
AC 2011-1689: THE ROLE OF INTENTIONAL SELF-REGULATION IN ACHIEVEMENT IN ENGINEERING

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The role of intentional self-regulation in achievement for engineering

Introduction

Although often overlooked and under assessed in engineering education, the acquisition of life, or “soft,” skills has been linked in adolescence to greater success in high school and even beyond, for instance to success in life (e.g., ^{1,2,3,4}). In particular, previous studies have looked at (1) student ability to define a goal, (2) develop an optimized strategy to reach that goal, and (3) to redefine the strategy as new obstacles arrive in the pursuit of the original goal. These skills align closely with the engineering design process (for instance McKenna’s, 2007 work on adaptive expertise⁵). Accordingly, the goal of the present NSF-sponsored EEC study was to apply the existing methods developed for measuring these soft skills to university undergraduate engineering students. Our underlying question is *Are such soft skills of particular importance to engineers as they develop their knowledge base during their undergraduate education?*

There are many factors to consider in creating a rich educational environment that fosters the development of engineering knowledge, skills, and achievement, both within college and in launching a successful career as an engineer. We define a successful engineering career as one that is beneficial to the young person and – through his or her skills, creativity and entrepreneurship – to society. While it is of course the case that students need to develop technical fluency in science, engineering, and math, as well as the ability to approach problems from a multidisciplinary perspective, there is reason to believe that these science/technology skills are not sufficient to foster engineering achievement in school and in life. The Personal factors, such as motivation, orientation towards teamwork, planning, persistence and even one’s perception of what it means to be an engineer influence how one engages in engineering design and problem solving. As educators and researchers we are compelled to understand better how students develop and use their cognitive, emotional, and social (interpersonal, team work skills) capacities to regulate their approach towards developing rigorous, innovative, and successful

engineering solutions. The study presented here was an initial attempt to identify the role of such personal factors in the achievements of engineering students.

This identification is important because the role of “soft skills” (those associated with the personal factors we have noted above) may be a largely unrecognized and, therefore, understudied moderator of achievement in engineering programs. Nobel Laureate Economist James Heckman^{3,4,6} identifies a set of skills involved in successful academic performance that are not the one’s measured by conventional indices of intellectual ability (e.g., “IQ” tests). These skills involve motivation and goal setting, strategic thinking, identifying and recruiting the resources needed for problem solving, and compensating when goals are blocked or when failure occurs; here, for instance, compensation may be shown by selecting a new goal or by finding alternative means to achieve one’s initial goal. There are clearly cognitive components involved in these skills. Nevertheless, Heckman and colleagues term these abilities “non-cognitive skills” in order to differentiate them from the specific cognitive abilities measured on conventional mental ability tests and, as well, to avoid the potentially pejorative connotations of the phrase “soft skills.” In turn, other scholars have used terms such as “life skills”⁷ or “fundamental pragmatics” of life^{8,9} to capture the essence of this set of motivational, cognitive, emotional, behavioral, and social skills.

However, whatever their label, these life skills often account more for school achievement – especially among young, socio-economically disadvantaged children and adolescents – and for greater life successes (involving both the occurrence of “good” outcomes, such as graduation and employment, and lower levels of “bad” outcomes, such as incarceration) than do the “hard skills” assessed by conventional mental ability tests^{1,2,3,4,6,10,11}. Based on these findings, we hypothesize that such life skills may be an important (albeit still largely unrecognized and unmeasured) “moderator variable” for college student engineering achievement. A moderator variable in behavioral science is a construct that changes the relation between two other variables, and it may be that soft skills have such a moderating influence between student “hard skills” and engineering achievement. We hypothesize further that possession of the “soft” skill abilities to select (S) appropriate (realistic, feasible) goals for ones’ engineering tasks; to optimize (O) the chances of meeting one’s goals through developing the strategies and recruiting the resources,

including eliciting cooperation from partners, to accomplish the goals; and to understand the need, and demonstrate the capacity, to compensate (C) when one's goals are blocked or when one fails through; for instance, one may make an alternative goal selection (termed a "lost-based selection, or LS) or devise new strategies for moving forward, will be of greater importance among successful engineering student as they advance in their undergraduate curriculum.

We base our expectation on the fact that the abilities marked by "S," "O," and "C" have been identified in human development research to constitute the motivational and decision making (executive) skills requisite not only for science, technology, engineering, and math (STEM) attainment but, as well, for succeeding in life more generally, e.g., for protecting against school failure and drop out and for promoting healthy life styles and success in interpersonal relationships, including peer relationships, student-teacher relationships, family relationships, and civic engagement and community contributions^{9,12,13}. Indeed, the "soft skills" indexed by SOC reflect both practical (planning, coordination) and analytical (problem solving) abilities and, in the case of compensation (and the loss-based selections) a component of creativity. Understandably, then, these soft skills have been characterized by Baltes and colleagues¹² as constituting the fundamental pragmatics of life and, as well, the building blocks of wisdom.

In turn, within the engineering education literature, the skill sets marked by SOC have been termed adaptive expertise. As explained by McKenna⁵, an adaptive expert is someone who not only has deep subject matter knowledge but also can effectively apply his or her knowledge adaptively, or in innovative ways. Adaptive experts can flexibly respond to new learning situations; they function with innovation and efficiency¹³ and, by integrating their hard skills and the set of skills we believe are marked by SOC, they can adaptively use STEM knowledge to succeed as an engineer.

The engineering community, as represented by the engineering accrediting board ABET, recognized that the "hard skills" that are traditionally most prominent in undergraduate engineering education might not be the only skills important to successful engineering. In 2001, ABET made effective a set of six "professional skills" within their engineering accreditation

criteria. These six skills that engineering programs must now include throughout their curriculum include:

- an ability to function on multi-disciplinary teams;
- an understanding of professional and ethical responsibility;
- an ability to communicate effectively;
- the broad education to understand the impact of engineering solutions in a global, economic, environmental, and societal context;
- a recognition of the need for, and the ability to engage in life-long learning;
- and a knowledge of contemporary issues.¹⁵

We believe these skills as defined by ABET highlight the nature of engineering as being much more than simply the application of STEM knowledge to solve problems; and that great solutions to the problems we face in the world will require engineers to use much more than their knowledge of STEM principles. However, merely declaring these skills requisite in engineering curriculum does not ensure students will attain them. As Shuman et al.¹⁶ argued, including these skills in undergraduate education pose a set of challenges for educators in teaching and assessing these very subjective skills.

Accordingly, the purpose of this study is to provide initial, descriptive information about the role of the life skills of SOC in the engineering achievement of a cross-sectional sample of undergraduate, freshman through senior engineering students. Both within and across the two university settings involved in this research, we will assess as well the hard skills of these students and if SOC contributes to engineering achievement when effects associated with hard skills (and non-engineering GPA) are controlled. Moreover, we will assess whether the links between SOC and engineering achievement differ between male and female students. Finally, by comparing engineering undergraduates with undergraduates majoring in the social sciences or humanities, we will be able to see if the relation between SOC and achievement is different for engineering versus non-engineering students.

Methods

We used a cross-sectional design to assess at the end of the first academic semester a random sample of second-, third-, and fourth-year undergraduate engineering students and a matched comparison sample with majors in the social sciences or in the humanities. Our intent was that the results of this research would usefully provide engineering educators, policy makers, and business and industry leaders heretofore unavailable scientific information about how to assess and to integrate key features of the development of behavioral characteristics in promoting engineering achievement across the college years. Our goal was that this information would provide a model for future engineering education research and a baseline against which future educational innovations may be measured. It will also help faculty better balance hard and life skill sets in the undergraduate curriculum.

To implement our research, the project team designed and conducted a web survey. The survey was adapted from Freund and Baltes⁹ and included information about students' majors, GPA, activities, and demographics. The complete web survey is included as an appendix to this report. The web survey was then sent out to Watchamacallit undergraduate students and re-sent until we achieved our targeted sample size. The data we collected included the responses to the surveys as well as the students' GPA. The data were then cleaned, coded, and analyzed. Multiple regression analyses were conducted.

Results

Using multiple regression analysis, there appears to be a *direct* and *positive* relation between these intentional self-regulations skill sets (i.e., as defined by the SOC measure) and the GPAs of engineers and liberal arts students from both Watchamacallit University and Whatsit University. In addition, for all groups of students there was a relationship between participating in out-of-classroom extracurricular activities and GPA. Greater activity participation predicted higher GPA among both the engineering and liberal arts students. Table 1 presents the results and ranges of F and R^2 values.

Table 1. Parameter estimates (standard errors), approximate p values, and goodness-of-fit tests for a nested taxonomy of regression models that describe the relationship between sex, major (engineering or liberal arts), university (Watchamacallit or Whatsit), year of graduation, overall SOC, and participation in extracurricular activities in predicting GPA for imputed sample (n =677).

	M1	M2	M3	M4
Intercept	3.51***	3.22***	3.12***	2.93***
Sex (Female =1, Male = 0)	0.03 (0.03)	0.03 (0.03)	0.002 (0.03)	0.001 (0.03)
Engineering Major	-0.09 (0.03)**	-0.09(0.03)**	-0.09 (0.03)**	-0.09 (0.03)**
School (Watchamacallit=1, NW=0)	-0.12 (0.03)	0.001 (0.03)	-0.03 (0.03)	-0.03 (0.03)
Year of Graduation 2011	-0.04 (0.04)	-0.03 (0.04)	-0.02 (0.04)	-0.02 (0.04)
Year of Graduation 2012	0.01 (0.04)	0.02 (0.04)	0.06 (0.04)	0.06 (0.04)
Overall SOC		0.02(0.00)***	0.02 (0.01)***	0.03 (0.01)**
Sum of Activities			0.04 (0.01)***	0.09 (0.03)**
SOC x Activities				-0.003 (0.002)
R² - range	0.016-0.027	0.037-0.051	0.072-0.098	0.075-0.102
F score - range	2.05-3.46**	4.04***- 5.53***	6.88***- 9.66***	6.35***- 8.79***

Key: *p<.05, **p<.01,***p<.001

Although the links among the SOC skills and GPA do not account for large proportions of the variance in these cross-sectional data, the presence of significant and theoretically meaningful links between these attributes of intentional self-regulation and the outcomes measures is

intriguing. Of course, a clear limitation of this research is that we are examining this association between intentional self-regulation, activities, and academic achievement at one time point. Thus, we are not assessing at the status of these relations as change-sensitive, developmental processes. Accordingly, in order to adequately explore the relationship between intentional self-regulation skills, activity participation, and GPA, we need to obtain longitudinal data about how individuals' intentional self-regulation skills may be linked across time to activity participation and GPA. Based on our current findings, then, we will pursue such longitudinal research in our future work.

Discussion

Universities, and the nations that rely on them in the training of informed and skilled citizens, are vitally concerned with enhancing the educational experiences of their students. Given the pressing need for expertise and innovation in a rapidly, technologically progressing, “flat” world¹⁷, the need for enhancing education may arguably be most urgent in regard to the training of engineers, scientists, and other professionals (e.g., basic and applied mathematicians and statisticians) involved in the use of “hard” skills¹⁷. However, research in economics and developmental science (e.g.,^{3,4}) suggest that university curricula focused on enhancing the hard skills of engineering, science, and math students (i.e., science, technology, engineering, and math, or STEM, skills) may be necessary, but not sufficient for increasing the likelihood of either academic achievement in subsequent professional or life success (see too⁵).

Accordingly, the present research was aimed at providing initial information about the role of the sets of life skills – termed in various literatures “soft skills,” self-control behaviors, or intentional self-regulation attributes^{2,10,18} – in contributing to academic achievement among both undergraduate engineering students and liberal arts students in two highly competitive, private undergraduate institutions in the U.S. (Watchamacallit University and Whatsit University). Our investigation was predicated on both new developmental research that pointed to intentional self-regulation skills (such as those related to the selection, optimization, and compensation skills, indexed in the present study) in contributing significant, independent variance to the prediction of academic achievement and, as well, positive development and community contributions

among diverse adolescents^{1,2}. In addition, discussions in the engineering education literature have identified that a set of life skills, termed “adaptive expertise⁵” is linked to academic and professional achievement specifically among engineers; adaptive expertise enhances the prediction of such achievement beyond variables related to stem skills. Accordingly, we hypothesized that higher scores on the intentional self-regulation skills (as operationalized by the SOC framework) would predict higher achievement in student GPA for both engineers and liberal arts students. Furthermore, we tested the effects of sex, class year (sophomore through senior), university, and extracurricular activity participation on this relationship.

Although the links among the SOC skills and GPA did not account for large proportions of the variance in these cross-sectional data, the presence of significant and theoretically meaningful links between these attributes of intentional self-regulation and the outcome measures is intriguing. As predicted, SOC scores related positively to academic achievement (GPAs) of the participants from both universities suggesting the usefulness of research that explores the mechanism through which intentional self-regulation enhances the attainment of academic success. Furthermore, our finding that extracurricular activity participation was a strong predictor of academic achievement as well suggests that some students may be engaging in these activities (i.e., groups related to their major, student leadership, internships, studying abroad) as a mechanism of using intentional self-regulation for accessing knowledge about their major and/or area of interest and leveraging greater success in their majors.

Enthusiasm for this possibility must be tempered, of course, by the fact that we found no connection between SOC scores and extracurricular participation. However, we are mindful that our cross-sectional design provided only a moment-in-time (“snapshot”) assessment of the status of variables we assessed and, as such, possible antecedent connections among intentional self-regulation, extracurricular participation, and academic achievement could not be assessed. Moreover, in that our design included only sophomore through senior undergraduate students, and that intentional self-regulation skills may be most important in the first year of college, our design may have also omitted a key point-in-time when greater insights about mechanisms may have been possible.

Clearly, then, these limitations of design suggest the need for future, longitudinal research, beginning at students' entrance into college, to elucidate more precisely the role of STEM and life/intentional self-regulation skills in promoting academic success among engineering and other university students. Moreover, if such research could include waves of assessment after the college years, then the role of both sets of skills in professional development – and possibly in the innovation and entrepreneurship needed to enhance the economic development of society – might be ascertained. The use of accelerated, cohort-sequential research designs would be especially useful in such research¹⁹.

In turn, although the need for data from such future longitudinal research would be required before refined knowledge is available about the processes through which STEM and intentional self-regulation skills may enhance engineering success, the present research contributes greatly to discussions of engineering education curriculum. Clearly, education for STEM skills needs to be supplemental with instruction about the importance of intentional self-regulation skills and of extracurricular engagement in academic success. Instructors should devote time to imbuing students with the competencies to select, optimize, and compensate effectively in order to thrive in school, and perhaps as well, in life itself.

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