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Examining the Importance of Non-Cognitive and Affective (NCA) Factors for Engineering Student Success

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Edward Berger is an Associate Professor of Engineering Education and Mechanical Engineering at Purdue University, joining Purdue in August 2014. He has been teaching mechanics for over 20 years, and has worked extensively on the integration and assessment of specific technology interventions in mechanics classes. He was one of the co-leaders in 2013-2014 of the ASEE Virtual Community of Practice (VCP) for mechanics educators across the country. His current research focuses on student problem-solving processes and use of worked examples, change models and evidence-based teaching practices in engineering curricula, and the role of non-cognitive and affective factors in student academic outcomes and overall success.

Examining the Importance of Non-Cognitive and Affective (NCA) Factors for Engineering Student Success

Introduction

Undergraduate engineering and computing student outcomes have traditionally been viewed through the lens of graduation rates and student retention. On the individual level, student success in engineering and computing is usually defined based on a students' cognitive measures, including GPA and standardized test scores. Such metrics are used as predictors of students' future success, and student outcomes, in engineering. However, these metrics fall short in explaining why admitted students, with high GPA and standardized test scores, can still fail to stay in an engineering program or struggle to graduate on time [1]. Literature suggests that non-cognitive and affective (NCA) factors can play an important role in a students' success and encompasses measures such as stress, social support, engineering identity, meaning and purpose, mindfulness, belonging, and many others [2]–[11]. Incorporating NCA factors into how student success is defined and measured can lead to the development of better student support systems and better predictive models for engineering and computing student success.

This paper reports the work completed during the past year on an NSF-funded SUCCESS project studying the role that NCA factors have in undergraduate engineering and computing student success (collaborative IUSE awards NSF 1626287, 1626185, and 1626148). This project involves collaboration among three partner institutions: a large Midwestern research university, a large undergraduate-focused university on the western coast, and a large research university in the south. The goals of the larger project are contained within these three research questions:

RQ1. What are the NCA profiles of engineering and computing students, and to what extent do profiles vary by institution, academic program, demographics, or over time?

RQ2. In what ways are NCA factors predictors of academic performance, and how do they mediate a student's response to academic or personal obstacles they may face?

RQ3. To what extent can NCA-based interventions improve academic performance and the perceived quality of the undergraduate experience, and how do students at different institutions experience those interventions?

In this paper, we detail the development and deployment of the SUCCESS Survey to measure student NCA factors. Following, we describe how the survey data have been used to answer parts of RQ1 and RQ2. Finally, we present our ongoing efforts to answer RQ3. The overall progression of this paper, as well as how each of the efforts relates to the research questions, are provided in Figure 1.

Background

The SUCCESS survey was developed through an 18-month collaborative and iterative process involving researchers at all three partner institutions. In the course of developing the survey, the team chose constructs of interest, as well as items broadly related to student success, that had strong validity evidence. The resulting survey included constructs such as motivation, identity, belonging, personality, mindfulness, self-control, grit, gratitude, etc. [12]. In addition, the survey contained questions to collect students' self-reported GPA, SAT/ACT test scores, and demographics including race, gender, year classification, first-generation college student status, and other background/personal descriptors.

We piloted an initial version of the survey (*n* = 490) and evaluated the performance of the various constructs through exploratory factor analysis [13]. This analysis provided preliminary validity evidence for constructs within an engineering and computing context, while also showing that certain constructs that had validity evidence for different populations outside of engineering did not have validity in an engineering student context. We used these results from the pilot to refine the survey, which was then administered at 17 institutions (*n* = 2339). Confirmatory factor analysis was conducted on the larger national dataset and found 28 distinct factors with strong validity evidence [14]. More information about how the survey was developed, exploratory factor analysis, and confirmatory factor analysis, can be found in previous work [12]–[14].

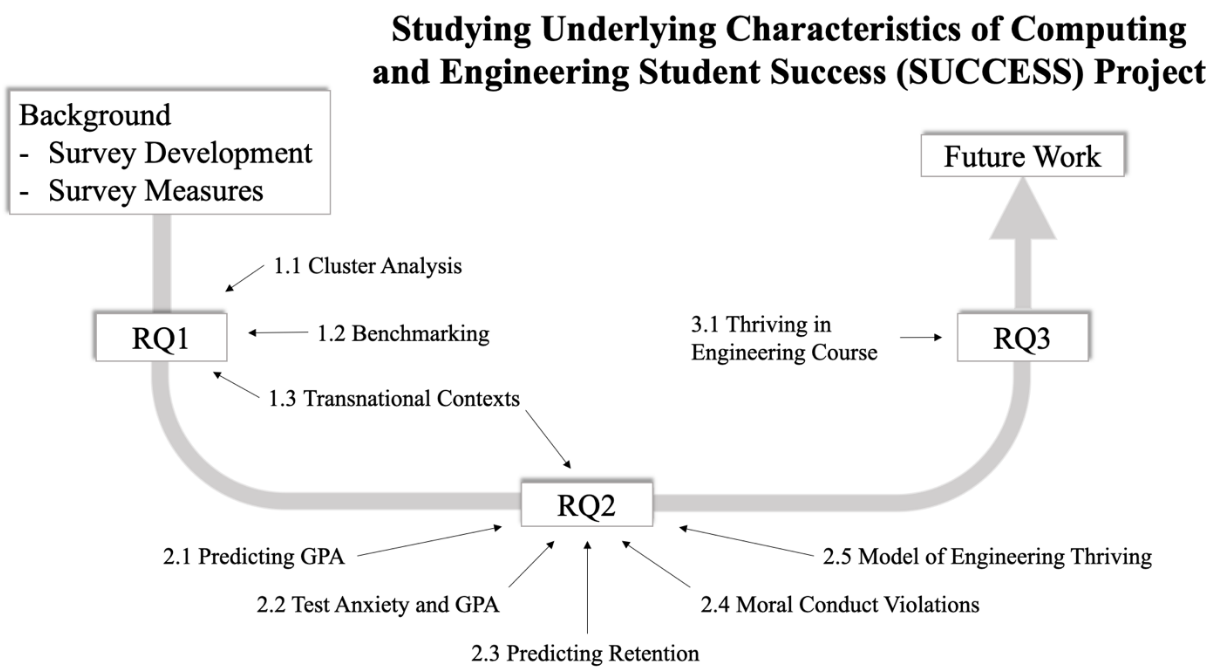

Figure 1: Description of project progress as well as the relationship between the research questions and the work to this date that supports answering the research questions.

Research Question 1

In pursuit of answering RQ1, we have completed three projects: 1) a cluster analysis of students NCA profiles; 2) a benchmarking study to understand how engineering and computing students may have similar or different NCA profiles, and 3) a study of students at a UK collaborating institution to understand how NCA factors may influence career pathways into industry jobs.

Cluster Analysis

First, to determine if students formed distinct groups based on their NCA profiles, we used Gaussian Mixture Modeling (GMM), an unsupervised machine learning approach to clustering [15]. GMM is a person-centered, probabilistic clustering approach that allows for within group and outside group membership [16], [17]. Five clusters of engineering students emerged from the data (n = 2339), with full details found elsewhere [15]. We provide broad details of the clusters below.

Members of Cluster 1 (34%) represented the "normative" cluster with all construct scores near the overall average for the entire sample of 2339 engineering undergraduates; other clusters are described based upon their differences from the sample mean. Compared to members of Cluster 1, members of Cluster 2 (20%) were overall high on factors associated with success including motivation, engineering identity, belongingness, gratitude, meaning and purpose, and connection with faculty, which are considered positive factors toward engineering and life success, but had an overall fixed mindset. Members of Cluster 3 (12%) scored low on overall motivation, engineering identity, as well as openness. Members of Cluster 4 (3%) were similar to those in Cluster 3, except even lower on dimensions of engineering identity, motivation, and belonging. This cluster was also low on social support, connection with faculty, and concientiousness. Overall, Cluster 4 was described as without feeling of support from faculty and peers. Through our analysis, a group of students did not fit within any of the four clusters (26%). We found no significant differences in standardized test scores across clusters or GPA. The only significant demographic differences were with a lower overall representation of women in Cluster 3 ($p < 0.05$. Overall, this analysis helps to answer research question 1 by providing NCA profiles of engineering students and identify any differences across demographics. It also suggests that groups of NCA factors may work in concert and are interrelated in complex ways that contribute to the four NCA profile types.

Benchmarking Study

In addition to performing a cluster analysis and looking at academic and demographic differences between the clusters, we also examined how engineering and computer science students' NCA factors differ from other populations [18]. We did this by benchmarking six traits measured by the SUCCESS survey and compared the scores of engineering and computing undergraduates at one of the three partner institutions (n = 396) with those found in previous studies of undergraduate students, and in some cases with undergraduate engineering students specifically. The six traits compared were Big 5 personality traits, self-control, grit, mindset, test anxiety, and test and study environment. These traits were selected for comparison because previous studies of these traits provided data on general college undergraduates. Although this comparison used only the scores from one (of three) partner institutions, we found the scores from this sample were very close to those from the larger SUCCESS student population.

We found differences between our sample population and previous studies in self-control, Big 5 personality, and grit. Self-control scores in our sample were substantially lower, by up to one full point out of a seven-point scale, in comparison to other samples. When comparing the scores for Big 5 personality, our population differed significantly for extraversion, neuroticism, and openness, with our sample showing lower scores for extraversion and openness, and a higher score for neuroticism. Finally, grit scores of our sample were consistently, but not substantially, lower in comparison to the three other undergraduate samples. We conclude that there are indeed differences in NCA scores between the engineering and computing students within the SUCCESS sample and undergraduates in previous studies in general. More information about these findings is available in the conference paper [18].

Transnational Contexts
Spanning both RQ1 and RQ2, as seen in Figure 1, is our work in deploying a modified version of the SUCCESS survey to a large, public research university located in the United Kingdom [19]. The United Kingdom has struggled with graduates entering engineering industry and also participation from women, traditionally underrepresented racial/ethnic students, and students originally born in the United Kingdom [20], [21]. The trends for students entering engineering industry jobs post-graduation are even lower than those within the United States. Based on this larger context, we answered the research questions: 1) What factors predict students' intentions to stay in or leave engineering industrial workforce positions upon graduation? and 2) Are these factors different for United Kingdom and European Union students versus overseas students? All data collection was conducted with approval from the United Kingdom University Research Ethics Committee.

The results of this comparison indicated that students who intended to stay in engineering industry careers upon graduation versus being undecided were more likely to have higher motivation from perceptions of the future, lower openness, lower conscientiousness, lower agreeableness, and lower desire to supervise others [19]. Students who were more likely to leave an engineering industry pathway after graduation versus being undecided had less interest in doing hands-on work, higher openness, lower extraversion, higher neuroticism, and were more likely to have chosen engineering as a field of study because it would guarantee a job upon graduation. The largest effect among all these significant results was the odds of staying in an engineering industry pathway versus being undecided for students who had high perceptions of future (Odds Ratio = 12.987; $p < 0.001$) [19].

This result indicates that students who have a strong desire to be an engineer in the future are more motivated to pursue that pathway in the present. Students with longer perceptions of the future can also more easily anticipate the implications of their present activities for the more distant future and elaborate longer behavioral plans or projects. Our finding may have implications for how engineering students may be supported in developing motivations that increase intentions to persist in their degree to career pathway. Again, as these results show, different NCA factors are related to different outcomes. For a more comprehensive description of this study see [19].

Research Question 2

In addition to the above work surrounding how NCA factors relate to students pursuing engineering careers, we have done a range of work to support answering RQ2—exploring how NCA factors relate to academic performance and how NCA factors mediate responses to academic or personal obstacles that students face. Through two projects, we examined how NCA factors relate to GPA, and in a third study, we examined how NCA factors relate to retention. In addition to understand how NCA factors relate to student obstacles, we are performing an exploratory analysis relating NCA factors to student obstacles, and we developed a model of thriving that provides a more holistic view of student success.

Prediction of student overall GPA
In the first project relating NCA factors to GPA, we used NCA factors from the pilot data (n = 490 from two intuitions) to predict self-reported GPA [22]. We were interested in predicting self-reported GPA, and specifically what NCA factors explained substantial variance beyond that explained by SAT/ACT score and common demographics. We found that the following factors predicted GPA after controlling for gender, year in school, institution, race, and composite SAT/ACT: Big 5 (Conscientiousness), Grit (Perseverance of Effort), Eng. Identity (Perf. Competence), Motivation (Expectancy), Test Anxiety, Time and Study Environment, Perception of Faculty Support, Self-Control (Impulsivity), Self-Control (Restraint), and Stress (Frustrations). Combined, these factors predicted 26.37% of the variance in GPA above that of the controls [22]. Alone the controls accounted for 10.26% of the variance in GPA, meaning that these few factors were able to substantially improve the explained variance in GPA, highlighting the impact of NCA factors as they relate to GPA above SAT/ACT scores.

Test anxiety and student STEM GPAs
The second study relating NCA factors to GPA expands upon the relationship between test anxiety and GPA found in the above study of engineering students. In this study, we used pairwise comparisons followed by path analysis to understand how test anxiety affects the science, mathematics, engineering, and overall STEM GPAs of n = 561 first-year students at a single institution [23]. We first used pairwise comparisons to explore demographic correlations (race, gender, neighborhood socioeconomic status, and first-generation status) to GPAs and test anxiety. We found only a few demographic differences in GPA. For science GPA, we saw significant variation for Latinx and Asian identifying students. For test anxiety, we found the only significant differences were between students who identified as female or gender non-binary and students who identified as male.

Next, we conducted a path analysis with all of the above variables. This approach allowed us to examine regression paths between the demographic variables on outcome variables (i.e., STEM GPAs) as mediated by test anxiety simultaneously. We found that, for female or non-binary students, test anxiety mediated science, mathematics, and engineering GPA. We also found that, for Native Hawaiaan or Other Pacific Islander students, there were variations in engineering, mathematics, science, and overall STEM GPAs while for Middle Eastern or North African students, there were variations in science and overall STEM GPA. More regarding this study can be found in conference work submitted parallel to this paper [23]. However, aforementioned demographic differences in GPA, as well as the additional effects of test anxiety on those GPAs, inform our project about the relationships between NCA factors and students' academic success.

Prediction of retention in engineering
In addition to exploring NCA factor relationships with GPA, we have also looked at how NCA factors relate to retention. In the study, which used a subset of data from the national SUCCESS Survey dataset (n = 540 at one institution), we compared the differences in NCA factors between students who remained in engineering and students who are no longer enrolled in an engineering program [24]. We found significant differences in Engineering Identity Interest (d = 0.46),

Meaning and Purpose ($d = 0.34$), Belongingness ($d = 0.51$), and both Instrumentality ($d = 0.33$) and Perceptions of the future ($d = 0.49$) from the Future Time Perspective Motivation construct. Therefore, according to our results, students who did not stay in engineering had less interest in engineering material and experienced less enjoyment in learning about it. These students also were less able to connect their current curriculum to their future goals and their future engineering selves, found less meaning and purpose in life, and did not feel that they belonged in engineering. Although the relationship between this group of factors and retention may seem intuitive, using this combination of factors, including the non-engineering specific "meaning and purpose in life," is novel and telling. From both this study, which examined retention, and the study which examined how NCA factors predicted GPA, we found that different factors are related to the two different measures of success. Therefore, different NCA factors can relate to different and commonly used measures of student success.

Relating NCA factors to student obstacles

To address the second aspect of RQ2, examining how NCA factors mediate the response to academic or personal obstacles, and moral conduct violations requiring disciplinary action (as characterized by records supplied by the Office of the Dean of Students) that engineering students' face, we are currently performing Multiple Correspondence Analysis (MCA) to relate NCA factors to student obstacles. MCA is a graphical dimension-reducing method based on Principal Component Analysis that allows the researcher to determine how strong or weak the association of many categories are to one another, and to determine whether such associations can be related to a series of underlying factors or dimensions [25]. Identification of associations required the user to quantify qualitative data into a series of nominal and binary categorical measures, which are analyzed and interpreted using the MCA method. Unlike other methods, MCA has no statistical power for determining finite relationships. Rather, it is meant to be exploratory and to inform the direction of future work.

In this study, we are exploring the relationship between NCA factors and their disciplinary history at a specific institution. To analyze this relationship, we quantified students' conduct violations that were obtained from the institutions' Dean of Students Office into specific categories (e.g., "Alcohol," "Drugs," "Academic Integrity," etc.), and mapped them alongside student cluster membership as well as students' scores on each of the 28 NCA factors in comparison to other students (i.e., "Low" or further than one standard deviation below the mean, "Mid" or within standard deviation of the mean, and "High" or further than one standard deviation above the mean). While analysis is still ongoing, we have since determined there may be specific relationships between students' NCA profiles (specifically engineering identity, feelings of support, feelings of gratitude, and feelings of meaning and purpose) and the number and severity/type of specific violations students commit.

Modeling engineering thriving

In addition to the above analyses, we are working to better understand how multiple NCA factors function together to support students to succeed not just in the traditional academic sense but also socially and personally in engineering programs. The relationships among NCA factors and between NCA factors and various external success outcomes are included in a model of engineering thriving [26]. We use the term "thriving" to describe the holistic success (personally, socially, and academically) instead of just academic success because thriving encompasses a broader definition than the primary focus on academic success found in the literature, which largely focused on traditional academic measures of student success and student outcomes rather than NCA factors. This model was first developed through a scoping literature review that investigated undergraduate engineering student success as defined in the literature. Our model provided novel insights on supporting holistic engineering student success using various NCA factors; united disparate lines of research studying various NCA factors independently; and critiqued the assumption–common in engineering education–that addressing barriers automatically leads to student success. Our findings indicate that engineering student thriving can be understood as a process of developing and refining various NCA factors that allow them to succeed in multiple dimensions of undergraduate engineering programs.

Beyond our initial model, we are also in the process of conducting a Delphi study to refine the model of engineering thriving based on expert consensus. This study engages a panel of experts (such as engineering professors, staff, and advisers) chosen for their considerable experience in teaching, supporting, advising, mentoring, or working directly with undergraduate engineering students. First, we asked participants to share their definitions of thriving for undergraduate engineering students. Then, we asked them to come to a consensus on the most important components, based on their experience, that help undergraduate engineering students succeed academically, personally, and socially. This information revealed multiple definitions of thriving amongst engineering professionals, as well as unique perspectives of student success.

Research Question 3

As an extension of the work detailed above on engineering student thriving, one of the authors developed and examined the impact of a novel interdisciplinary course titled, "Thriving for Engineering Leadership, Inclusion, and Diversity," which teaches undergraduate engineering students about gratitude, meaning, and mindfulness [27]. We developed and taught this novel one-credit course as an intervention to introduce the concept and language of thriving to undergraduate engineering students so that they can better articulate their conceptions of thriving and express their opinions on the most important components of thriving for engineering students. This intervention not only introduces engineering students to broader definitions of success (beyond traditional academic factors) but also helps inform future research and intervention development to promote thriving for undergraduate engineering students, a unique population for which general measures of thriving do not translate [13].

In an earlier paper, we also explored whether providing undergraduate engineering students knowledge and language about a subset of thriving (gratitude, meaning and purpose, and mindfulness) affects their own NCA profiles, and further, whether those changes continue to endure six months after completing the course [27]. Comparing pre and post tests, most students improved in gratitude and meaning. Mindfulness scores generally went down. Our findings indicate that engineering students' NCA factors are malleable over time and seem synergistically to affect students. The synergistic influence of NCA factors on students in this intervention, continue to suggest that individual NCA factors should not be researched in isolation.

Implications

Our research overall highlights the importance that NCA factors have in better understanding how and why engineering students are successful beyond the traditional cognitive metrics like GPA and SAT/ACT scores. Our work shows that engineering student success as it relates to academics and outcomes cannot be effectively described without also including understandings of NCA factors, and how they underlie and influence students' academic progression. This research also shows how different NCA factors are related to different outcomes across different contexts, highlighting the power of using multiple NCA factors to approach understanding student success. While we still have much more to study, this research provides a basis for a change in how engineering education can conceptualize, discuss, model, and predict engineering student success.

Future Work

Our plan for future work involves continuing to administer the SUCCESS survey to the three partner institutions, expanding our understanding of the relationships between NCA factors and academic outcomes, and further investigating how NCA factors can be intervened upon to help support engineering and computing student success.

The SUCCESS survey has resulted in a large and growing database of three types of data: 1) each participant's measure of NCA factors, 2) for the three partner institutions, all undergraduate grades, and 3) student disciplinary data during undergraduate studies. We have only begun to analyze this data through the studies described above and we expect continued analysis to extend well beyond the end of data collection, which at this point is set to be in 2021.

To continue to answer RQ2, we are planning and implementing a few studies. First, we are just starting a more detailed examination of the cluster analysis results, with the intention of further examining how cluster membership relates to academic outcomes. A second study we are planning to conduct is a longitudinal examination of students' NCA profiles, and how these evolve during undergraduate studies and the impact of this change on academic success.

A main focus for our future work is in developing and testing programs that intervene on particular sets of NCA factors that are informed by our ongoing analyses. In addition to the thriving course discussed above, preliminary efforts are underway in examining how existing interventions, aimed improving single NCA factors, apply to an engineering and computing student context. This represents just a first step in our goal of using NCA factors, and our research, to better support engineering and computing students.

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