering courses. Within "Instructor Interaction and Feedback", the statistically significant factors are providing detailed feedback to students, approachability of the instructor, instructor stressing the importance of the material, and relating course topics to student interests. For the "Classroom Environment", showing real-world applications of the subject material, relating course material to future careers, ensuring presentations, assignments, and activities all relate, and making students active participants in the class are all statistically significant factors. Finally, for "Modes of Teaching", making PowerPoint lectures interactive, offering problem solving sessions, and making time for group work were all statistically significant factors to undergraduate industrial engineering student satisfaction [1]. These significant predictors of undergraduate industrial engineering student satisfaction were used to develop the I-C-D methodology that has been implemented into multiple industrial engineering courses in the past three years.

Motivation in engineering design course work has been carried out in mechanical engineering to understand what drives motivation and performance of mechanical engineering students in the freshman and senior design courses. The initial results revealed differences in motivation between freshman and senior mechanical engineering students. This work has shown that test anxiety, self-recognition, cognitive value, and intrinsic value are the main motivational factors. This early work on student motivation in mechanical engineering has shown promise for predicting student persistence in engineering based on this set of motivational factors [2,3].

In this paper, the industrial engineering and mechanical engineering faculty members have combined their studies in an effort to propose an optimal methodology dubbed the "I-C-D-M: Interact-Cultivate-Deliver-Motivate" methodology to optimize student satisfaction, motivation, and performance in undergraduate engineering courses.

III. Related Literature

The basis for understanding the driving forces behind undergraduate student satisfaction begins with understanding how the students prefer to learn in the engineering classroom. In addition, motivation is one of the most important factors in the classroom, as it generates, directs, and sustains what students do to learn. Furthermore, understanding how student satisfaction and motivation are interrelated and how to maximize both is an important step to developing an optimal undergraduate engineering course delivery methodology.

A. Engineering Student Dominant Learning Styles

The Kolb Experiential Learning Model is used to classify students by the way they take in and process information. One of the most widely recognized instruments for determining student learning styles is the Myers-Briggs Type Indicator. Felder and Silverman created a model of students' learning styles that pulls components from both the Myers-Briggs Type and Kolb's Experiential Learning Model [4-6]. The Felder and Silverman assessment is centered on four different questions regarding perception, sensing, processing, and understanding [7].

Prior to the recent emphasis placed on engineering course delivery, most engineering courses were taught predominantly in a verbal fashion, with writing on chalkboards and verbal explanations. Active learners prefer to take information in through conversations, physical activities and group work. Reflective learners prefer to contemplatively take in information and reflect on ideas. Sequential learners grasp information in a series of logical steps, they prefer to learn information in a specific sequence and will only progress to the next step after they have mastered the previous one. Global learners often struggle understanding information until they understand the "big picture". Sensing learners prefer facts and are inclined towards real world applications. Intuitive learners, like theoretical and abstract ideas and are uninterested in specific details. Most engineering teaching is more favorable to intuitive learners. Sensors are very systematic, attentive, and methodical and make successful experimental scientists or plant engineers. Intuitors are innovative and perceptive and make exceptional designers, theorists, and inventors. Visual learners learn more effectively through graphic materials such as posters and charts. Verbal learners learn best through auditory descriptions and written accounts [7].

B. Student Satisfaction

In relation to the classroom, student satisfaction is the perception of the learning experience and value in the course. Satisfied students tend to persist through difficult classes and have overall higher academic performance in their academic careers. Learners can gain satisfaction in many ways, from feeling a sense of achievement or receiving reinforcement for results. Intrinsic reinforcement may be given by having a former student speak to the class about the benefits of the skills gained in the classroom. Students also tend to be more satisfied if the same expectations and grading standards are used throughout the semester. Students see more value and become more satisfied with the course material when the newly learned material can be directly applied to a real-life application [8].

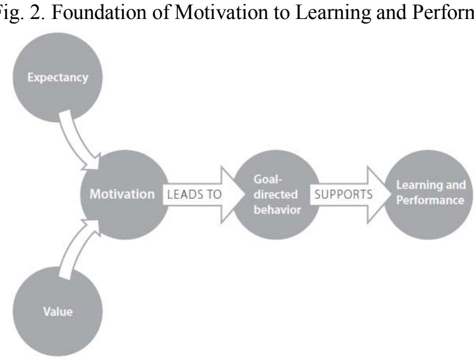
Students have increased satisfaction through student-teacher interactions in the classroom. These relationships have been correlated to higher overall GPAs, degree attainment, graduating with honors, and pursuing further higher education. In a study performed at The Pennsylvania State University based on a first-year engineering design course, it was found that instructor interaction was the main driving factor to overall student satisfaction. Most notably, when the expectations of students are clearly defined by the instructor, the students feel they are able to succeed in the classroom [9].

C. Student Motivation

Motivation is one of the most important factors in the classroom, as it generates, directs, and sustains what students do to learn. Personal motivation becomes especially important as students enter college, where they have the freedom to choose how and what time is devoted to each part of their academic and social lives. If students do not find the course material relevant to their current or future lives, interest and time to master the material is lost rapidly. Often, instructors do not understand why students are lacking motivation, as the current course structure and requirements would have motivated the instructors when they were students [10]. If the learning styles of students are not being met in the classroom, students will not be motivated to study the material, attend class, or be active participants in the classroom [10, 11].

At the core of motivation are two pillars: the subjective value of a goal within a course and the expectancies of achieving that goal. Without these two foundations, students will lack motivation, leading to a possible lack of learning and poor performance, as seen in Figure 2 [12].

Fig. 2. Foundation of Motivation to Learning and Performance [12]



The Expectancy-Value theory has been tested with many students and it is found that students' expectancies on a task relate directly to their performance [10, 12]. This theory has not been applied to engineering education studies until recently in 2008 when Li et al. and Matusoviach et al. began to study its relation to persistence in engineering programs. Their results show that engineering students exhibit higher value and sense of social utility from pursuing engineering as a career path when values and expectancies of the course are well defined [12].

Goals often relate to many parts of the student lifestyle, including intellectual pursuits, relationships, self-concept, material possessions, and desires. Mismatches between goals often occur between students and teachers, especially when performance goals are in place. Performance goals provide students a threshold to work towards demonstrating basic competence to pass the course. While students are primarily focused on performance goals, instructors often focus on learning goals. Learning goals focus solely on the mastery of the material for understanding and retention purposes [10]. This disconnect with goals often causes frustration on both the instructor and student sides of the classroom. As stated earlier, the two main pillars of motivation are value and expectancy. The overall importance of a goal is defined as its subjective value. Students are often motivated to engage in behaviors that will allow achievement of the highest valued goals. Value can be categorized into three distinct types: (a) attainment value, (b) intrinsic value, and (c) instrumental value. Attainment value is the satisfaction that is gained from mastering a concept or task, whereas intrinsic value relates to value gained by simply performing the task and not the final outcome. Instrumental value relates to how the current task relates to reaching other goals and gaining rewards such as praise or recognition. Expectancies in the classroom relate to the students' perception of a successful or failed outcome. Students must hold positive expectancies when pursuing a desired outcome for maximum motivation. One important factor in predicting student expectancies in the classroom is their overall success in a prior experience [12].

D. Maximizing Student Satisfaction, Self-Efficacy, and Motivation

Literature suggests that student satisfaction, self-efficacy, and motivation are most effective when all three are maximized in the classroom. The relationship between how each of these student perceptions feeds on one another is of pivotal importance for instructors to understand. When students are satisfied with the educational experience and hold positive self-efficacy beliefs, students will be motivated to participate and excel in the classroom. Self-efficacy is the driver of motivation, as personal capability views can be heavily influential in the student mind. Positive self-efficacy correlates with college achievement and high levels of motivation. The factor that connects satisfaction, self-efficacy, and motivation is the classroom environment as determined by the instructor.

Students in positive and supportive classroom environments are able to learn, integrate, and apply new knowledge gained in the classroom. Students also have increased satisfaction through student-teacher interactions in the classroom. The student-teacher relationships can help build self-efficacy, through the teacher reinforcing that the student is capable of completing the tasks within the course. These relationships can also cause students to be motivated, since the students feel more engaged to the material and the instructor. Often, when students recognize the instructor is passionate and willing to assist, students understand the material at hand and are motivated and curious about the topic. Instructors can also act as mentors and explain potential routes for success in the course, which will create a supportive environment that builds student satisfaction and self-efficacy [10].

The ARCS model provides a connection between these three student perceptions in the classroom and provides implementation strategies for instructors. In 1999, Keller created the ARCS model of motivation, which provides strategies and analysis of reaching students. The four categories on which the model is based are attention, relevance, confidence, and satisfaction. This model is the synthesis of many bodies of literature on student motivation. The instructor must find a way to grasp the students' attention in the beginning of the course, as well as introduce variety in the classroom to maintain attention for the class period. Secondly, the instructor must build a bridge between the students' interest and the course material. The students must know the value of the material to either their current life, the realm of the course such as quizzes or exams, or future careers. The third construct is confidences, which are directly related to self-efficacy concepts. By making the objectives clear and providing goals that are attainable to students, students will build a sense of confidence and ability in the classroom. If students are able to stay attentive, see relevance in the material, and have confidence in their abilities, the students are more likely to be satisfied. Satisfaction can also be obtained through recognition of success. Grades, promotions, or other privileges allow students to see tangible success [13].

IV. METHODOLOGY

A. Student Satisfaction

The methodology behind the exploration of optimizing student satisfaction with their industrial engineering courses began with an analysis of the learning styles in the industrial engineering classroom. The NC State University Index of Learning Styles Questionnaire by Dr. Richard Felder was administered to fifty-one junior and senior level industrial engineering students [1]. In the second phase of this study, a questionnaire was administered to forty-one junior and senior level industrial engineering students to identify the significant factors that drove students to be satisfied with their industrial engineering education [1]. Twenty-two significant factors driving undergraduate industrial engineering student satisfaction were identified. Results from phase two were applied to the third phase of this research. A new survey was created on the basis of three significant areas of student satisfaction: (a) instructor interaction and feedback, (b) classroom environment, and (c) modes of instruction. These three factors were found to be the most statistically significant when implemented into an Industrial Engineering classroom. A student satisfaction questionnaire was administered to 107 junior-level industrial engineering students, at-will, at the Pennsylvania State University. Each student was given one of three randomly assigned courses that they would have taken or were currently enrolled in. The three classes had approximately 35 students in the sample set. The questions and format among the class versions remained the same. All courses were chosen based on the following factors: being offered in the same semester as the survey and only having one instructor teaching the course. These constant factors were important to the design of the study to be free of bias for different teaching in different semesters. The results of this questionnaire would become the basis for the I-C-D methodology and its measure of success [14].

B. Student Motivation

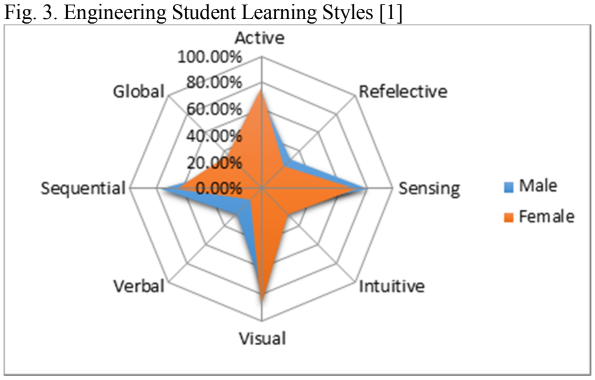
The next phase of this study focused on the motivational differences between senior and freshman engineering design students. The goal of the study was to observe the motivation of students in five key factors during their freshman engineering and senior capstone course. Four hundred and eighteen undergraduate students from both Florida Institute of Technology and Pennsylvania State University, Behrend were the subjects of the study. The population contained a mixture of male and female, international and domestic, and freshman and seniors. The Motivation Learning Strategies Questionnaire (MSLQ) was a survey that also used the Likert scale to study the five major factors of motivation: (1) self-efficacy, (2) self-regulation, (3) cognitive value, (4) intrinsic value, and (5) test anxiety [15]. The MSLQ survey was structured to evaluate these key factors [16, 17]. A statistical analysis was performed to observe the motivation of students and its change. Further, the analysis revealed significant differences between various student demographics.

V. RESULTS

A. Student Satisfaction

In the first phase of this work that was completed, the NC State University Index of Learning Styles Questionnaire by Dr. Richard Felder was administered to fifty-one junior and senior level industrial engineering students. The results shown in Figure 3 overwhelming illustrate that industrial engineering students were predominantly visual (80.39%), active (77.25%), sensing (76.47%), and sequential (70.58%) learner types [1]. There were no significant differences between genders observed.

Fig. 3. Engineering Student Learning Styles [1]



In the second part of this phase, twenty-two significant factors were identified for undergraduate engineering student satisfaction [1]. These twenty-two significant factors were used to construct the questionnaire outlined in the third part of this study. From the questionnaire administered in the third part of this study, a regression analysis was used to determine the statistically significant parameters [14].

The analysis revealed that all of the following had a p-value of less than 0.05:

- Instructor gives detailed feedback,
- Instructor was approachable,
- Instructor stressed the importance of the material,
- Instructor relates class topics to student interests to increase motivation and value in the course,
- Instructor has real world conversations,
- Skills gained are applicable to future careers,
- Relate all course activities,
- Students are encouraged to be active participants in the classroom,
- Interactive power point lectures,
- Use problem-solving sessions,
- Promote group work.

From these eleven statistically significant factors, the I-C-D method was formed and tested in an engineering economy classroom to perform an impact analysis. After the I-C-D method was implemented in an industrial engineering, engineering economy course, the SRTE data was analyzed to determine how many students were above the "satisfied" rating on the 7-point Likert-item scale. The 7-point Likert-item scale was set by officials at Penn State University. This scale is standard for all SRTE course across the Penn State system. The selected questions used for analysis were the overall quality of the course and the overall quality of the instructor. The percentage of "6" or "7" responses for the question "Rate the overall quality of this course" was 98.61%. The percentage of "6" or "7" responses for the question "Rate the overall quality of the instructor" was also 98.61% on the instructor report of scores. This data showed little doubt that when fully implemented the I-C-D methodology has had a significant positive effect on the ratings of student satisfaction when compared to courses that did not fully implement the I-C-D methodology [1]. The data taken from the engineering economy course was only for one instructor of the engineering economy course. Future work should be carried out for multiple sections (i.e. multiple instructors) of the same course. The industrial engineering study also did not specifically test the factors behind student motivation.

B. Student Motivation

Understanding the factors that motivate undergraduate engineering students is important to developing lasting satisfaction within the classroom. The five major factors of motivation identified for study were: self-efficacy, self-recognition, cognitive recognition, intrinsic value, and test anxiety. As seen in Table 1, the results show statistically significant changes between freshman and senior students for anxiety, self-recognition, cognitive recognition, and intrinsic value. Anxiety decreased throughout the years, overall showing that as the student goes through the engineering program they learn more effective presentation and test skills. Intrinsic Value increased which means the confidence the students have for themselves within a class increased. Cognitive recognition increased which means the awareness of the student within a course increased.

Table I. Comparison of the Difference Between the Average Values of Freshman and Senior Mech. Engineering Students [3]

Factor	Freshman	Senior
Anxiety**	3.87	3.45
Self-Efficacy	5.23	5.17
Self-Recognition***	4.43	5.31
Cognitive Recognition**	4.91	4.68
Intrinsic Value**	5.50	5.71

$^{**}p<0.05$ $^{***}p<0.001$

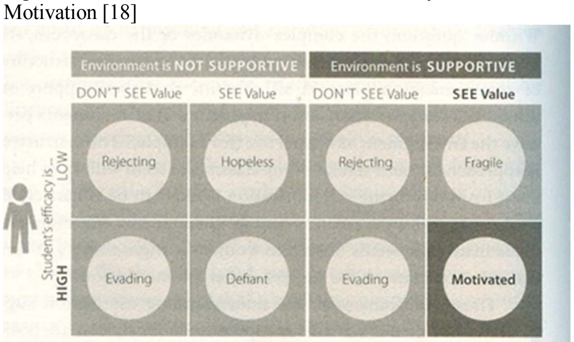
VI. INTEGRATION OF RESULTS

The goal of this study is to combine the Interact Cultivate and Deliver (I-C-D) method developed in industrial engineering with the outcomes of the work done on motivation in mechanical engineering to craft an optimum teaching methodology that can be rolled out across industrial and mechanical engineering and used as a teaching tool for incoming faculty members in growing engineering programs. Both studies showed significant gains in both understanding what motivates and satisfies industrial and mechanical engineering students in the undergraduate classroom. Putting the significant outcomes of both studies together will put engineering educators on a path to maximize student motivation and satisfaction leading to increased engineering student retention and performance. By consiering the results of both studies, the I-C-D-M teaching methodology is proposed for adoption by engineering educators in an effort to maximize student motivation and satisfaction, Figure 4.

Fig. 4. The I-C-D-M Methodology

The literature has shown for a student to achieve the highest motivation, he or she must value his or her aspirations, have positive expectancies for success, and believe that his or her environment is supportive, as is seen in Figure 5.

Fig. 5. Interactive Effects of Environment, Efficacy, and Value on Motivation [18]



A student that has low aspirations and negative expectancies for success tends to behave in a rejecting manner in environments that are both unsupportive and supportive. Students behaving in a rejecting manner may not participate in learning activities and may appear apathetic, unreceptive, or even isolated [18]. A student that is confident in his or her aptitude, but does not value a goal, will behave in an evading manner, regardless of a supportive or unsupportive atmosphere. This type of student will typically do the minimum amount of work that is required and will be very easily distracted from class. A hopeless student values a goal, but does not have the self-confidence that he or she can be successful. Hopeless students that feel his or her environment is unsupportive will remain feeling helpless and will have low motivation. Hopeless students that feel they are in a supportive environment are often fragile. Fragile students want to do well, but are doubtful of their own abilities. They may pretend that they understand material, when they really do not, to guard their own confidence. Additionally, they may not admit struggling with material, and may have excuses for when they perform poorly [18].

Students that value a goal and believe in their capabilities will become defiant or motivated depending on the supportiveness of the environment. If their environment is unsupportive they will become defiant and will try to aggressively prove their mastery. However, if students value a goal, believe in their capabilities, and have a supportive environment they will become motivated. It is crucial to have positivity in all three areas to achieve motivated behavior. Motivated students strive to make the most of their education by acquiring new information and using it to further their knowledge [18].

VII. Conclusions and Future Work

The results of the I-C-D implementation were positive for significantly improving the satisfaction of the undergraduate engineering students with their industrial engineering courses. The mechanical engineering study on motivation has shown that statistically significant differences existed between freshman and senior students for the following motivational factors: anxiety, self-recognition, cognitive recognition, and intrinsic value. The I-C-D-M method was created from these results. The factors involved in the Interact section of this methodology are to provide detailed feedback, be approachable to students, stress the importance of the course material daily, and relate course content to student interest. The factors involved in the Cultivate section of this methodology are to provide real world connections, connect skills to future career, relate all course activities, and encourage active student participation. The factors involved in the Deliver section of this methodology are to use interactive PowerPoint Presentations, create problem-solving activities, and promote group work. The factors involved in the Motivate section of this methodology are reminding faculty members to incorporate the I-C-D method and to be aware of the importance of looking for ways to decrease anxiety, improve self-recognition, improve cognitive recognition, and improve intrinsic value as this will increasingly lead to student self-motivation. If an instructor implements the I-C-D-M methodology in a course, student satisfaction, motivation, and performance values in the course should significantly increase.

The plan forward is for full implementation of the I-C-D-M methodology for engineering students in their freshman year through their senior year in an effort to log data to quantitatively measure the changes in student satisfaction, motivation, and performance values in their courses.

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