SUCCESS in Engineering Education: Applying an ID Motivational Framework to Promote Engagement and Innovation

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Abstract: The purpose of this study was to identify motivational gaps and design to optimize for motivational needs in a current university course in mechanical engineering. The course instructor and instructional designer collaboratively used the SUCCESS framework (Hardré, 2009) to assess the existing motivational components of the course, examine gaps in the course relative to its goals, and then propose motivating strategies to address those gaps. This paper presents the model and course description, process and products of the analysis, and strategic redesign of the course to optimize motivation for engagement and innovation. This project demonstrates the iterative process of exposing both implicit and explicit motivational elements of instruction and identifying opportunities to improve them. For this process it utilizes coursework in an applied profession that requires open-ended problem-solving and solution design. It illustrates the utility of the SUCCESS framework, as well as an implementation process, for identifying and addressing motivational gaps in instruction, based on key competencies and performance goals.

Keywords: Motivational design, engineering education, collaboration of designer with SME-faculty member.

No instruction is ever only cognitive, informational or rational in nature (Dai & Sternberg, 2004). All teaching and learning includes and is powered by motivational features, for better or worse (Merriam, Caffarella & Baumgartner, 2006). Motivation and learning are situated within the context of learning environments (Brown, Collins & Duguid, 1989). In every professional field and academic subject area, instruction can be improved by explicit attention to motivational features (Hardré, 2009; 2012). Such attention is even more critical in fields with historically lower motivation, lower retention rate and existing skill gaps, such as engineering.

Need for Motivation in Engineering and Mechanical Engineering

The United States is facing an unprecedented shortage of engineers (Blue, Blevins, Carriere & Gabrielle, 2005), while the alignment of engineering curriculum models with professional career preparation is in question (Lang, Cruse, McVey & McMasters, 1998). Engineering matters more now than ever, with much of our technological innovation in every area of specialization depending on superior engineering design and development (Sheppard, Macatangay, Colby & Sullivan, 2009). Today's engineers formulate complex problems as well as solve them (National Academy of Engineering, 2004, 2005). Engineering work in the twenty-first century demands a sophisticated understanding of the interface between the natural world and the artificial (Sheppard, Macatangay, Colby & Sullivan, 2009), an interface that is central to technological advancement (Williams, 2002).

There is clear evidence of attrition and demotivation in engineering education in the United States, which has resulted in a lack of a next generation of well-prepared engineers (National Academy of Engineering, 2004, 2005). Engineering student retention represents a significant challenge in engineering education, as only about half of students who enter engineering majors actually earn engineering degrees (Burtner, 2005; Felder, Shepard & Smith, 2005). Course and program attrition are high for engineering programs nationally (Grose, 2008; Marra, Rodgers & Shen, 2012) and even higher for some engineering specialties (Hoit & Ohland, 1998). Yet fewer than 10% of students who leave engineering do so because of low grades (Kuh, Kinzie, Buckley, Bridges & Hayek, 2006). This apparent gap between demonstrated ability and success indicates that there are other (negative) motivational factors in play. As engineering educators and partners in the development of engineering educators, we cannot afford to ignore an opportunity to improve the motivational potential of engineering instruction.

Nature of Expertise in Next-Generation Mechanical Engineering

Engineering involves a good deal of technical expertise and some elements of creativity, similar to other scholarly and applied design and technical professions (Chi, 2006; Nelson & Stolterman, 2003). Corporations and employers historically report a lack of critical professional skills, such as critical thinking, problem-solving, communica-tion and teamwork among engineering graduates (e.g., Allan & Chisholm, 2008; Bradford School, 1984; Earnest & Hills, 2005; Evers, 2005; McLaughlin, 1992; Sparkes, 1990). These gaps have led the U.S. Accreditation Board for Engi-neering and Technology (ABET) to transform its accreditation criteria from content-based to out-comes-based (ABET, 2012). ABET now proposes to hold engi-neering schools accountable for the knowledge, skills, and professional values engineering students acquire (or fail to acquire) in the course of their educations.

The skills of the next-generation engineer need to be adaptive enough to address changing needs, and include innovation to address unforeseen challenges (Blue, Blevins, Carriere & Gabriele, 2005). In an innovation economy, critical thinking provides the foundation for developing meta-compe-tencies to the highest possible degree (Business Roundtable, 2005; Christensen, 2011; Dai, 2013). Consistently engag-ing in higher level cognitive activities (of analysis, synthesis, and evaluation) that lead to adaptive design expertise involves more than following a new set of procedures (Lave & Wenger, 1991; Lawson, 1997; Lawson & Dorst, 2009). As engineering educators, we want learners not merely to adopt a rote process cycle or follow a set of simplistic, external procedures; we want them to develop higher order habits of mind (Chubin, May & Babco, 2005).

Every professional field has two levels of competencies, field or task-specialized competencies, and generalized skill sets (or meta-competencies) (Bereiter & Scardamalia, 1993; Brown & Green, 2003). Task-specific competencies are benchmarks for graduates in a given field, and their level of attainment defines how prepared students are to meet job demands and excel in future (Allan & Chisholm, 2008; Earnest & Hills, 2005). General (meta) competencies are skill sets that enable them to function glob-ally, such as to communicate effectively, work in teams, function in organizations and meet quality standards, and transfer task-specific skills to new challenges or tasks not previously encountered (Radcliffe, 2005; Wulf & Fisher, 2002). Future engineering innovation will increas-ingly originate from teams of collaborators who can bring together multiple skills and perspectives (Downey, Lucena, Moskal, et al, 2006; Warnick, 2011). To revolutionize learning, we need to develop an intentional culture of reflection, in which both students and faculty develop strengths in meta-cognition and self -regulation.

The competencies and meta-competencies required of successful next-generation engineering are different from those needed in earlier eras, due to increased demand for innovation (ABET, 2012). Raw production of ideas and technical skills are insufficient for achieving innovation (Business Roundtable, 2005). The problems facing society today are increasingly global and complex in nature, so engineers need to be equipped to address issues involving economic, social, ecological, and intel-lectual capital (Christenson & Raynor, 2003). These needs include global competencies encompassing, "knowledge, ability, and predisposition to work effectively" with diverse groups of people who define problems differently (Downey et al. 2006, p. 110), to facilitate communication and understanding across nations and cultures, teams with diverse backgrounds, and technologies (Warnick, 2011).

The development of competencies to support engineering in general, and innovation in particular, spirals upward with students building on existing competencies and adding new ones as they progress through the curriculum. In this paper we focus on motivation related to developing meta-competencies that support innovation, with the understanding that specialized technical domain competencies are pre-requisite to expert problem-solving. We build on a set of meta-competencies for engineering innovation complied by various educators and researchers (e.g., Allan & Chisholm, 2008; Radcliffe, 2005). These are summarized in Table 1.

Current State of Instructional and Motivational Practice

One of the basic premises of project-based course design is that projects—in and of themselves—are motivating (Sheppard, Macatangay, Colby &

Table 1. *Metacompetencies for Engineering Innovation*

Manage Information • Ability to gather, interpret, validate and use information • Understand and use quantitative and qualitative information • Discard useless information
Manage Thinking • Ability to identify and manage dilemmas associated with the realization of complex, sustainable, socio-techno-eco systems • Ability to think across disciplines • Holistic thinking • Conceptual Thinking • Ability to speculate and to identify research topics worthy of investigation • Divergent and convergent thinking • Ability to engage in critical discussion • Identify and explore opportunities for developing break-through products, systems or services • Ability to think strategically by using both theory and methods
Manage Collaboration • Ability to manage the collaboration process in local and global settings • Ability to create new knowledge collaboratively in a diverse team • Competence in negotiation • Teamwork competence
Manage Learning • Ability to identify the competencies and meta-competen-cies needed to develop to be successful at creating value in a culturally diverse, distributed engi-neering world • Ability to self-instruct and self-monitor learning • Ability to interact with multiple modes of learning
Manage Attitude • Ability to self-motivate • Ability to cope with chaos • Ability to identify and acknowledge mistakes and un-productive paths; • Ability to assess and manage risk taking

Sullivan, 2009). Research does demonstrate that active learning (hands-on and project-based learning) is generally perceived as more motivating and engaging than passive learning (such as by lecture and reading alone) (Bransford, Brown & Cocking, 1999; Huber & Hutchings, 2005; Laster, 2009). At the same time, the nature and goals of a given project can be more or less interesting, important, engaging and motivating for different learners, based on their interests, value for the content and outcomes, and prior experience in the field of application (Cross, 2007; Fox & Hackerman, 2003; Hardré & Burris, 2011). Thus, for different tasks and learners, different projects and ways of designing project-based learning environments can have very different motivational effects (Hardré, 2009). The most effective projects for engineering education are not simple and linear, with well-defined end goals, but are characterized by true problems, that is, issues and questions without "right" or absolute answers, amenable to a range of possible solutions, some more creative and innovative than others (McCray, DeHaan, Kasper & Schunk, 2003; National Science Foundation, 2004).

The SUCCESS Framework—Potential Toolkit for Change

No instruction is ever motivationally-neutral. Every item of information, every activity, every appearance by an instructor, and every item of instructional material has motivational potential (Hardré, 2003). If these are not explicitly designed with positive motivating effects, then they may inadvertently have negative motivational consequences (Hardré, 2011). However, motivation is a rich and complex area of research and practice. It is informed by myriad theories, subfields and perspectives that can leave many designers and instructors confused and frustrated. Knowing and integrating each of these theories, and reconciling their various outcomes into a consistent motivational approach for instruction can be time-consuming and difficult, so many designers and instructors give up or default to simplistic approaches (Hardré, 2003). However, a tool that helps them make sense of this complexity can provide the structure necessary for selecting and implementing motivational components systematically in the design of instruction, and optimize effects for both designer-instructors and learners (Hardré & Miller, 2006).

The SUCCESS framework of motivating opportunities for instructional design is just such a tool (Hardré, 2011). It integrates an array of useful, theoretically-based motivating principles into a structure that supports their systematic application to instructional needs (Hardré & Miller, 2006). The seven-part structure provides a framework for applying the principles, and the mnemonic (SUCCESS) cues the various areas of application to promote coverage of all aspects of instruction. It can be used to examine the motivating elements of current instruction, and to identify and fill gaps in those areas not yet motivationally optimized.

Applying SUCCESS to Engineering Education

The following section uses an extended case illustration of implementing the SUCCESS motivational design framework in mechanical engineering education. It begins by describing the course goals, content, tasks and learners as context for the application. Then it illustrates use of SUCCESS for both assessing current strategies and guiding design of additional strategies. First, the framework is used to assess the current state of instruction, through identifying and classifying its existing motivational elements (both explicit and implicit). Second, it is used to identify where gaps exist and to design in additional motivating opportunities and elements to address SUCCESS components that were previously less well-supported, to fill those gaps.

Course Overview

Principles of Engineering Design (AME 4163) is a required university undergraduate course in mechanical engineering (ME). It functions as the pre-capstone experience for all ME majors, which means that it provides opportunity for students to synthesize and integrate their previous 80 hours of mathematics, physics and engineering subject-specific coursework, through applied team and individual projects.

AME 4163 is a single, semester-long course, which meets twice weekly for 75 minute sessions, over a 14-week semester (28 meetings, 150 contact hours). The single course section generally has 80 students enrolled. It has no outside labs, but students are required to meet in project teams, scheduled on their own times and locations. There are no content-based examinations, only applied projects comprising all graded assignments. Students form and remain in the same project teams (of 4-5 students) for the whole semester.

About ¾ of the way through the semester, the students transition to spending more time focused on preparation for the degree-culminating Capstone experience, which involves them in teams (4-5 students) working on an authentic design challenge with industry project sponsors and faculty advisors. The teams work to understand a design problem, then submit a solution design to the sponsors and instructor for the capstone project at the end of the semester

Instructor

This course is taught by a single instructor, a full professor in ME at the university, who has taught this course, in this university program, annually for 13 years. His philosophy of instruction is linking engineering fundamentals to a range of professional applications through project based learning. His research is in the area of product family design, Computer Aided Design, and Design Theory. He is also interested in understanding different aspects of engineering education and developing new tools to enhance student learning. This instructor also coaches the award-winning [university name masked] Racing Team, which participates in the Formula – SAE (Society of Automotive Engineers) student design competition. The instructor coordinates the Mechanical Engineering Capstone Program, engaging students in sponsored industry projects.

Target Outcomes and Assignments

The overarching goal of instruction for Principles of Engineering Design is that learners will demonstrate through instructor-supported experiences that they are equipped with the knowledge and skills to do eight performance tasks in mechanical engineering. These tasks are demonstrated in nine different assignments. The performance outcomes and assignments are summarized in Table 2.

Learners

Students take this course in their fifth semester of the structured degree program, so all are college juniors majoring in ME. Immediately following this course, all will progress to the Senior Design Capstone experience, so they share a vested interest in preparing for success there. In the longer term, these learners are preparing for somewhat similar career trajectories and share many of their future-oriented goals. They function as a near-cohort, in the curricular framework. Though they have not moved through the program in a single group, all have all taken the same set of 16 courses required for ME majors, from the same instructors, over the past two years. Thus, they have been in classes together numerous times, have worked together on projects before, and know each other as students.

All of these learners entered with high math and science aptitude scores (SAT average of 1280; mathscores 600-700) and combined 28.3 in ACT scores (ACT Math range of 32-25), so this is a relatively homogeneous group characteristic. Since they have all

Table 2. *AME 4163 Performance Outcomes and Assignments*

Specific Outcomes of Instruction:

Students will demonstrate (through supported performance) that they have acquired adequate knowledge and skill to:

1. Apply a systematic approach to solve design problems.
2. Plan the design process.
3. Generate, evaluate and develop engineering design concepts by applying knowledge of facts, science, engineering science, and manufacturing principles.
4. Use analysis and simulation tools to understand design performance and then improve the design.
5. Manufacture an engineering design prototype
6. Generate solid models and engineering drawings of a final design using 3D modeling software.
7. Give an oral presentation and demonstration of a design project.
8. Work on a team to complete a design project.

Assignments

The following list includes the graded assignments for the course, both individual (I) and team (T) projects:

1. Assignment 1 (Planning and Customer Requirements) (T)
2. Assignment 2 (Concept generation, and reduce to 4 concepts) (T)
3. Assignment 3a (CAD) * (I)
4. Assignment 3b (FEA – Structural and Heat)* (I)
5. Assignment 4a (Selection of Concepts) (T)
6. Assignment 4b (Detail design – Engineering drawings, CFD, & Simulation) (T)
7. Project 1 Final Deliverables: (T)
   a. Presentation
   b. Report (Putting everything together)
   c. Prototype Demonstration
8. Short and In Class Assignments/Quizzes (T)
   a. Short Assignment 1: Setting Goals and Evaluating your competencies
   b. Short Assignment 2: Understanding the Design Process – Building bridges
   c. Short Assignment 3: Professional and Ethical Responsibilities
   d. Short Assignment 4: Thermal analysis
9. Learning Essay (Self-evaluation of learning and competencies) (I)

taken the same course program for the past two years (as required by the major curriculum) they have fairly homogeneous course-relevant, recent prior knowledge and academic experiences.

Individually and viewed as a group, ME students in this institution are diverse in characteristics and background, such as socioeconomic status, race and ethnicity, nations of origin, family status and career experience. The gender mix is about 88% male and 12% female. From 90-95% tend to be traditional and 5-10% non-traditional students. About 94% are US citizens, 6% international students, and 5-10% non-Native English speakers. The diversity of the students in the course in any given semester has increased over time, so the instructor is interested in reaching a potentially broader range of motivational needs.

Design

The design of instruction is a combination of whole-class lecture-with-discussion and projects. The professor uses large-group lecture, questioning and discussion to review and support recall of students' previous course content, and to introduce principles of engineering design. Lectures are accompanied and illustrated by Powerpoint slides, presented in class and also uploaded to the course management system (CMS) website.

Students synthesize and apply the content holistically on a set of individual and group projects over the semester, with instructor support and feedback, as well as peer discussion and feedback. Projects are completed mostly outside of class and submitted as demonstration of a physically functional prototype. Each team submits a final written report to the instructor, and verbally presents its design to the class. Feedback occurs explicitly through instructor and peer feedback, and implicitly through performance of the functional prototype relative to project requirements. Students spend about 60% of class time in lecture and 40% in various forms of dialogue (questioning, discussion, feedback).

Defining the Need

The instructor has seen reduced engagement and less effective synthesis of information over the past few years. The designer and instructor recognize that a number of motivational factors can influence students' engagement, and that motivation influences students' learning, understanding and ability to synthesize information and ideas and apply them adaptively, leading to innovation. We proposed that redesigning the motivational aspects of the course across all elements would present the greatest potential for improving these key outcomes and more effectively meeting students' needs. We chose the SUCCESS framework as a strategic tool to structure that process.

We proceeded intentionally, not assuming that any existing element (such as the course being project-based) was already optimally motivating. Instead, we used the nature of existing design components as foundational starting points from which to build an even more motivating dynamic, whole-course design. We focused on individual design aspects for analysis and examined them each fully, yet throughout the process considered the course and learning environment as an integrative, coherent whole, together much more dynamic than merely the sum of its parts. Through this lens, we utilized the existing motivational elements as resources on which to leverage additional motivating strategies.

Procedure

Together the course instructor and the designer used the previously-published SUCCESS framework: first, to examine the existing mechanical engineering course and identify existing motivational strategies; and second, to identify areas that could be enhanced and to design in additional and more effective motivating strategies. The analysis and redesign process was carried out iteratively and collaboratively, with the instructor contributing primary expertise in the learners, task and subject area, and the designer contributing primary expertise on motivation theory, principles and practice. To keep the SUCCESS elements flexible and clear in our analysis and redesign processes, we referenced those sharing starting letters in the mnemonic as sequentially numbered (S_1-U-C_1-C_2-E-S_2-S_3). We also coded the strategies that supported each of our two key outcomes: engagement (e) and innovation (i).

Phase I—Analyzing Existing Strategies

In phase I, the instructor and designer used existing materials from several recent course years to identify the types of motivating components, both global design elements, and explicit strategies, that were already included in the course. This required not only extracting the elements documented in the materials, but also the designer and instructor developing an elaborated think-aloud dialogue, to illuminate additional fluid and implicit components that the instructor tended to use in his actual teaching practice. Some of these were strategies implemented as cognitive learning strategies, but which also contained embedded motivational elements informed by the SUCCESS framework. Others were strategies for communication or class management that had underlying and previously unrecognized motivating elements. Table 3 shows the results of the analysis of existing strategies.

Summary of Motivational Analysis

We identified particular strengths in the Situational (S_1), Utilization (U), Competence (C_1), Content (C_2) and Social (S_2) components. The course was already team and project-based, and included a high degree of student autonomy and control. It already provided reference to the professional design competencies in the field, and access to the technical tools needed to develop specific required performance skills. The cohort nature of the program and the digital LMS provided access to social support to develop teamwork skills and seek out expertise if individual students needed it and sought it out.

An apparent weakness across these areas was the observed lack of use of these resources, so we concluded that while access technically existed, the limited number of students actually taking advantage of them might be explained by one of three motivational phenomena: 1) lack of *perceived* (vs. actual) access (students being unaware or feeling unable to access the resources they needed); or 2) inaccurate perceptions of need (students thinking they didn't need help when they did); or 3) ego-involvement/performance goals (students perceiving that seeking help communicated perceived weakness or or incompetence). Thus, motivating more active use of the existing resources emerged as a critical goal for the redesign.

Areas with fewer or less robust motivational strategies identified were the Emotional (E) and Systemic (S_3) components. These had not been a focus of the instructor's design decisions historically, as he had concentrated on content and competence-related motivation strategies, as do most subject-area experts (instructors and trainers) without specific training or expertise in human motivation. We did identify some motivating elements in these areas, but more implicit than explicit, and most were residual effects of content-focused design decisions. Seeking to add explicit motivational enhancements in these two components was an additional goal of the redesign. In addition, the instructor adopted the goal of adding at least one enhancement strategy in each of the seven SUCCESS

Table 3. *Using the SUCCESS Framework to Identify Existing Motivational Features in the Course*

S_1: Situational (Contextual and Access issues)	Focuses on nature of learning and performance contexts, their support for autonomy, authenticity, access and control (both actual and perceived by learners). Learners provided with motivationally-positive situational features (such as choice about how they do tasks) and with access to materials and support resources more readily engage and fit instruction to their needs.	1. The learners are given a description of a problem, which requires them to address an open-ended problem -solving task. This supports engagement for active learning, along with adaptive application for innovation. (e)(i) 2. Some requirements for the device are set, but other requirements are more flexible and are not provided. Students set boundaries for their solutions. This supports autonomy independence. (e)(i) 3. Students set their own steps for solving projects, based on the phases of design processes. Deadlines for assignments and the final prototype are fixed, but students are free to determine steps needed to get from one assignment to the next. These are authentic elements, analogous to professional demands. (Assignment 1) (e)(i)
U: Utilization (Use and Transfer Issues)	Focuses on facilitating transfer by bridging the relevance gap from instruction to application. Utilization-focused motivational features of instruction connect learning and transfer through a motivational framework. Instruction needs to address how learners recognize their need for instruction and see themselves using it, both during instruction and later.	1. Lectures provide information on how material is linked to design of devices and systems. This scaffolds perceived transfer needs & relevance. (e) 2. Learners utilize the steps to solve the project, which is a novel problem (has not been solved yet), so they experience the relevance of skills in-process. (e)(i) 3. Students are shown the use of "House of Quality" for a simple problem, to support understanding of performance expectations. (Assignment 1) (e) 4. Use of engineering tools (CAD, FEA, CFD) provided for examples. (Assignments 3A, 3B) Having the tools they need accessible frees up students' thinking and motivation for problem-solving (e)(i) 5. During detail design (Assignment 4b) students set parameters and dimensions for components before building the prototype. They plan and envision goal achievement using their chosen strategies. (e)(i) 6. Students observe how other groups solved the same design problem, but generated a different solution, which supports understanding of innovation. (i)
C_1: Competence (Considerations Focused on Expertise Development)	Focuses on motivational considerations related to current competence development and future, continuing expertise development in the field. Competence is more than just confidence; it's both the actual and perceived components related to an individual's achieving target standards of knowledge and skill. This includes prerequisites (preparation), current position (readiness), and future-oriented perceptions and expectations of success (confidence and efficacy). It can be normative (comparing their ability to others'), or criterion-based, (comparing to established standards of expertise). Competence goals can be ego-involved (working to look good and be better than others) or mastery-focused (aimed at learning and being one's personal best).	1. Course uses the professional competencies as implicit scaffolds and rationales to justify design demands. This supports students in relevance and clear, credible expectations of expertise targets (e) 2. Students evaluate their own and teams' competencies, along with setting goals to develop skills. (Short Assignment 1) This causes them to review the competencies and rehearse them continuously, in order to develop definitions and vision for professional expertise. (e) 3. All assignments require students to use course material in novel situations, to develop actual and perceived competence. (e)(i)
C_2: Content (Knowledge & Information Components)	Focuses on motivational elements of information provided and supported through instruction, and needed for performance. In considering motivational features of content, designers focus on how information is communicated, how it is supported, and what is emphasized (explicitly or implicitly) about it. Content features are the most familiar to most designers, but their motivational components are often neglected.	1. Students use materials from various previous courses, to analyze components and develop project devices (Assignment 3) (e)(i) 2. The performance of the prototype provides students with feedback on their design process, leading back to evaluation of content knowledge and its utility. (e) 3. Uses students' content knowledge to support relevance perceptions, linking current instructional demands to past design courses and experiences. (e)

Table 3. *Using the SUCCESS Framework to Identify Existing Motivational Features in the Course (continued)*

E: Emotional (Affective & Personal Issues)	Focuses on personal, perceptual factors with motivational implications for instructional effectiveness. Emotional, affective, and personal issues in motivation include characteristics and thoughts about the job, knowledge, and skills that create positive or negative emotions and states (hope, optimism, anxiety, fear, curiosity, hopelessness). Emotions drive responses such as trying (vs. giving up), taking risks to innovate (vs. stay safe), and honesty (vs. cheating)—to protect the emotional self. Temperament & tendencies (relatively stable), moods (less stable & more circumstantially-driven), and emotions (complex & volatile).	1. The project and the competition present some anxiety and frustration for students, which is an authentic part of the design process. If they resolve ego issues, this is stimulating and productive. (e)(i) 2. Students get to observe how their device performs, which informs their competence and provides success experiences, or recognition of need to remediate. 3. Students design and build the prototype by themselves, so they own the project and products, promoting independence and empowerment. (e)(i)
S_2: Social (Group & Interpersonal Interactions, Relationships)	Focuses on motivational effects of social & interpersonal elements of instruction. These include how groups learn & work together, how they communicate, and how they interact with teacher-trainers and systems. Social environment considerations influence learning and performance.	1. Students work in teams, enabling social support, sharing of expertise, and encouragement. (e) 2. The near-cohort program model ensures that by this point students know each other, recognize relevant strengths, are reasonably comfortable together. 3. Teams have high degrees of shared knowledge and skill (supporting common discourse and effort), promoting healthy teamwork. (e) 4. Members also each bring some unique expertise, promoting recognition and value of individual skills, and insights gained through differences. (e)(i)
S_3: Systemic (Organizational & Systems Considerations that Facilitate Performance Improvement)	Focuses on motivationally-relevant elements of instruction, related to the system & organization in which it exists & for which it occurs. Systemic motivational elements support learners' being motivationally positioned to put forth consistent effort. Designers need to examine reasons for instruction in the larger workplace system and determine how to inform & align learners' motivations & efforts.	1. Students use mathematics, physics, statics, dynamics, etc. learned during their course of study and try to apply it to design a device to solve the problem. This presents authentic use of discrete information selection and application to unique, open-ended problems. (e)(i) 2. Course pulls together and requires synthesis and application of all courses to date (solids, thermal, mechanical components), supporting the links across the whole curriculum to competent design. (e)(i)

components, whether analyzed as strong or weak, to help ensure optimizing motivation for this instruction. In particular, these enhancements are targeted to address an even broader range of this increasingly diverse student group.

Phase II—Enhancing Instruction with Additional Strategies

In phase II, the instructor and designer used the SUCCESS framework to identify additional motivating opportunities in the course, both in its global design elements, and among more nuanced explicit strategies. This required identifying those course components that were more and less well-supported with motivating features, across the scope of motivating elements presented in the SUCCESS framework. We used the terms, lists and illustrative examples from the SUCCESS model to cue possible ideas and then collaboratively developed these into motivating elements. The focus of optimizing motivation was on areas of the course that we had judged as less motivationally optimized, and those historically demonstrated as either more challenging or less engaging based on learner behaviors and explicit feedback (e.g., verbal comments and formal course evaluations). The target instructional outcomes of this process were to enhance engagement to support learning and development, aimed at facilitating ME innovation. Table 4 shows the results of the development of additional strategic motivating opportunities based on the SUCCESS framework.

Summary of Motivational Redesign

We identified a number of implicit motivating strategies that the instructor saw but admitted that some students apparently understood and used, but others were probably missing. These were not functioning as optimally motivating, because of an apparent gap in students' perceived needs or access. The instructor added explicit elements to make these strategies clearer, more obvious to all learners. In some instances this involved actually *explaining why* they were included in

Table 4. *Using the SUCCESS Framework to Identify Additional Motivating Opportunities in the Course*

S_1: Situational (Contextual & Access issues)	Focuses on the nature of the learning and performance contexts, their support for autonomy, authenticity, access and control (both actual and perceived by learners).	1. Students will be provided with greater access to information and examples of design processes, to improve the range of challenge and meet diverse needs of learners (remedial/ advanced-extended). This also offers the motivational benefit of independent exploration for solution development. (e)(i)
U: Utilization (Use & Transfer Issues)	Focuses on facilitating transfer by bridging the relevance gap from instruction to application.	1. Students provided with more complex examples of "House of Quality" to show that it is used in practice to determine & set different requirement targets. (Assignment 1) (e)(i) 2. Examples will be provided for detail design (Assignment 4b) to set parameters and dimensions for components before building the prototype. (e)(i)
C_1: Competence (Considerations Related to Expertise Development)	Focuses on motivational considerations related to current competence development and future, ongoing expertise development in the field.	1. Final prototype provides more specific and concrete performance feedback, opportunity for students to go back and reflect on their design decisions, to determine what worked & what did not. (e)(i) 2. Use professional competencies more explicitly and openly to scaffold design reasoning and also model how they operate in multiple solution paths. (e)(i) 3. Innovation will be even more explicitly encouraged, and as component of future professional needs. It functions as an indicator of advanced competence in addition to basic performance on assignments. (i)
C_2: Content (Knowledge and Information Components)	Focuses on motivational elements of information that is provided and supported through instruction and needed for performance.	1. Develop scaffolds that will build on student knowledge of CAD, FEA, and other simulation based design software to analyze and predict performance of design. (e)(i)
E: Emotional (Affective and Personal Issues)	Focuses on the personal, perceptual factors with motivational implications for instructional effectiveness.	1. Encourage more active group-based learning, by modifying some of the assignments to more team-oriented tasks, where students can learn from each other. (e) 2. To help ensure productive effects of competitive stress, instructor will monitor for learning versus performance goals. (e)
S_2: Social (Group, Interpersonal Interactions, and Relationships)	Focuses on motivational effects of social and interpersonal elements of instruction.	1. Students will have greater access to instructor and peers in class through message boards, lectures & office hours. (e) 2. Instructor monitors even more closely not providing students with answers, but supporting original ideas for possible approaches to independent problem-solving. (e)(i) 3. Strive to balance competition and the cooperative climate, to gain motivational advantages of both. (e)
S_3: Systemic (Organizational & Systems Considerations that Facilitate Performance Improvement)	Focuses on motivationally relevant elements of the instruction in relation to the system and organization in which it exists and for which it occurs.	1. Students are provided with examples that relate how the different concepts are applied to design systems, across a broad range of systems and in the context of different jobs that students may have after graduation. (e)(i)

the course.

To address the goal of increasing actual use of the existing resources, we designed explicitly to address the three possible causes of students' lack of use. For possible perceived lack of access, we added more information about the resources, where they were located and how to access them. These were embedded in the instruction both up-front in the syllabus and at strategic points in the lecture-discussion notes (to remind the instructor when to feature them). To address the issue of possible lack of perceived need, we added more explicit guidance on how and when particular resources could or should be most useful, and under what circumstances students should seek them out. These also were embedded both in the general course information (within the LMS) and also highlighted in the lecture-discussion notes, for the instructor to explicitly share in class.

Addressing the possible explanation of students' individual or group performance goals preventing them from seeking help they needed was a more complex challenge that required explicitly supporting a culture change toward reduced ego-involvement and a shared culture of learning-through-error. While this culture was consistent with the instructor's philosophy and style, he had assumed the students "caught" it implicitly, so he didn't need to have "taught" it explicitly. In discussion, the designer and instructor determined that given the potential value-added for students, it would be worthwhile to make this component of the course design much more explicit. Designing in this type of goal revision required several elements: 1) intentional role modeling of error acceptance and value of learning goals by the instructor (instructor modeling or "stepping off the pedestal moments"); 2) explicit and clear statement of the importance and necessity of seeking help (or "it takes a village messages"); and 3) acknowledgement and celebration of students demonstrating productive help-seeking (highlighting peer modeling). Together these strategies addressed the key components required for goal retraining. Some students already demonstrated high error tolerance, willingness to take risks and learning goal orientations, so the instructor and designer believed they would readily adopt the learning culture and support the shift for their peers retaining performance goals.

Specific strategies to address the two weaker areas included attention to systemic features of the course and curriculum, along with balancing some emotional class features. The instructor was already aware of strong emotions and expectations tied to the course, but was concerned that these were not always healthy emotions. He identified a high level of performance anxiety around the design competition for some students, while others just seemed to thrive on the competitive element. Based on these observations and our discussion of various goal sets and their benefits for different students, he more explicitly designed in balance across the competitive and cooperative components of the course, in an effort to gain the motivational benefits of both.

Additional enhancements across the course design included one or more in each area, including:

S_1: Enhancing access to examples

U: Providing more complex illustrative examples

C_1: Enhancing performance feedback, Linking more clearly to professional competencies, and More explicitly encouraging risk-taking toward innovation

C_2: Increased scaffolding for use of software tools

E: Encouraging more group-based learning and monitoring goal sets

S_2: Increasing access to instructor and peers, supporting original and innovative ideas

S3: Providing a broader range of examples across professional systems and contexts

Some key elements of the redesign overall included: making implicit efforts more explicit, drawing students' attention to resources that already existed, enhancing students' willingness to seek help from others by infusing that value into the learning climate, and addressing the "why" question regarding design elements with underlying motivational potentials. It is notable that most of these enhancements constitute only minor, not major, course revisions. They require only small investment of additional resources, costing little to implement (in terms of funding, equipment or technology, or extra instructor time or energy). They result mostly from redirecting or increasing the students' and instructor's awareness and perceptions of opportunities already afforded to them. Part of the redesign was the shift to assuming less and making explicit more, increasing the accessibility, salience and motivational effectiveness of existing instruction for more of the students in the class.

Discussion

This collaborative project illustrates the strategic process of systematic motivational redesign, showing how to make an already good course or educational program even better. It is grounded in first design principles (Merrill, 2007), and moves beyond them to integrate advanced principles of motivation (Hardré, 2009), along with domain-specific competencies (ABET, 2007; NSF, 2004). This approach supports solution-driven design via developing critical thinking and innovation (Kruger & Cross, 2006), contributing to future needs of mechanical engineering design (Lattuca, Terenzini & Volkswein, 2006). It takes engineering education beyond rote tasks or procedures, into a dynamic of learning environments that targets requisites of next-generation engineering. This process addresses the need for focused scholarly work on the redesign of teaching and learning environments (Weimer, 2006).

Engineering courses and curriculum are notorious for very low retention rate of students, and many who do finish are not developing adequate skills to be successful. Motivation plays a crucial role in retention and development of basic competencies, and even more in the adaptive thinking necessary to support innovation demanded of future engineers. Yet, at the course level, many engineering instructors do not focus on motivational features, let alone design them systematically to infuse motivation. Ironically, direct attention to motivation is lacking, while engineering educators and employers raise concern about factors that motivation has the power to influence, like task performance, course completion and program retention. One reason for ignoring motivation may be that engineering instructors lack knowledge and expertise in this area and have not yet found a tool to make it accessible. Even instructors with knowledge of and consciousness of motivation tend to focus on content and information almost exclusively, rather than the broader social, contextual and systemic features of the learning environment captured in the SUCCESS framework. Like the engineering professor in this project, instructors with or without expertise in motivation and psychology can utilize a framework like SUCCESS, which contains a no-frills distillation of key motivating strategies. With it they can analyze the existing motivational features of their courses, identify gaps and areas for improvement, and fill the gaps with strategies to enhance the motivational effectiveness of their courses.

Another reason that engineering instructors may not see the need to attend to motivation in more advanced and applied courses is that they assume that project-based courses are automatically motivating. Indeed, research does demonstrate that doing something is generally more motivating than doing nothing, that having content-relevant hands-on activities tends to help most learners engage than sitting for hours listening to lectures. However, there is a vast range of motivating potential among project-based components and designs, so they are not all equally or optimally motivating. This project demonstrated that even an already project-based, learner-centered, hands-on engineering course can be further enhanced through systematic analysis and redesign. Implementing this kind of motivational enhancement program-wide offers potential not only to increase immediate engagement, but also to improve longer-term course completion and program retention. For students, value and utility in course content and activities, and positive motivational culture in learning environments help keep them going even when challenges arise. Beyond individual students and courses, the accrued effects of motivated learning yield lasting benefits for instructors and programs.

From a curricular perspective, as engineering students develop more advanced skills, laboratory and project-based courses with open-ended design problems provide students with opportunity to work on authentic projects and consequently can improve student motivation. However, in most fundamental and foundational courses, it is more difficult to introduce authentically complex projects because students do not yet have adequate skills to succeed at them. While any course can be motivationally enhanced, foundational courses present even greater motivating challenges than more advanced courses. They tend to be taught by less experienced instructors, and include fewer applied (more lecture) activities. It is in the first years, in these foundational courses, that most engineering student become disillusioned (or simply bored) and quit to pursue other majors. It is also in these early courses that students need to develop the foundations of expertise, which include not only technical skills but also habits of mind like adaptive and creative thinking. Students can benefit from motivational strategies explicitly considered and implemented in all courses and at all levels, particularly in these foundational courses that set them up for success or failure. As demonstrated in this engineering design course, the SUCCESS framework provides instructors with a tool to identify motivational gaps and redesign motivational features of both the course content and the learning environment. The framework and approach are also applicable to courses at all levels (not just advanced), to all types of engineering (not just mechanical), and to other complex applied sciences beyond engineering.

From a professional development perspective, having instructors learn to use a toolkit based on a broader framework than they normally plan within can help them think about and become aware of more potential strategic design options than before. As the engineer-instructor in this project found, the process of strategically implementing the SUCCESS framework on even a single course may have residual effects on instructors' thinking about future courses and less formal mentoring, promoting innovation and ongoing development in teaching. It is, in effect, giving them tools to go on teaching themselves (colloquially "teaching them to fish" for motivating students).

The process demonstrated in this project was also an example of reciprocal, collaborative interdisciplinary faculty learning, as the engineer-instructor grew to better understand the terms and principles of motivation, and the instructional designer grew to better understand the terms and principles of engineering. As each developed deeper and more integrative understanding, we were individually and collectively more able to leverage that understanding to develop nuances within the course redesign. By working iteratively and collaboratively, we checked and vetted each other's ideas, refining as these developed, and considering options from multiple divergent perspectives. As we worked, we recognized that we were engaged in the very same process that we were working to promote in the learners. We also recognized that we were experiencing the same motivational characteristics that we sought for students to experience.

From a program improvement perspective, beyond individual faculty, such strategic improvement offers potential to update and improve whole programs, providing documentable change aligned with the demands they face. Through improved student learning and skill development, motivation can address student performance standards like improving scores on engineering professional exams (which now explicitly reflect on quality judgments of engineering programs). It can address needs like the recent ABET challenges to program accountability and innovation. Instructors often resist unfamiliar, novel or innovative changes to their teaching, but resist less if the change is consistent with some aspects of their style and expertise, if it fits in some way with their existing habits of mind. The SUCCESS framework offers a reasonably intuitive and palatable way to promote faculty improvement that leverages the pragmatic tendency of engineers to integrate theory and design for adaptive problem-solving (in what one engineer termed "a design-it, build -it, and make-it-work" way). Because of these parallels, born of the similarities between instructional design and other design disciplines (like architecture and engineering), the nature of the framework may help bridge the gap to improve motivation and its critical effects in engineering education.

Overall, this applied case demonstrates the utility of the SUCCESS framework as a tool for analyzing and optimizing motivational elements of instruction design to address specific instructional outcomes. The SUCCESS framework is multi-theoretical so it reconciles the conflicting strategic messages and assertions that practitioners often experience from trying to collect ideas from discrete theories separately. It is integrative of cognitive and affective elements of instruction with potential motivational impacts, so that learning and motivational goals of instruction need not compete in design decision-making. The framework is designed to be independent of any particular instructional design process or curriculum model, to function adaptively across them. It has further been demonstrated as applicable across learner groups, disciplines and subject areas, and target outcomes from foundational knowledge and applied skill development to social and cultural change.

Engineering is a challenging field, requiring the integration of advanced math and science skills, a depth of both discipline-specific "book knowledge" and applied skills, and a degree of creativity and adaptivity to support innovation. However, it can be made accessible and motivating to many more students who possess the requisite background and ability, those whom the field has historically not retained. As this application project demonstrates, a strategic motivational framework can be used to gain a broad and integrated perspective of the motivational elements of a course or program; to examine their theoretical effects for a given learner group, context and tasks; and to consider the potential for motivationally enhancing the whole from this perspective. The benefits result from a bit of design engineering, integrating information on motivation theory (operationalized into a usable strategic framework) with subject area expertise (that enables leveraging those strategies into the specific goals and context).

References

Accreditation Board for Engineering and Technology (ABET) (2012). *Criteria for Accrediting Engineering Programs.* Retrieved December 14, 2012 from: http://www.abet.org.

Allan, M. & Chisholm, C. (2008). Achieving engineering competencies in the global information society through the integration of on-campus and workplace environments. *Industry and Higher Education*, 22(3), 145-152.

Bereiter, C., & Scardamalia, M. (1993). *Surpassing ourselves: An inquiry into the nature and implications of expertise*. Chicago: Open Court Publishing Company.

Blue, C. E., Blevins, L. G., Carriere, P. & Gabriele, G. (2005). The engineering workforce: Current state, issues, and recommendations. Final report to the Assistant Director of Engineering. Arlington, VA: National Science Foundation.

Bradford School of Technical Management (1984). *Managerial skills and expertise used by samples of engineers in Britain, Australia, Western Canada, Japan, the Netherlands and Norway*. University of Bradford: Bradford, UK.

Bransford, J. D., Brown, A. L. & Cocking, R. R. (1999). *How people learn: Brain, mind, experience and school*. Washington, DC: National Research Council.

Brown, J. S., Collins, A., & Duguid, P. (1989). Situated cognition and the culture of learning. *Educational Researcher 18* (1), 32-42.

Brown, A. & Green, T. D. (2006). *The essentials of instructional design.* New York: Pearson.

Burtner, J. (2005). The use of discriminant analysis to investigate the influence of non-cognitive factors on engineering school persistence. *Journal of Engineering Education*, 94, 335-339.

Business Roundtable (2005). *Tapping America's potential: The Education for Innovation Initiative.* Washington, DC: Business Roundtable.

Chi, M. (2006). Two approaches to the study of experts' characteristics. In N. Charness, P. Feltovich, & R. Hoffman, (Eds.), *Cambridge handbook of expertise and expert performance (pp.21-30)*. Cambridge: Cambridge University Press.

Christensen, C.M. (2011). *The innovator's dilemma: The revolutionary book that will change the way you do business*. New York: Harper Business Press.

Christensen, C.M. & Raynor, M.E. (2003). *The innovator's solution: Creating and sustaining successful growth*. Cambridge, MA: Harvard University Press.

Chubin, D. E., May, G. S. & Babco, E. L. (2005). Diversifying the engineering workforce. *Journal of Engineering Education*, 94(1), 73-86.

Cross, N. (2007). *Designerly ways of knowing.* Basel, Switzerland: Birkhäuser Verlag, AG.

Dai, D.Y. (2012). *Design research on learning and thinking in educational settings: Enhancing intellectual growth and functioning.* New York: Routledge.

Dai, D. Y. & Sternberg, R. J. (2004). Beyond cognitivism: Toward an integrated understanding of intellectual functioning and development. In D. Y. Dai & R. J. Sternberg (Eds.), *Motivation, emotion and cognition: Integrative perspectives on intellectual functioning and development* (pp. 3 -40). New York: Taylor & Francis.

Downey, G.L., Lucena, J.C., Moskal, B.M., Parkhurst, R., Bigley, T., Hays, C., Jesiek, B.K., Kelly, L., Miller, J., Ruff, S., Lehr, J.L. & Nichols-Belo, A. (2006). The globally competent engineer: Working effectively with people who define problems differently. *Journal of Engineering Education,* 95: 107-122.

Earnest, J. & Hills, S. (2005). ABET Engineering technology criteria and competency-based engineering education. 35th ASEE/IEEE Frontiers in Education Conference, Indianapolis, IN.

Evers, F.T. (2005). *The bases of competence: Skills for lifetime learning and employability*. Guelph, Ontario.

Felder, R. M., Sheppard, S. D. & Smith, K. A. (2005). A new journal for a field in transition. *Journal of Engineering Education*, 94(1), 7-12.

Fox, M. A. & Hackerman, N. (2003). *Evaluating and improving undergraduate teaching in science, technology, engineering and mathematics.* Washington, DC: National Academies Press.

Grose T. K. (2008). Staying on track: Engineering schools used to shrug off high attrition rates. Now they're working to help students achieve early – and enduring – success. *Prism*, February 2008: Retrieved December 14, 2012 from http://www.prism-magazine.org.

Hardré, P. L. (2012). SUCCESS for teaching assistant professional development. *Journal of Applied Instructional Design, 2* (1), 50-56.

Hardré, P. (2003). Beyond two decades of motivation: A review of the research and practice in human performance technology. *Human Resource Development Review*, *2,* 1, 54-81.

Hardré, P. L. (2009). The Motivating Opportunities Model (MOM) for performance SUCCESS: Design, development and instructional implications. *Performance Improvement Quarterly 22* (1), 5-26.

Hardré, P. L. (2011). Motivating math learning for rural students: Teacher and student perspectives. *Math Education Research Journal, 23,* 213-233.

Hardré, P. L. & Burris, A. (2012). What contributes to TA development: Differential responses to key design features. *Instructional Science, 40* (1), 93-118. doi: 10.1007/s11251-010-9163-0.

Hardré, P. L. & Miller, R. B. (2006). Toward a current, comprehensive, integrative, and flexible model of motivation for instructional design, *Performance Improvement Quarterly, 19(3),* 25-52.

Hoit, M. & Ohland, M. (1998). The impact of a discipline-based Introduction to Engineering course on improving retention. *Journal of Engineering Education, 87(1)*, 79-85.

Huber, M. T. & Hutchings, P. (2005). *The advancement of learning: Building the teaching commons.* San Francisco, CA: Jossey-Bass.

Kruger, C. & Cross, N (2006). Solution driven versus problem driven design: Strategies and outcomes. *Design Studies, 27* (5), 527-548.

Kuh, G.D., Kinzie, J., Buckley, J., Bridges, B.K. & Hayek, J.C. (2006). *What matters to student success: A review of the literature*. National Symposium on Postsecondary Student Success, Retrieved December 12, 2012 from: http://nces.ed.gov/npec/pdf/Kuh_Team_ExecSumm.pdf.

Lang, J. D., Cruse, S., McVey, F. D. & McMasters, J. (1998). Industry expectations of new engineers: A survey to assist curriculum designers. *Journal of Engineering Education*, 88(1), 43-51.

Laster, M. T. (2009). *Teach the way the brain learns.* New York: Rowman & Littlefield.

Lattuca, L. R., Terenzini, P. T. & Volkswein, J. F. (2006). Engineering change: A study of the impact of EC2000. Baltimore, MD: ABET.

Lave, J. & Wenger, E. (1991). *Situated learning: Legitimate peripheral participation*. New York: Cambridge University Press.

Lawson, B. (1997). *How designers think: The design process demystified.* Burlington, MA: Elsevier.

Lawson, B. & Dorst, K. (2009). *Design expertise.* Burlington, MA: Elsevier.

Marra, R. M. Rodgers, K.A., Shen, D., & Boque, B. (2012). Leaving engineering: A multi-year single institution study. *Journal of Engineering Education*, January, 2012.

McCray, R. A., DeHaan, R., Kasper, M A. & Schunk, J. A. (2003). *Improving undergraduate instruction in science, technology, engineering and mathematics.* Washington, DC: National Academies Press.

McLaughlin, M. (1992). Employability skills profile: What are employers looking for? Conference Board of Canada: Ottawa, ON.

Merriam, S. B., Caffarella, R. S. & Baumgartner, L. M. (2006). *Learning in adulthood: A comprehensive guide*. New York: Wiley.

Merrill, M. D. (2007). First principles of instruction: A synthesis. In R. A. Reiser and J. V. Dempsey (Eds.), *Trends and issues in instructional design and technology (2nd ed.)* (pp. 62-71). New York: Pearson.

National Academy of Engineering (2004). *The engineer of 2020: Visions of engineering in the new century.* Washington, DC: National Academies Press.

National Academy of Engineering (2005). *Educating the engineer of 2020: Adapting engineering education to the new century.* Washington, DC: National Academies Press.

National Science Foundation (2004). *Invention and impact: Building excellence in undergraduate science, technology, engineering and mathematics (STEM) education.* Washington, DC: American Association for the Advancement of Science.

Nelson, H. G., & Stolterman, E. (2003). *The design way: Intentional change in an unpredictable world: Foundations and fundamentals of design competence.* Englewood Cliffs, NJ: Educational Technology Publications.

Radcliffe, D.F. (2005). Innovation as a meta graduate attribute for engineers. *International Journal of Engineering Education, 21*(2): 194-199.

Sheppard, S. D., Macatangay, K., Colby, A. & Sullivan, W. M. (2009). *Educating engineers: Designing for the future of the field.* San Francisco: Jossey-Bass.

Sparkes, J.J. (1990). Quality in engineering education. *International Journal of Continuing Engineering Education and Life-Long Learning. 1(1), 18-32.*

Warnick, G.M. (2011). Global competence: Its importance for engineers working in a global environment. 118th ASEE Annual Conference and Exposition, June 26-29, 2011, Vancouver, CA.

Weimer, M. (2006). *Enhancing scholarly work on teaching and learning: Professional literature that makes a difference.* San Francisco: Jossey-Bass.

Williams, R. (2002). *Retooling: A historian confronts technological change.* Cambridge, MA: MIT Press.

Wulf, W.A. & Fisher, G.M.C. (2002). A makeover for engineering education. *Science and Technology*. 18(3): 35.