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

Morgan M Hynes, Tufts University
Ann F. McKenna, Arizona State University, Polytechnic campus

Ann McKenna is an Associate Professor in the Department of Engineering in the College of Technology and Innovation at Arizona State University (ASU). Prior to joining ASU she served as a program officer at the National Science Foundation in the Division of Undergraduate Education and was on the faculty of the Segal Design Institute and Department of Mechanical Engineering at Northwestern University. Dr. McKenna’s research focuses on understanding the cognitive and social processes of design, design teaching and learning, the role of adaptive expertise in design and innovation, the impact and diffusion of education innovations, and teaching approaches of engineering faculty. Dr. McKenna received her B.S. and M.S. degrees in Mechanical Engineering from Drexel University and Ph.D. from the University of California at Berkeley.

Chris Rogers, Tufts University

Chris is a professor of mechanical engineering at Tufts University and the director of the Center for Engineering Education Outreach. He has worked for many years with LEGO and the NSF to better understand how students learn and use that to inform the development of educational tools.

Megan Kiely Mueller, Tufts University
Xaver Neumeyer, Northwestern University
Richard M. Lerner, Tufts University

Richard M. Lerner is the Bergstrom Chair in Applied Developmental Science and the Director of the Institute for Applied Research in Youth Development at Tufts University. He went from kindergarten through Ph.D. within the New York City public schools, completing his doctorate at the City University of New York in 1971 in developmental psychology. Lerner has more than 500 scholarly publications, including more than 70 authored or edited books. He was the founding editor of the Journal of Research on Adolescence and of Applied Developmental Science, which he continues to edit. He was a 1980-81 fellow at the Center for Advanced Study in the Behavioral Sciences and is a fellow of the American Association for the Advancement of Science, the American Psychological Association, and the Association for Psychological Science. Prior to joining Tufts University, he was on the faculty and held administrative posts at The Pennsylvania State University, Michigan State University, and Boston College, where he was the Anita L. Brennan Professor of Education and the Director of the Center for Child, Family, and Community Partnerships. During the 1994-95 academic year, Lerner held the Tyner Eminent Scholar Chair in the Human Sciences at Florida State University. Lerner is known for his theory of relations between life-span human development and social change, and for his research about the relations between adolescents and their peers, families, schools, and communities. As illustrated by his 2004 book, Liberty: Thriving and Civic Engagement among America’s Youth, and his 2007 book, The Good Teen: Rescuing Adolescence from the Myth of the Storm and Stress Years, his work integrates the study of public policies and community-based programs with the promotion of positive youth development and youth contributions to civil society. He is married to Dr. Jacqueline V. Lerner, Professor in the Department of Applied Developmental and Educational Psychology in the Lynch School of Education at Boston College. They live in Wayland, Massachusetts. They have three children, Justin, 30, a director and screen writer living in Los Angeles, Blair, 27, an advertising executive at Media Contacts in Boston, and Jarrett, 23, a 2009 English major graduate of Tufts University and an aspiring fiction writer.

©American Society for Engineering Education, 2011
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 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” or “fundamental pragmatics” of life 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. 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 one’s 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. 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 colleagues 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 McKenna, 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 efficiency 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.\textsuperscript{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.\textsuperscript{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 Baltes\(^9\) 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).

<table>
<thead>
<tr>
<th></th>
<th>M1</th>
<th>M2</th>
<th>M3</th>
<th>M4</th>
</tr>
</thead>
<tbody>
<tr>
<td>Intercept</td>
<td>3.51***</td>
<td>3.22***</td>
<td>3.12***</td>
<td>2.93***</td>
</tr>
<tr>
<td>Sex (Female =1, Male = 0)</td>
<td>0.03 (0.03)</td>
<td>0.03 (0.03)</td>
<td>0.002 (0.03)</td>
<td>0.001 (0.03)</td>
</tr>
<tr>
<td>Engineering Major</td>
<td>-0.09 (0.03)**</td>
<td>-0.09(0.03)**</td>
<td>-0.09 (0.03)**</td>
<td>-0.09 (0.03)**</td>
</tr>
<tr>
<td>School (Watchamacallit=1, NW=0)</td>
<td>-0.12 (0.03)</td>
<td>0.001 (0.03)</td>
<td>-0.03 (0.03)</td>
<td>-0.03 (0.03)</td>
</tr>
<tr>
<td>Year of Graduation 2011</td>
<td>-0.04 (0.04)</td>
<td>-0.03 (0.04)</td>
<td>-0.02 (0.04)</td>
<td>-0.02 (0.04)</td>
</tr>
<tr>
<td>Year of Graduation 2012</td>
<td>0.01 (0.04)</td>
<td>0.02 (0.04)</td>
<td>0.06 (0.04)</td>
<td>0.06 (0.04)</td>
</tr>
<tr>
<td>Overall SOC</td>
<td></td>
<td>0.02(0.00)***</td>
<td>0.02 (0.01)***</td>
<td>0.03 (0.01)***</td>
</tr>
<tr>
<td>Sum of Activities</td>
<td></td>
<td>0.04 (0.01)***</td>
<td>0.09 (0.03)***</td>
<td></td>
</tr>
<tr>
<td>SOC x Activities</td>
<td></td>
<td></td>
<td>-0.003 (0.002)</td>
<td></td>
</tr>
<tr>
<td>$R^2$- range</td>
<td>0.016-0.027</td>
<td>0.037-0.051</td>
<td>0.072-0.098</td>
<td>0.075-0.102</td>
</tr>
<tr>
<td>$F$ score - range</td>
<td>2.05-3.46**</td>
<td>4.04***-</td>
<td>6.88***-</td>
<td>6.35***-</td>
</tr>
<tr>
<td></td>
<td></td>
<td>5.53***</td>
<td>9.66***</td>
<td>8.79***</td>
</tr>
</tbody>
</table>

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” world\textsuperscript{17}, 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” skills\textsuperscript{17}. However, research in economics and developmental science (e.g.,\textsuperscript{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 too\textsuperscript{5}).

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\textsuperscript{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\textsuperscript{1,2}. In addition, discussions in the engineering education literature have identified that a set of life skills, termed “adaptive expertise\textsuperscript{5}” 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 research\textsuperscript{19}.

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.

References


