NAVAL POSTGRADUATE SCHOOL

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THESIS

ASSESSMENT OF SELF-EFFICACY IN SYSTEMS ENGINEERING AS AN INDICATOR OF COMPETENCY LEVEL ACHIEVEMENT

by

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June 2014

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13. ABSTRACT (maximum 200 words)

Systems engineering (SE) competencies are defined based on the knowledge, skills, and abilities (KSAs) necessary for a systems engineer to perform tasks related to the discipline. Proficient systems engineers are expected to be able to integrate, apply, and be assessed on these KSAs as they develop competencies through their education and training, professional development, and on-the-job experience. The research conducted by the Naval Postgraduate School, assessed where SE graduate students stood as far as developing the necessary competency levels they need to be successful systems engineers. A survey methodology was used to achieve this objective. Systems engineering students enrolled in SE courses at the Naval Postgraduate School represented the population surveyed.

Survey items were written with the intent to capture self-efficacy for knowledge and skill sets as a subset of the overall set of competencies required for systems engineering, namely critical thinking, systems engineering, teamwork and project management. A total of four surveys were administered to two SE cohorts. Results show that self-efficacy in systems engineering can be reasonably assumed to be positively affected by a graduate level educational program. The implications of the research can be used to develop structured curriculum content, assessment, and continuous process improvement techniques related to the development of SE learning, and to develop more valid and reliable instruments for assessing what systems engineers need to learn, need to know, and need to do.

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LIST OF ACRONYMS AND ABBREVIATIONS

COMPOSE	Competency model for the profession of systems engineering
DAU	Defense Acquisition University
DOD	Department of Defense
EI	Emotional intelligence
ELO	Enabling learning objects
ER	Educational requirements
ER-L	Level of self-efficacy
ER-S	Strength of self-efficacy
EVT	Expectancy value theory
FA	Factor analysis
IT	Information technology
KSA	Knowledge, skills, abilities
MIS	Management information systems
NPS	Naval Postgraduate School
SCT	Social cognitive theory
SE	Systems engineering

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EXECUTIVE SUMMARY

This research focused on how self-efficacy might be used as a means to assess the competency development of systems engineering (SE) students. The method was also developed as a first step in attempting to predict future work performance of systems engineers. Self-efficacy, as it relates to research within systems engineering, is defined as an individual's belief that he or she can be proficient in skills necessary to become a systems engineering professional. SE self-efficacy is also defined as one's beliefs in his/her ability to learn SE knowledge, skills and abilities (KSAs). The research is significant as current studies suggest that proficient systems engineers are expected to be able to integrate and apply competencies throughout their education, professional development and experience. The thesis presents a brief introduction to the Naval Postgraduate School's (NPS') competency model, how the competency model relates to the *SE Competency Survey*, an in-depth analysis of the related self-efficacy research, methodology, and the results of the *SE Competency Survey* instrument.

The study determined how self-efficacy items, identified in the *SE Competency Survey* instrument, relate to a SE competency model developed at NPS. Systems engineering competencies were identified as the educational learning objectives needed to be acquired by systems engineers to perform tasks related to the discipline. The KSAs were grouped into cognitive and affective domains, As such, the *SE Competency Survey* presents the cognitive and affective KSAs as measures of performance. The *SE Competency Survey* instrument is based on a subset of the SE learning domains that systems engineering students are expected to be proficient in (systems engineering, critical thinking, project management and teamwork). University faculty and engineering organizations can use the instrument to assess areas of skill sets that students and/or entry-level engineers are strong, weak in, or need to develop further.

A literature review led the team to believe that a gap exists between being able to assess SE KSA and measure the competency of students/entry level engineers as a way to predict future career performance. The research presents an assessment of the roles self-efficacy and cognitive/affective skills play in indicating future performance in systems

engineering related careers. The role of self-efficacy in indicating performance in SE related careers can be seen as that of a psychosocial construct. It is influenced by one's own sense of capability and by the education, training and support received by others. The NPS research team cited findings by the National Security Leadership Foundation, which suggest that an individual's level of self-efficacy is a motivational predictor of how well a person will perform tasks and can be utilized and developed to leverage performance enhancing advantages; an individual's perceived self-efficacy greatly affects his/her ability to achieve domain specific tasks. Self-efficacy serves as a regulator across a broad range of functioning, as the key determinant for cognitive and affective processes. Similarly, the research is partially based on Prawat's finding that both cognitive and affective skills are determined to be vital in indicating performance in SE because having a broad range of KSAs enables knowledge acquisition and application (1989). The NPS team considers that acquiring domain specific knowledge has the advantage of allowing one to facilitate the application, or performance, of work.

The study of self-efficacy is presented with a detailed explanation of the statistical tests, factor analysis (FA) and Cronbach's alpha, which were used to assess the reliability of the survey instrument. The FA process and the determination of Cronbach's alpha added weight to the reliability of the *SE Competency Survey* as a tool to assess the perceived self-efficacy of systems engineering students to perform tasks within the SE domains. Current research findings suggest that using questionnaires, such as the *SE Competency Survey*, can aid in the identification of complex, latent psychological traits— in this case, self-efficacy. Current research also suggests that participants in a study such as this, are not likely to perceive themselves to be poor in a competency area they think is very important (Moore and Rudd 2005, 76). With this in mind, and to add weight to the findings, our analysis shows that Cronbach's alpha was determined to be high— providing support that the NPS survey data results have a relatively high internal consistency for evaluation.

To provide verification of the research method used to measure acquisition of domain specific knowledge, the NPS team used two pre- and post-survey renditions of the *SE Competency Survey*. The goal of the survey was to gauge the perceived levels of

self-efficacy among systems engineering students, over time, in four systems engineering domains as they continued through the systems engineering program at NPS. Survey items were written with the intent to capture domain specific skills and knowledge sets within critical thinking, systems engineering, teamwork and project management. The discussion provided describes detailed findings on the results of the survey research on each of the four domains, as well as commentary on possible reasons for the findings.

In general, the teamwork results indicate mixed findings as the results for the first cohort did not show significant differences in the average response rates towards many of the teamwork aspects, while the second cohort seems to have improved at significant levels. Among the first cohort's results, the skill was observed to be significant at $p<.01$, with a percent increase in pre- and post-results of nine percent. The second cohort's percent increase between pre- and post-average scores was 30 percent, and was statistically significant at $p<.001$. A possible explanation for this observation is that lead faculty incorporated course work that addressed teamwork into the curriculum of the second cohort (*RT19A*), but not the first cohort. This was because, for the first cohort, it was assumed the students could effectively work in teams. This structural method may have impacted the results. This finding is indeed interesting as research has found teamwork in engineering has the advantage of solving complex problems (Ponton et al. 2001, 249).

The critical thinking data analyses of the first cohort's results seem to indicate that the self-efficacy scores in critical thinking did not go up enough to exceed rejection criteria for traditional hypothesis testing—which would contend that there would be a significant difference between pre- and post-averages. All but two of the skills surveyed demonstrated higher averages in the post-survey results—meaning that even though the gains were not significantly different, there was at least a general sense of improvement among students. An analysis of the second cohort yields markedly different results, with most of the post-mean differences relating to critical thinking self-efficacy skills statistically significant from pre-survey results at $p<.001$. In reviewing the critical thinking results, it should be noted that the structural format in teaching the first cohort involved referring the students to textbooks on the topic of engineering reasoning,

whereas the second cohort was more formally taught from lectures (i.e., through parts of course work and seminars) on what critical thinking is and how it is used. The NPS research team feels that this change in structure may have impacted the survey results.

For systems engineering, the first cohort's results showed significant differences in several areas. Two skills in particular showed significant differences between pre- and post-results at p<.01. These were the student's ability to *use projected warfighting capability gaps to estimate the future need for a new system* and to *describe what resources will be necessary to conduct tests to demonstrate that a system meets its requirements.* One self-efficacy item in particular reflected statistically significant pre- and post-survey results at p<.001, which was the student's ability to *pick a technology for a system considering that the technology readiness level is estimated, and uncertain.* There were significant differences in means observed in all self-efficacy items relating to systems engineering. These results may be due to the change in structural format of instruction delivery between that of the first and second cohort. The first cohort integrated their authentic project within each of the courses in the curriculum. The second cohort had three additional consecutive project courses added to their curriculum in which the instructor reviewed all SE methods and processes in the context of the project. This facilitated near transfer of the learning of SE methods and processes to the authentic project context. The NPS team feels that this approach to teaching systems engineering concepts in context of authentic-learning projects seems to improve self-efficacy and is more effective in teaching.

For project management, most of the first cohort's results did not go up enough to exceed traditional rejection criteria for hypothesis testing. An exception to this observation was in the skill of *estimating quantitatively the likelihood and relative impact of events on a development project that represent the most pressing risks*, which had an increase of 11 percent, and the difference in mean scores was statistically significant at p<.05. Results of the second cohort's survey items relating to project management showed statistically significant differences in the mean scores at p<.001—exceeding rejection criteria for traditional hypothesis testing. Similar to the analysis discussed on systems engineering, the project management results may be due to the change in

structural format of instruction delivery between that of the first and second cohort. As in the case in the systems engineering domain, the second cohort was explicitly taught how SE skills relate to the project via learning activities. The NPS team feels that assisting them in near transfer of knowledge and ability to their project may have influenced the survey results to reflect an increase in self-efficacy.

Results from the survey analysis led to the conclusion that self-efficacy in systems engineering can be reasonably assumed to be positively affected by a rigorous educational program and training. As such, the NPS team feels that the *SE Competency Survey* can be used by university faculty and engineering enterprises to measure self-efficacy in systems engineers in an overall effort to predict future career performance.

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I.   INTRODUCTION

Recent studies into career development models have led to the general finding that contemporary firms are searching for well-rounded individuals, who possess both technical and non-technical skills (Joshi et al. 2010, 3). Scholarly studies examining hiring practice trends through content analysis of job advertisements and job types, have observed that stakeholders prefer to employ well-rounded employees with business knowledge, interpersonal skills and technical skills (Joshi et al. 2010, 3). According to Joshi et al., "Students gain their awareness of the importance of technology related job skills from the academics who teach them" (2010, 3). As such, a goal of university curricula and systems engineering enterprises should be to educate to provide the necessary technical and non-technical background to enable students to become proficient in performing systems engineering competencies. Systems engineering (SE) competencies are defined as the knowledge, skills and abilities (KSAs) necessary to perform tasks related to the discipline. Proficient systems engineers are expected to be able to integrate and apply such competencies throughout their education, professional development and experience.

Pertinent to our goal as an academic institution to educate students towards becoming proficient engineers was the need to identify the current KSAs major stakeholders seek in the employment of systems engineers. When considering the development of key technical and non-technical KSAs, we also examined the role of self-efficacy as a regulator of cognitive and affective learning processes, as studies have shown perceived self-efficacy contributes to cognitive and affective development and functioning (Bandura 1993, 1).

This thesis describes the process that was undertaken by the Systems Engineering Department at the Naval Postgraduate School (in Monterey, California), to measure and evaluate the level of competency, or "self-efficacy," perceived by systems engineering students. To obtain an understanding of where graduate systems engineering students stand as far as developing the necessary competencies they need to be successful systems engineers, we developed a series of surveys to gauge their level of self-efficacy.

Systems engineering self-efficacy, in this study, is defined as the individual's belief that he or she can be proficient in skills necessary to become a systems engineering professional. System's engineering self-efficacy also refers to one's beliefs in his/her ability to learn systems engineering skills.

Self-efficacy can be further defined as a "psychological characteristic known for its ability to have an enduring influence on related behavior and interests" (Mau 2003, 234). Expanding on this description, self-efficacy has also been described as a formative social characteristic which can have a spiral effect, in that once it is well established in an individual, it can influence that individual to make choices and attempt tasks that further strengthen and increase confidence in his or her abilities to perform tasks within a domain (Lucas and Cooper 2004, 12). An objective of this study was to determine whether self-efficacy, alongside being a psychological trait, can be taught, or enhanced, through education. Research suggests that when looking at self-efficacy, particularly in engineering students, it is important for an engineering professor to understand how self-efficacy relates to learning concepts.

The context of how engineering students learn is often categorized using Bloom's taxonomy. Engineering education involves learning objectives, which are typically organized around Bloom's taxonomy of cognitive and affective processes. Cognitive and affective processes within Bloom's taxonomy refer to levels of observable actions which indicate learning is occurring. The cognitive domain involves knowledge and the development of intellectual skills, whereas the affective domain deals with the motivations and attitudes involved in learning (Clark 1999).

In keeping engineering learning objectives in mind, it takes a great amount of effort on behalf of the professor to use mastery experiences, vicarious experiences, verbal persuasion, and physiological/emotive arousal strategies within instruction, to improve self-efficacy (Ponton et al. 2001, 249). As such, we hope findings from this study can be used to gauge self-efficacy in systems engineering students and to implement changes to improve systems engineering instructional delivery strategies.

The thesis begins with a discussion on the methodology that was utilized to acquire and analyze data necessary to evaluate the level of self-efficacy of systems engineering students to independently perform systems engineering tasks. The review includes a discussion on the survey methods used to study self-efficacy in systems engineering, which included the process of utilizing the statistical method of rotated factor analysis as a means to test for the validity, or effectiveness, of the survey instrument to capture reliable data.

The goal of the survey was to gauge the perceived levels of self-efficacy among systems engineering students, over time, in four systems engineering domains as they continued through the systems engineering program at NPS. Survey items were written with the intent to capture domain specific skills and knowledge sets within critical thinking, systems engineering, teamwork and project management. The discussion provided describes detailed findings on the results of the survey research on each of the four domains, as well as commentary on possible reasons for the findings. Results from the survey analysis led to the conclusion that self-efficacy in systems engineering can be reasonably assumed to be positively affected by a rigorous educational program and training.

A.   RESEARCH QUESTIONS

The background of this topic has presented several issues that were considered in the formulation of the research questions. The following research questions have been developed in response to the previously outlined research objectives. These research questions will guide the path of this research that will culminate in their answers and conclusions provided in Chapters IV and V.

1.   Primary Research Question

The primary research question will help determine whether self-efficacy can be reliably measured to validate the attainment of domain specific skills among systems engineering students.

- Primary research question 1: Can self-efficacy be used as an indicator of systems engineering competency level achievement?

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2. Secondary Research Questions

While examining the possible methods to reliably measure and assess self-efficacy as a competency construct, a set of secondary research questions developed.

- Secondary research question 1: What is self-efficacy in systems engineering?

- Secondary research question 2: How might self-efficacy be used in systems engineering?

- Secondary research question 3: What methods can be used to assess self-efficacy? What methods can be used in systems engineering?

- Secondary research question 4: Can a survey instrument be used to identify achievement of specific knowledge, skills and abilities (KSAs) as indicators of competency in performing systems engineering tasks?

- Secondary research question 5: If possible within time, participant, and resource constraints, can the systems engineering survey instrument be used by other engineering disciplines as a model to implement the self-efficacy based method, and can it be tailored to meet an organization's requirements with minimal effort/changes?

- Secondary research question 6: What roles do self-efficacy and cognitive/affective skills play in indicating performance in systems engineering related careers?

B. PURPOSE/BENEFIT

The benefit of the study will be two-fold. First, a direct result of the research will be a survey instrument, which can be used to reliably measure self-efficacy as it relates to competency levels in systems engineering. The research will serve to test and verify the usefulness of the self-efficacy survey instrument in determining levels of competency achievement. Second, the survey instrument will be a tool that naval system commands and educational institutions can use to measure and verify the level of competency their employees/students have achieved. This can then be used by organizations to track workforce development, to confidently assign work tasks, to assess the ability to perform standard systems engineering tasks, and to create individual development plans for career management.

C.   THESIS STATEMENT

Our research maps competencies as theory based indicators of self-efficacy to establish, with confidence, which measures of graduate level education would be expected to indicate higher-levels of SE self-efficacy.

D.   RESEARCH METHODS

The research methods discussed in the following chapters will discuss and describe the process, methods and products developed by NPS to answer the aforementioned research questions. The primary NPS research product was a survey instrument, which was designed to gather information from students on self-efficacy. Specifically, the survey was given over a period of two years to two different cohorts. The research methods used to examine the reliability of the survey instrument to measure self-efficacy as a latent psychological construct included factor analysis and Cronbach's alpha.

E.   CHAPTER SUMMARY

In this chapter an introduction to the research topic was presented along with a stakeholder analysis on the needs of industry, which concluded that there is a need for engineers who are competent in both technical and non-technical skills. The introduction followed with a description of self-efficacy, and how it relates to systems engineering. The first chapter concluded with a brief introduction to the survey instrument and methodology used to conduct the research in an effort to answer the research questions, which were also provided. Finally, the purpose and benefit of the research was stipulated to be two-fold. The research led to the development of a survey instrument, which can be used to reliably correlate self-efficacy to competency levels in systems engineering. Alongside the SE competency career development model, the survey instrument was suggested as a resource whereby organizations can: track workforce development, assign work tasks, assess the ability of engineers to perform standard SE tasks, and create individual development plans for career management.

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II.   LITERATURE REVIEW

The following is a brief literature review of past and current research on self-efficacy constructs, and in particular addresses literature that supports the importance of self-efficacy and its influence on academic achievement and work performance. The review suggests relevant connections can be made between self-efficacy and social cognitive theory (SCT), entrepreneurship (Lucas et al. 2009), development of leadership and technical skills (Joshi et al. 2010), and meta-cognition (Lang 2012). Metacognition, the knowledge of one's own cognition and the regulation of such skills, has been found to be an important factor in successful task performance (Kraiger, Ford and Salas 1993).

Several studies extending self-efficacy theory have related it to vocational behavior, suggesting expectations of self-efficacy aid in the determination of career decisions, can serve as predictors of achievements of men and women, and may be particularly useful in understanding women's career development (Hackett and Betz 1981). However, the focus of our discussion is a literature review of the lessons that can be gleaned from research on the importance of self-efficacy in indicating a predilection towards successful work performance.

A.   SELF-EFFICACY IN RELATIONSHIP TO SOCIAL COGNITIVE THEORY

According to Lent et al., "In a review of Social Cognitive Theory (SCT) and career and academic interests, Lent et al. (1994) provide evidence that self-efficacy in a particular domain helps develop the individual's initial interest in a corresponding career area, followed by the selection of career paths, and then supports the higher levels of both academic performance and persistence in those domains" (2009, 740). We argue that such "higher levels" of academic performance are indicative of the development of cognitive and affective processes, which we have identified via the NPS competency model, as discussed in Chapter III, on the methodology and results of the NPS research.

SCT posits that human agency (defined here as intentional behavior) is affected by the "reciprocal interaction between personal behavior, internal personal factors (i.e.,

one's cognitive, biological, and affective characteristics) and the environment (i.e., everything external to the individual) where all three determinants interact with various magnitudes of influence that is context dependent" (Ponton et al. 2001, 247).

Foundational research performed by Lucas et al. (2009), summarizes the role self-efficacy has in enabling students to pursue careers involving innovation. Lucas et al. suggest, "based on Social Cognitive Theory, one would expect that individuals with a high self-efficacy in a particular domain both perform work tasks better, and are more innovative in the way in which they go about their work in that domain" (2009, 740). They suggest that self-efficacy is central to career choice and in accepting careers in more challenging fields, particularly in science and engineering. Furthermore, Lucas et al. cite Bandura's findings that suggest that domain self-efficacy (in this context, the confidence individuals have in their ability to undertake a range of activities within a specific domain) applies to career selection.

1. Work Performance

In referencing Stajkovic and Luthans (1998), Lucas et al. contend that the role of self-efficacy continues to be important once individuals have entered their careers, predicting better work performance (Lucas et al. 2009, 740). In addition, they go on to explain, "Causal inferences about the effect of self-efficacy on work performance are supported by experimental research that uses random group assignment and the manipulation of self-efficacy" (Lucas et al. 2009, 740). Lucas et al. (2010, 738) have explored the correlation between various workplace experiences and venturing and technology self-efficacy. They also focus heavily on the development of self-efficacy through authentic work experience.

For work experience to increase self-efficacy for future entrepreneurial and technical applications, it must be authentic (Lucas et al. 2009, 741). Lucas et al. define authentic as being seen by the students as having required similar skills and levels of performance that they believe will be expected of them if they pursue innovative careers in engineering (2009, 741). They also contend that if self-efficacious individuals set themselves more challenging goals and are prepared to take on unfamiliar tasks then, as

previously mentioned, self-efficacy is expected to greatly influence the likelihood that the individuals will attempt innovative behavior (Lucas et al. 2009, 740). Their research measures two types of self-efficacy, one for venturing skills (starting one's own business; entrepreneurial) and the other for technology. They then map the factors in social cognitive theory that predict higher self-efficacy to the elements of undergraduate work experience.

Lucas et al. (2009) achieved the aforementioned objectives via a survey methodology, which we aimed to emulate in our study. Their model and research examined the effects of IT skills self-efficacy and IT importance on student's attraction to IT careers. A key difference between our research emphases is that Lucas et al. discuss and describe implications of self-efficacy and background characteristics of survey participants, types of industry placement and the university the students are drawn from, in a test for possible sampling bias. We did not ask for student demographic and background data in an effort to encourage honest responses, and as such, do not have a valid means to match student demographic and background data with responses for any correlation analysis.

The Lucas et al. (2009) self-efficacy survey items intended to measure venturing and technical self-efficacy in undergraduate engineering students who had previous work placements. Their survey also included questions that characterized different elements of work experiences, including the orientation of the company at which the students worked, the nature and difficulty of assigned work, and the presence of role models where the students were placed (Lucas et al. 2009, 739). Of particular interest to our study was the survey scale, which asked students to rate their self-confidence in performing science and technology related tasks, as a measure of engineering competency. The survey instrument scale ranged from 0 (not at all confident) to 10 (completely confident). Items were written to measure self-confidence in performing tasks undergraduates would be expected to perform if they were to be proficient in technology related work. These skills and abilities included understanding the limits of technology, translating user requirements into technical requirements, and leading a team of technical professionals.

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Lucas et al. (2009) then used regression analysis to examine correlations among student background, organizational and other predictor variables. The results of their survey data analysis led to the conclusion that on average, work experience had little effect on student self-efficacy. Yet, when the survey data reflected that the student experiences had the qualities generally accepted to predict enhanced self-efficacy, strong differences were observed. Lucas et al. suggest that these generally accepted constructs are: authentic experience, social influence, vicarious experience and emotional states (2009). Their results indicate that authenticity, feedback on performance, and how well students feel they have performed, are the dominant predictors of self-efficacy (2009).

Lucas et al. explain, "The effect of workplace experience, generally found in literature to be important, is widely viewed by university instructors as having a consequential impact on student readiness for the world of work" (2009, 739). Lucas et al. stipulate that one approach to prepare university students for innovative technical careers is to emphasize methods of education that replicate aspects of real work experience (2009, 739). They also very astutely point out that a "major task for higher education is the development of employees who not only have the right skills and attitudes, but also the ability to learn from experience and adapt within a dynamic and rapidly changing environment" (Lucas et al. 2009, 739). The role of research should be to determine what aspects of a student's experience enhance self-efficacy for venturing and, independently, self-efficacy for technology (Lucas et al. 2009, 739). Lucas et al. state, "Pinquart et al. (2003) suggest that increased knowledge and understanding of the industry environment as a workplace helps to ease the transition from education to employment" (2009, 740). We argue that the use of our survey instrument can aid in the identification of where students are at in gaining the required knowledge and understanding of industry practices to be proficient engineers. The NPS's competency development model can help to identify at which career developmental stage students should gain the knowledge, which would, we assert, ease the transition from their education to subsequent work assignments. Research by Lucas et al. (2009) does not answer whether or not this requires a higher level of cognition, our research fills this gap.

Furthermore, we contend that our research aids in the identification of the characteristic experiences and knowledge students need to strengthen self-efficacy in technical and non-technical fields.

B.   SELF- EFFICACY: PREDICTOR OF WORK PERFORMANCE

Stajkovic and Luthans (1998) surveyed 114 research reports on self-efficacy and work-related performance and found that it consistently predicts higher levels of work performance across various types of organizations and activities. They researched the correlation between self-efficacy and work-related performance, hypothesizing that there is an overall positive relationship between self-efficacy and work-related performance (Stajkovic and Luthans 1998, 241). A meta-analysis (empirical research examining the results of all 114 studies) performed by the team aggregated and assessed individual research findings pertaining to the relationship between self-efficacy and work-related performance (Stajkovic and Luthans 1998, 240). In their meta-analysis, they investigate the overall magnitude of the relationship between the two constructs (Stajkovic and Luthans 1998, 240).

Their findings indicate that a variable of potential moderating importance regarding the relationship between self-efficacy and work-related performance is task complexity, and that past research on self-efficacy has shown it is related to several work-performance measures. Such measures are "adaptability to advanced technology, managerial idea generating/performance, skill acquisition, newcomer adjustment to an organizational setting and naval performance at sea" (Stajkovic and Luthans 1998, 240).

1.   Self-Efficacy: Predictor of Academic Performance and Perceived Career Options

Lent et al. (1984) tested their hypothesis that efficacy expectations should relate to persistence and success in pursuing educational and career goals. Their findings suggested that students' beliefs about their ability to complete the educational requirements of various engineering and science fields were indicative of subsequent academic performance. For instance, students reporting comparatively strong self-efficacy were generally found to achieve higher grades and were much more likely to

persist in technical/scientific majors over a one-year period compared to those with low self-efficacy. Subsequent research by Lent et al. (1986) served to extend results of other studies (Hackett and Betz 1981) by assessing the relation of efficacy beliefs to perceived career options in science and engineering students. In particular, they studied the applicability of self-efficacy, alongside "ability, achievement, and interest measures in predicting academic success, persistence, and range of perceived career options in technical/scientific fields" (Lent et al. 1986, 265).

Self-efficacy was assessed via survey instruments that measured self-efficacy, career indecision, self-esteem, expressed vocational interests, and range of perceived vocational options in technical/scientific fields (Lent et al. 1986). Similar to our mode of survey delivery, their surveys were administered as pre and post surveys, specifically during the first and final class sessions. Self-efficacy was assessed by asking subjects to indicate whether they believed they could successfully perform the educational requirements (ER) and expected job duties in 15 science and engineering fields. Individual levels of self-efficacy (ER-L) scores were obtained by summing the number of fields subjects believed they could complete. Strength of self-efficacy (ER-S) was assessed by having subjects estimate their degree of confidence in their ability to complete the ER and job duties. Similar to our study, self-efficacy to perform a task was indicated using a numerical scale. Whereas our scale was 0 to 100, with 0 representing no confidence and 100 representing complete confidence, Lent et al. used a range of one to ten, from completely unsure (1) to completely sure (10) (Lent et al. 1986, 266). Then, strength scores for each subject were calculated by dividing the summed strength estimates by 15, the total number of major/career fields (Lent et al. 1986, 266). It is noteworthy to emphasize here that again, similar to our study, students were asked to rate their ability to perform specific accomplishments considered to be critical to academic success and performance in science and engineering fields.

Subsequent findings by Lent et al. concluded that student's beliefs about their ability to complete the educational requirements of various science and engineering fields were predictive of subsequent academic performance (1984, 265). Furthermore, hierarchical regression analyses indicated that "self-efficacy contributed signification

unique variance to the prediction of grades, persistence, and range of perceived career options in technical/scientific fields" (Lent et al. 1984, 265).

Thus, self-efficacy has been shown to be a useful measure in the prediction of academic performance, yet there is a lack of research to support the assertion on the usefulness of self-efficacy as a reliable indicator in relation to competencies that define career performance. Our research aims to close this gap.

C.   RESEARCH   ON   SELF-EFFICACY   IN   INFORMATION TECHNOLOGY—A PARALLEL TO SYSTEMS ENGINEERING

Similar to SE self-efficacy, information technology (IT) self-efficacy refers to one's beliefs about his/her ability to learn IT skills necessary to conduct IT work (Joshi et al. 2010, 2). High self-efficacy for a domain such as IT would be theorized to lead to choice (versus avoidance) of IT coursework and college majors, to facilitate performance on IT related tasks, and to lead to persistence during difficult academic/career related experiences (Joshi et al. 2010, 2). As Joshi et al. explain, "Students gain their awareness of the importance of IT job skills from referent others—including the academics who teach them, peers who socialize with them, and parents who guide them" (2010, 3). This sense of IT skills importance refers to one's beliefs about the value of IT skills necessary to be successful in the IT profession (Joshi et al. 2010, 2). Our research does not correlate a student's perceived level of importance of SE skills—perhaps this could be a future area of research.

Similar to Lucas et al., Joshi et al. analyzed self-efficacy survey responses of university students with the intent to study gender differences (2010, 2). Joshi et al. (2010) conducted a three-part study that aimed to enhance the overall understanding of attitudes about the IT field and subsequent interest in an IT career. The significance of their research, as it relates to the NPS study on SE self-efficacy, is that both research teams are aiming to study the dynamics between self-efficacy in technical fields. So, for the purposes of NPS's research, their findings are particularly relevant and noteworthy.

Phase I of the Joshi et al. project involved an analysis of three categories of IT job skills (technical, human and business), across three genres of texts: scholarly articles,

practitioner literature and online job ads (2010, 2). Likewise, in a study of employment opportunities for recent college graduates, Wong, von Hellens and Orr used both IT job ads, surveys and interviews with stakeholders and determined that non-technical skills are increasingly more important than technical skills (Joshi et al. 2010, 3). The Phase II study revealed that while masculine stereotypes are applied to most technical skills, and feminine stereotypes to most interpersonal skills, gender neutral skills (i.e., initiative, ability to work under pressure, critical thinking, and problem solving) have emerged as important constructs today's students must possess. Phase III of their study focused on the development, validation and effects of IT related self-efficacy and IT skills importance on IT career intentions (Joshi et al. 2010, 2). To achieve this objective, Joshi et al. used a survey methodology similar to Lucas et al. and NPS research. The Joshi et al. survey asked students to specify their level of self-confidence in their perceived ability to "learn and engage" in 36 IT skill items. Results were subjected to factor analysis, to uncover the underlying factor structure of the IT self-efficacy construct. Two constructs emerged from the factor analysis results: non-technical and technical self-efficacy. The significance of the research of Joshi et al., particularly within Phase III, is that it is another example of a successful attempt at measuring a latent psychological trait using a survey model. It adds weight to the idea that task specific measures in the form of a survey, might be superior to other approaches to self-efficacy assessment (i.e., ER) (Hackett and Betz 1984).

1.   **Stakeholder Analysis**

According to Joshi et al., "The process of consulting with stakeholders to solicit feedback regarding the importance of skills and the quality of training that universities provide, ensures that education meets the needs of industry" (2010, 2). Stakeholder analyses assessing the need for technically competent professionals in industry have led to the observation of the shifts in the composition of the IT workforce and accompanying changes in the relative importance of IT skills (Joshi et al. 2010, 3). For instance:

> low skilled IT job positions (such as data entry and computer operators) are disappearing. IT jobs are shifting from traditional, centralized MIS [management information systems] divisions out to business units,

necessitating employees to have more business knowledge and stronger interpersonal/management skills for working with clients. (Joshi et al. 2010, 3)

Joshi et al. note, "In addition to studies that examine the perceptions of stakeholder groups, scholars have investigated shifts in IT skills demand and job types through content analysis and job advertisements" (2010, 3). Findings have suggested that systems analysts mostly value their non-technical roles and skills, whereas systems users allocate more significance to the analyst's technical skills (Joshi et al. 2010, 3). In a similar study of webmasters and users, it was found that users valued the importance of technical skills, whereas webmasters asserted organizational skills were more important to their successful job performance (Joshi et al. 2010, 3).

McGee suggests that the lack of non-technical skills will result in a failure of an IT professional to be promoted to a manager position (Joshi et al. 2010, 3). Stakeholder analyses also indicate that "the high failure rate of IT projects is not attributed to the technological complexities of projects or the technical incompetency of the project teams. Rather, it is attributed to the non-technical skills within the IT project management teams" (Joshi et al. 2010, 3).

D.   ENHANCING SELF EFFICACY AND COGNITIVE MOTIVATION

Literature suggests that the presence of self-efficacy helps to motivate students to delve into engineering course work, which aids in their development as a capable professional (Ponton et al. 2001, 249). Sources of self-efficacy evaluations are mastery experiences, vicarious experiences, verbal persuasion and physiological/emotive states (Ponton et al. 2001, 249). Ponton et al. point out that curricular education is typically designed to develop self-efficacy through mastery experiences (2001, 249).

Mastery experiences refer to the performance of past activities and the resulting observances regarding whether the performances were successful or not. A noteworthy observation from this research is that if the individual perceives that he or she was successful in an activity, then the individual will develop a self-perceived sense of capability in being able to perform the same, or a similar activity in the future (Ponton et

al. 2001, 249). In the process of designing mastery experiences, two important aspects to consider are: what exactly do we want students to master; and how are we going to let them know? (Ponton et al. 2001, 249). After deciding the important skills a practicing engineer should master, we must also tell students why the chosen skills are important and develop assessment measures that reinforce the value of the desired skill (Ponton et al. 2001, 249). In regards to curriculum development, Ponton et al., stress that the important point to consider is that a decision should be made concerning the specific skills (behavioral or cognitive) that are important to a practicing engineer, and then create mastery experiences that will enhance a student's sense of competency in performing the skills (2001, 249).

A vicarious experience refers to the development of self-efficacy in an activity after observing similar persons engaging successfully in that same activity (Ponton et al. 2001, 249). Vicarious experiences are used to augment self-efficacy when students see similar others performing desired skills. Finally, verbal persuasion refers to developing self-efficacy when important referents tell a person he or she has the capability to successfully perform an activity (Ponton et al. 2001, 249).

1.   Cognitive Motivation

Studies have shown that "self-beliefs of efficacy have a large role in the self-regulation of motivation and that most of human motivation is cognitively generated" (Bandura 1993, 128). For example, students who motivate themselves do so by forming beliefs about what they can do; they set personal goals and then plan a series of tasks aimed to accomplish the goal(s). Three theories have been postulated by Ponton et al. that describe the aforementioned mechanisms of cognitive motivation. These are goal theory, expectancy value theory (EVT) and attribution theory.

Ponton et al. note, "The basic premise of goal theory is that when people adopt performance goals that they wish to accomplish, motivation is induced by the discrepancy between their current and future desired (i.e., goal) states" (2001, 248). Recognizing the discrepancy between present and future states is the source of motivation towards reaching the goal. As Ponton et al. further explain, "A challenging goal provides

a greater discrepancy and as a result, greater motivation because of the anticipated self-satisfaction one hopes to attain from achieving the stated goal" (2001, 248). Research suggests that goals should be challenging, but not perceived to be beyond one's capability (Ponton et al. 2001, 248). Distal goals that are considered to be beyond one's capability may be achieved if proximal sub-goals are set within one's scope of self-efficacy (Ponton et al. 2001, 248). As such, self-efficacy plays an important role in goal theory (Ponton et al. 2001, 248).

Goal proximity influences motivation in that while distal goals provide a general (but weak) motivation for performance, proximal sub-goals that provide immediate indicators of success and support the ultimate distal goals, provide a greater source of motivation. Accomplishing sub-goals can enhance self-efficacy, thereby increasing an individual's commitment to the overall, distal goal. Thus, the theoretical findings suggest that distal goals for students should be apportioned into sub-goals that motivate behaviors "leading to the accomplishment of the sub-goals and ultimately the distal goal itself" (Ponton et al. 2001, 248).

Expectancy value theory (EVT) describes the form of cognitive motivation whereby individuals engage in "activities to accomplish goals because of the perceived value associated with their likely outcomes" (Ponton et al. 2001, 248). EVT holds that the "greater the expectation that a particular behavior will lead to a valued outcome, the greater is the motivation to engage in that behavior" (Ponton et al. 2001, 248). EVT also holds that the presence of self-efficacy facilitates the process (Ponton et al. 2001, 248). Ponton et al. suggest that an important mediating factor self-efficacy includes in relation to an individual's accomplishments is perseverance (2001, 248). For instance, their research provides an example whereby even if a student perceives that he or she has the required capabilities to perform engineering coursework, the student may not fully delve into the "engineering curriculum due to a feeling of self-inefficacy with regards to sustaining the effort required to complete the program" (Ponton et al. 2001, 249).

Attribution theory "describes the motivating influences of how an individual attributes causes of past accomplishments and failures thereby affecting future choices of behaviors" (Ponton et al. 2001, 249). According to attribution theory, if an individual

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attributes the success of a past performance to hard work or failure to a lack of effort, then that same individual is more likely to engage in a similar performance in the future as the need arises (Ponton et al. 2001, 249). As such, effort attributions are mediated through the self-efficacy mechanism (Ponton et al. 2001, 249).

Effort attribution "refers to how an individual attributes the causes of the effort expended in performing a chosen behavior, for example, high effort is indicative of low ability" (Ponton et al. 2001, 249). Effort attributions are based on whether ability is understood as being of "static or dynamic proportions" (Ponton et al. 2001, 249). If ability is understood to be static and temporarily stable, then a high level of effort is understood as an indicator of low self-efficacy. Conversely, if ability is understood to be dynamic and capable of influence, then ability is enhanced with effort alongside a parallel increase in self-efficacy (Ponton et al. 2001, 249).

Cognitive motivation also works retrospectively, as when an individual reflects on the possible causes of successes, failures and effort—forming such evaluations can influence future actions (Ponton et al. 2001, 248). For instance, an individual may interpret through an activity that causes stress (either emotional or physical) that a lack of the essential capability required for success is present (Ponton et al. 2001, 249). Ponton et al., provide a case study example to describe how physiological/emotive arousals can affect self-efficacy. For instance, when a student is engaged in a stressful assignment, the student may interpret induced stressors as indicators that the capabilities needed to successfully complete the assignment are lacking (Ponton et al. 2001, 250). Thus, physiological/emotive arousals supply self-efficacy information through the interpretations of the reactions (Ponton et al. 2001, 249).

Ponton et al. conclude their research on the motivational constructs of self-efficacy by suggesting that because of the important mediating influence self-efficacy has been observed to have on self-motivation, an educator should understand how the trait can be increased so that such motivating principles can be used in the design of effective instructional strategies (2001, 249).

E. SELF-EFFICACY IN COGNITIVE DEVELOPMENT AND FUNCTIONING

According to Bandura, "Conceptions of ability affect thought processes and performance attainments through the self-efficacy mechanism" (1993, 121). Human functioning is influenced by the beliefs individuals have on how their ability can evolve over time (Bandura 1993, 121). For instance, individuals who consider ability as a biologically decreasing aptitude with aging are likely to infer poor performance as indicative of declining capability. And, they do little to utilize their capabilities. Whereas, individuals that perceive ability as a skill that can be developed and practiced, accomplish higher achievements (Bandura 1993, 121).

At this point in the literature review, it is noteworthy to provide an overview on theoretical findings of self-efficacy and cognitive development and functioning. One such finding is that perceived self-efficacy exerts its influence through four major processes: cognitive, motivational, affective and selection (Bandura 1993, 117).

1. Cognitive Processes

Research on self-efficacy has shown that it contributes to cognitive development and functioning (Bandura 1993, 117). Cognitive processes, similar to cognitive motivation discussed earlier, require a strong sense of self-efficacy for one to remain task oriented when faced with pressing situations and failures that have social repercussions (Bandura 1993, 120). For instance, individuals who perform poorly on tasks may do so because they lack the requisite skills, or have the requisite skills, but lack the sense of efficacy to use the skills effectively (Bandura 1993, 118). Relative to this theory is the conception of ability—a belief system whereby how people regard ability affects their cognitive functioning. For instance, some children consider ability as an acquirable skill that can be increased by gaining knowledge and competencies. This cognitive process leads to a functional-learning goal, in which they seek challenges that provide opportunities to expand their knowledge and competencies and consider errors as opportunities to learn from their mistakes. Other children see ability as an inherent capacity. For them, performance is diagnostic of their inherent intellectual capacities. As

Bandura states, "deficient performances carry high evaluative threats that they lack basic intelligence." That is why, they prefer tasks that reduce errors and demonstrate proficiency "at the expense of expanding their knowledge and competencies." Furthermore, this acquirable skill view allows for a task-diagnostic focus aimed at honing one's competencies and mastering challenges (Bandura 1993, 120).

In reference to cognitive processes, self-efficacy seems to have a particular mediating effect on writing skills and memory. According to Bandura, "Enhancement of perceived writing efficacy by instruction raises, through different paths of influence, perceived self-efficacy for academic activities, personal standards for the quality of writing considered self-satisfying and academic goals and attainments" (1993, 136). Similarly, higher cognitive effort has been shown to produce better memory performance (Bandura 1993, 121).

2.   Motivational Processes

The ability to practice self-influence by personal challenge and evaluate reaction to an individual's achievements provides a major cognitive tool of motivation. Behavior is motivated and guided by cognized current goals. Research indicates that precise, challenging goals improve and sustain motivation (Bandura 1993, 130).

3.   Affective Processes

According to Bandura, "People's beliefs in their capabilities affect how much stress and depression they experience in threatening or difficult situations, as well as their level of motivation" (1993, 132). This affective processing is the emotional mediator of self-efficacy belief.

4.   Selection Processes

Self-efficacy can influence the decisions individuals make by affecting their selection of activities and environments. For instance, "people avoid activities and situations they believe exceed their coping capabilities. Yet, they readily opt for challenging activities and select situations they judge themselves capable of handling" (Bandura 1993, 134). Research has suggested that the higher an individual's self-efficacy

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within a domain, the more career options he or she envisions as possible and the greater the interest he or she demonstrates in the chosen career (Bandura 1993, 135). Similarly, high self-efficacy mediates the process whereby an individual can better prepare himself/herself educationally for various occupations along the chosen career path (Bandura 1993, 135). One cannot underestimate the lasting impact these findings suggest, which is that high self-efficacy within an occupational domain can positively influence one's "staying power and success in difficult occupational pursuits" (Bandura 1993, 135).

F. SELF-EFFICACY IN THE DEVELOPMENT OF TECHNICAL AND PROFESSIONAL SKILLS

The literature review suggests that there are three categories of skills needed by leaders to be successful: conceptual, human and technical (Moore and Rudd 2005, 69). A research model, similar to our own, supports this theory by way of results of a survey instrument that was designed with 39 competencies. Factor analysis results of the 39 competency items revealed nine broad competency areas: four represented conceptual skills, three represented human skills and two represented technical skills (Moore and Rudd 2005, 69).

Research on leadership competencies has suggested that conceptual competencies are the most important, followed by human competencies, and finally with technical competencies as the least important asset in leadership KSAs (Moore and Rudd 2005, 69). Conceptual skills are perhaps the most important at top management levels where policy decisions, long term planning, and broad scale actions are required (Moore and Rudd 2005, 69). Conceptual skills involve being able to see both what is going on within an entire organization and how different components of the organization interact and depend on one another (Moore and Rudd 2005, 26).

Human competencies are defined as the "people skills" or the ability to work effectively as a group member and to build cooperative effort within the team being led (Moore and Rudd 2005, 69). It is noteworthy to mention here that the NPS's survey instrument and SE competency model encompass such human competencies in the form of the "teamwork" domain. Moore and Rudd state that the presence of human skills is

important throughout all management levels (2005, 69). Ideally, human skills are shown in how a leader perceives and behaves towards those around him or her, including superiors, peers, and followers. More importantly, it must be demonstrated in every action of the leader (Moore and Rudd 2005, 69). This is why the NPS's competency model maps leadership KSAs throughout a system engineer's career.

Goleman extends the theoretical framework on leadership competencies from purely technical skills and cognitive abilities to include that of emotional intelligence (EI) (Moore and Rudd 2005, 69). He suggests that there are five components to EI: self-awareness, self-regulation, motivation, empathy and social skill (Moore and Rudd 2005, 69). Goleman includes EI as a set of leadership skills because he sees it as a distinguishing competence of senior leaders (Moore and Rudd 2005, 69). A noteworthy research finding is that Goleman found EI to be twice as important as the other leadership skills when applied to all levels of jobs within the organizational hierarchy. He also found that EI (rather than conceptual skills) explained 90 percent of the difference between the effectiveness of lead performers and average senior level leaders (Moore and Rudd 2005, 69).

An agricultural study conducted by Moore and Rudd used data on land-owning individuals to assess the importance and level of six leadership skill areas (2005, 68). Their research cites the notion that while "leadership skills can be taught and learned, skilled leaders continue to be in short supply" (Moore and Rudd 2005, 68). To be successful as a leader, an individual must understand how to motivate a group of individuals (i.e., students, or entry level employees) towards a common goal (i.e., the desired future state) (Ponton et al. 2001, 247).

Robbins, Bradley and Spicer (2011) designed a leadership competency assessment instrument for healthcare administration, with 52 items classified as technical skills, industry knowledge, analytic and conceptual reasoning or interpersonal and EI (Moore and Rudd 2005, 70). Their findings conclude that industry knowledge should be included as a domain of skills due to the complex nature of the health care industry (Moore and Rudd 2005, 70). Industry knowledge is defined as having expansive knowledge of the industry and the organization. It is "essential to creating the broad

outlook needed by leaders to produce an organizational vision and strategies to accomplish that vision" (Moore and Rudd 2005, 70). As such, one could argue that this is another domain of competencies within engineering, and one that should be further studied to see if industry knowledge affects self-efficacy.

Moore and Rudd suggest that technical skills are associated with understanding and are the skills, methods, processes, procedures and techniques required to complete specific activities (2005, 69). Their findings suggest that technical skills are more important at the lower levels of administration, and that specifically, as a leader moves up in the organizational hierarchy, he or she relies on the technical skills of followers more than on his or her own technical skills (Moore and Rudd 2005, 69). Survey research led Moore and Rudd to find that survey participants perceived technical skills to be the least important of the skills set expected of leaders (2005, 75). Their finding that technical skills are perceived as less important than other leadership competencies is consistent with literature that reports the amount of technical skills required by leaders decreases the higher in the organizational hierarchy the leaders go, because of the tendency to delegate technical tasks to lower level staff (Moore and Rudd 2005, 69). Finally, Moore and Rudd recommend that competencies within the communication skill area be included in leadership and professional development programs (2005, 70).

G. CHAPTER SUMMARY

The literature, thus, suggests that domain self-efficacy aids in the development of an individual's initial interest in a corresponding career area, influences his/her motivation to pursue a career within the field, as well as the behavior towards the selection of relevant career paths, and then supports the higher levels of both academic performance and persistence in the field. Pertinent to NPS's research on self-efficacy within engineering is foundational research performed by Lucas et al. via a survey model, which found that the role of self-efficacy continues to be important past education and training, when individuals have entered their careers, as the sociopsychological construct can be used to predict better work performance. Similar research by Joshi et al. provides another example of a successful attempt to measure self-efficacy as a latent psychological

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trait using a survey instrument. Elaborating on these and other research findings that suggest that high levels of self-efficacy are indicative of the development of mature cognitive and affective processes (which can be used to predict proficient work performance), NPS has undergone research to identify, via a competency model and the *SE Competency Survey*, relevant engineering KSAs and the developmental stages of such cognitive and affective processes. In closing, NPS stipulates that self-efficacy is a useful measure of academic and work performance, and provides research to support the assertion on the usefulness of the construct as a reliable indicator of career performance.

III. MODEL BASED RESEARCH ON TECHNICAL SKILLS, NON-TECHNICAL SKILLS AND SELF-EFFICACY AS REGULATORS OF COGNITIVE AND AFFECTIVE PROCESSES

A.   INTRODUCTION: COMPETENCY MODEL DEVELOPMENT

Relative to NPS's research was the role of competency modeling, defined as the "activity of determining the specific competencies that are characteristic of high performance and success in a given job" (LaRocca 2013). To understand the relationship competency modeling has with the identification of the KSAs required of engineers, NPS developed a systems engineering career development competency model. Referred to in research and literature as the competency of the profession of systems engineering (COMPOSE), the model highlights an aggregate of the core technical, technical management and professional (i.e., non-technical) KSAs researched from the current hiring manuals of various naval and engineering enterprises (White 2014, 4). The NPS team feels that systems engineers need the professional competencies at higher proficiency levels in the earlier stages of a career than disciplinary engineers (Whitcomb, Khan and White 2013).

NPS believes the competency model can be used to identify and evaluate KSAs required to develop self-efficacy across various engineering domains. As such, it can be used by universities to ensure training and education meet the needs of industry. Two key objectives of the COMPOSE model were to: develop an approach and methodology to obtain baseline information needed for SE competency model development (for example the related KSAs, relevant education, training, and experience required) and to define career paths for systems engineers (jobs, assignments, and timing).

Research on self-efficacy has suggested that an individual's level of self-efficacy is a motivational predictor of how well a person will perform at almost any endeavor, and can be utilized and developed to leverage performance enhancing advantages (National Security Leadership Foundation n.d.). Thus, it can be understood that self-efficacy serves

as a regulator across a broad range of functioning, as the key determinant for human cognitive/affective, motivational and decision-making processes (National Security Leadership Foundation n.d.).

B. DEFINING SE COMPETENCIES: CLASSIFICATION BASED ON AFFINITY

The NPS research team developed a holistic approach to the design and structure of COMPOSE as a systems engineering competency model. Several competency models were used to verify the COMPOSE model in an effort to combine skills from different sources to generate a complete scope of SE KSA. Collectively, the competency models were mapped to the 41 competencies of the DAU SE Competency Model to form the basis of the competency list for the COMPOSE model. The competency classification verification process, based on affinity, was achieved by mapping KSA to proficiencies within the competencies using key words from Bloom's taxonomy, and then correlating the KSA to a specific cognitive or affective category. In the current version of the COMPOSE model there are 27 technical and technical management competencies, 14 professional competencies, and 2,914 KSAs along three notional skill levels, discussed in the next section (Whitcomb, Khan and White 2013).

C. COGNITIVE AND AFFECTIVE LEARNING DOMAINS: BLOOM'S TAXONOMY

Of noteworthy significance to the purpose of this thesis is the research conducted by White on the development of the COMPOSE model, and its identification and evaluation of the cognitive and affective domains associated with SE KSA (2014). The COMPOSE model categorizes KSAs in the form of Bloom's taxonomy into either the cognitive or affective domain, for each KSA in both technical and non-technical SE competencies. As such, the COMPOSE model allows for investigation into the break out into cognitive and affective processes (reference Figures 1–3). As White's research (reference Figures 2 and 3) reflects, 67 percent of the COMPOSE model's KSAs are mapped into the cognitive domain, with the remaining 33 percent being in the affective

domain (2014, 18). As reflected in Figures 1–3, the COMPOSE model illustrates how the specific SE related competencies that are characteristic of high performance and success in SE related jobs can be apportioned. With 33 percent (Figure 1) of the KSAs being grouped in the affective domain, this illustrates that this is important to the development of a SE. In addition, the NPS research provides weight to current research findings that suggest that affective learning domains, such as to value and respond (Figure 3), are "important constructs today's students must possess" and are essentially a deciding factor to the successful career achievement of lead performers (Joshi et al., 2012; Moore and Rudd 2005).

Furthermore, the analysis illustrates how cognitive and affective levels span the entire domain of SE (Figures 2 and 3). In COMPOSE, every level within each learning domain is represented, so as such, it is important to include all of the levels in aspects of assessing self-efficacy, as NPS does so via the *SE Competency Survey*. If one can identify his/her level of self-efficacy in each of the SE domains, and by doing so, also quantify KSA associated with the cognitive/affective learning domains, it is reasonable to assume one can then also gain an understanding of where he/she is at in being able to perform domain specific tasks. This is significant as research indicates an individual's perceived level of self-efficacy greatly influences his/her ability to achieve domain specific tasks (Lucas and Cooper 2004, 12).
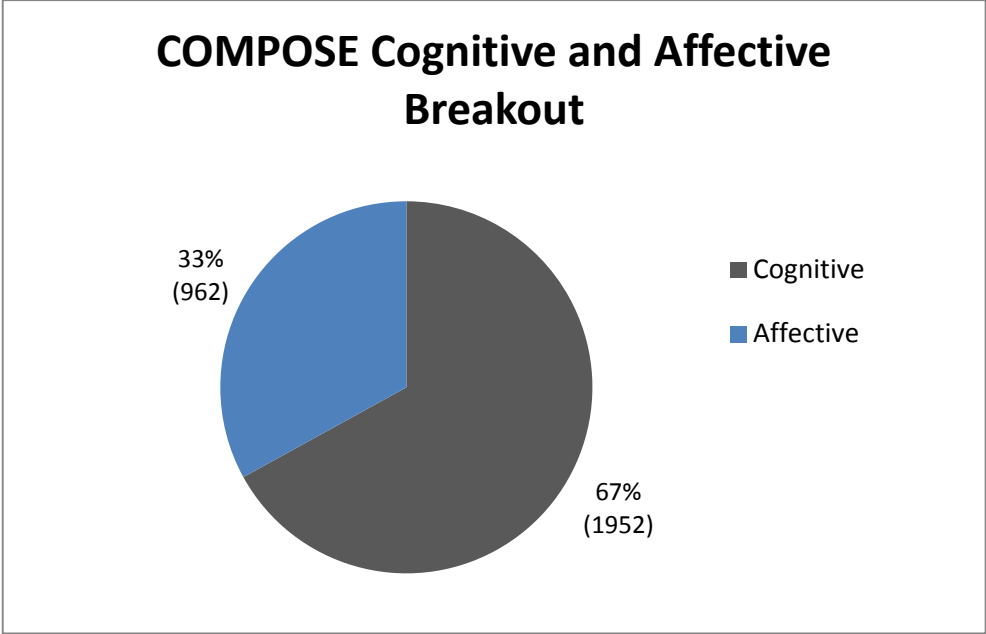
Figure 1. COMPOSE Model's Cognitive and Affective Category Breakout (from White 2014, 54).
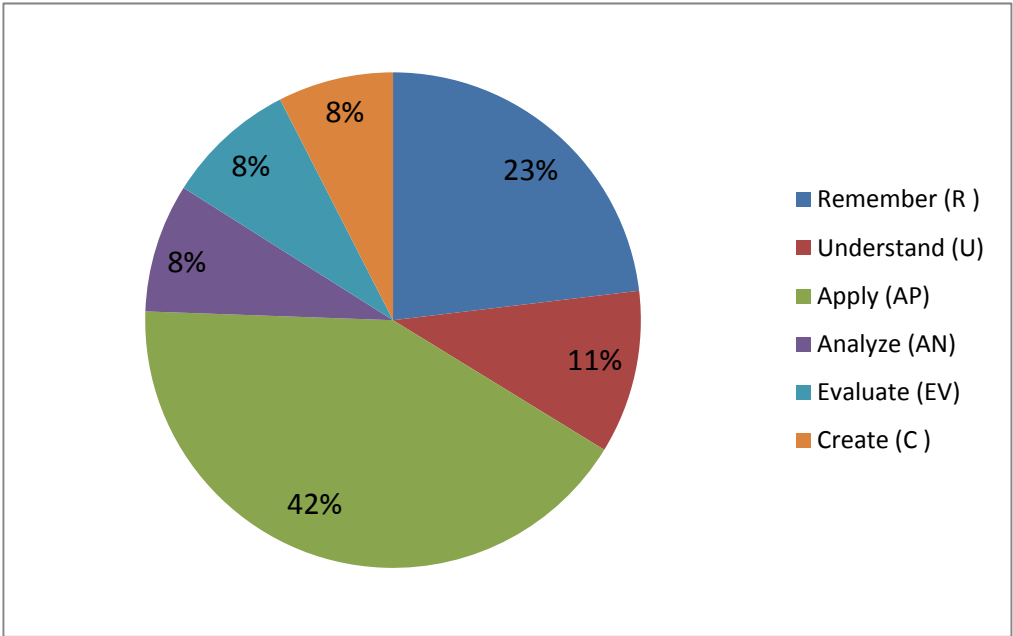
Figure 2. Bloom's Cognitive Levels within the COMPOSE Overall Model (from White 2014, 55).
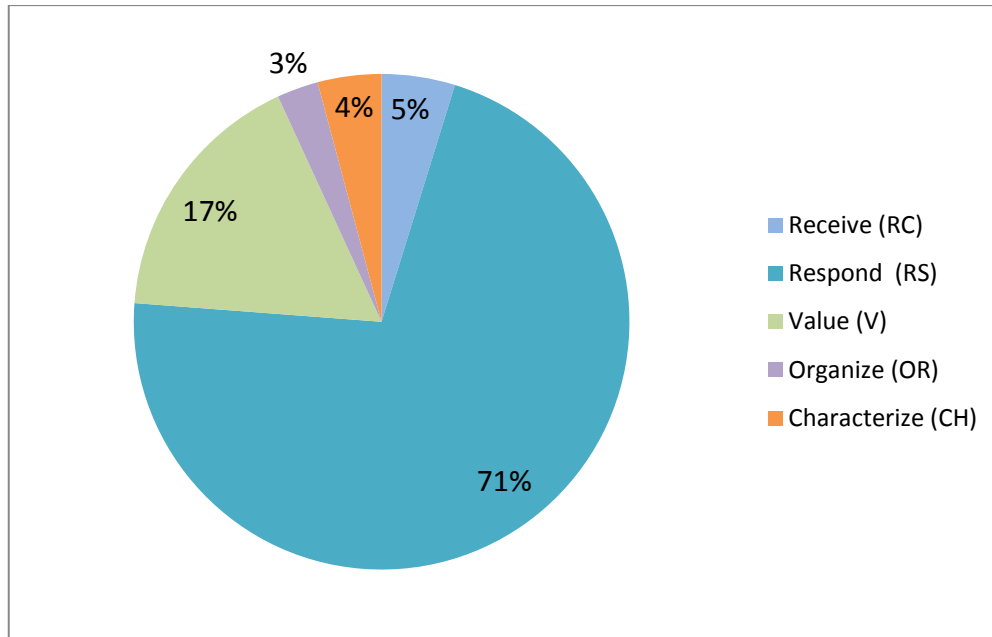
Figure 3.　Bloom's Affective Levels within the COMPOSE Overall Model
(from White 2014, 56).

In reference to the COMPOSE model, the cognitive domain includes knowledge, critical thinking and the development of intellectual skills (White 2014, 15), whereas, the affective domain deals with the emotions, feelings and attitudes of systems engineers. Affective KSAs describe growth in awareness, attitude, emotion, changes in interest, judgment and the development of appreciation (White 2014, 16). While most educators do not include the affective learning domain in the development of their curriculum, White states, "these outcomes are especially critical to the success of systems engineers as [they] lead systems projects, negotiate outcomes with a diverse group of stakeholders, make value judgments and must have the ability to deliberately take the systems perspective" (2014, 16).

The development of cognitive and affective domains is categorical and hierarchical, with increasing degrees of complexity (Clark 1999). Bloom's theory of categorical and hierarchical domains of learning is mirrored in the COMPOSE model, as it utilizes Bloom's taxonomic approach to aid in the description and classification of KSAs required of engineers.

To illustrate, as an engineer progresses from various levels of experience, it is assumed he/she improves in knowledge, skills and abilities related to the field. This is significant to mention as research suggests that skill development is a continuous process, and as knowledge and procedures continue to be compiled, more "elegant task strategies emerge" (Kraiger, Ford and Salas 1993, 315).

The NPS competency model takes the taxonomic approach one step further by providing an applicable method to document and assess at which points, and at which depth, should an engineer demonstrate particular KSAs within the 27 core technical and 14 non-technical competencies identified.

D.   SELF-EFFICACY   AND   KSAS: PREDICTORS   OF   WORK PERFORMANCE

Research on self-efficacy within engineering suggests that while work experience will facilitate the acquisition of considerable knowledge and the learning of new skills, it also has the advantage of enabling engineers to carry out work tasks where their performance will be assessed both by workplace professionals and the engineers themselves (Lucas et al. 2009, 741).

As previously described, the 41 competencies included in the COMPOSE model can be viewed as the core technical and non-technical competencies vital to the performance of an engineer. Select KSAs represented in the *Systems Engineering Competency Survey* allow a means whereby competencies defined by the COMPOSE model can be applied in a practical means by workplace professionals and engineers to assess performance. As such, the survey instrument aids in the assessment a person within a supervisory role can make of where an engineer is at in his/her respective field in terms of performance, and it also offers a means by which an engineer can measure his/her own level of self-efficacy in performing engineering functions. This is significant as research linking self-efficacy to performance indicates it "continues to be important once individuals have entered their careers, predicting better work performance" (Lucas et al. 2009, 740).

A survey of 114 research reports on self-efficacy and work-related performance show self-efficacy reliably "predicts higher levels of work performance across a wide variety of types of organizations and activities" (Stajkovic and Luthans 1998). For instance, in business it has been observed that real-estate agents with higher self-efficacy in their competencies have higher sales, and otherwise outperform peers with lower self-efficacy. Similarly, "causal inferences about the effect of self-efficacy on work performance is supported by experimental research that uses random group assignment and the manipulation of self-efficacy" (Lucas et al. 2009, 740). Research also suggests that self-efficacy links with cognitive/affective behaviors such as innovation and opportunity recognition (Ardichvili, Cardozo and Sourav 2003).

1.   Role of Cognitive and Affective Competencies in Job Performance

Research suggests that an individual's level of self-efficacy is a motivational predictor of how well a person will perform at almost any endeavor, and can be utilized and developed to leverage its performance enhancing advantages (National Security Leadership Foundation n.d.). An individual's belief in their level of self-efficacy (or *perceived* self-efficacy) greatly influences their ability to achieve domain specific tasks. In turn, self-efficacy serves as a regulator across a broad range of functioning, as the key determinant for human cognitive, affective, motivational and decision-making processes (National Security Leadership Foundation n.d.).

Research on the role of cognitive learning strategies suggests that individual differences exist in the extent to which knowledge can be accessed or applied more rapidly or fluidly (Kraiger, Ford and Salas 1993, 311). One theory relating the role of cognitive learning strategies suggests that through continued practice, complex behaviors are internalized. The greater the internalization, the more cognitive resources are available for higher level functions or strategy development (Kanfer and Ackerman 1989). In context to how strategy development relates to the NPS SE competency model and survey instrument, it is the "broad range of mental activities [i.e., KSAs] that facilitate knowledge acquisition and application" (Prawat 1989). Thus, as knowledge is acquired, it facilitates the application, or performance of work.

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E. CONCLUSION

The analysis aimed to look at the cognitive and affective learning processes of each KSA for the professional development SE competencies identified through the analysis of various engineering development models. Skills are a composite of abilities, techniques, and knowledge. They are developmental and incremental, and reference-based for a desired application, in our case, systems engineering (Clark 1999). The COMPOSE model, which serves as a guide to identify and evaluate the KSAs required to be a proficient engineer, identifies the technical and non-technical competencies across three notional proficiency levels within each competency. Furthermore, the COMPOSE model includes 14 non-technical competencies in the framework of professional skills a leader (especially one within an engineering discipline) should develop, and offers an analysis of how the competencies can be decomposed into individual KSAs. The thesis argues that self-efficacy, through competency modeling and surveying, can be enhanced within an individual, and, as a predictor of work performance, can aid in the development of proficient, highly skilled engineers.

F. CHAPTER SUMMARY

The chapter focused on describing NPS's efforts on applying model based research of technical and non-technical skills and self-efficacy to develop a competency model. The chapter began with a description of the process whereby NPS developed a systems engineering career development competency mode—COMPOSE. The chapter also detailed how the COMPOSE model maps relevant cognitive and affective processes to SE specific KSAs. The NPS research team contends that the competency model can be used to identify and evaluate KSAs required to develop self-efficacy across various engineering domains. And, as such, the model can be used by universities to ensure education and training meet the needs of industry. The chapter concluded with the argument that self-efficacy, through competency modeling as the basis for surveying, can aid in the development of proficient, highly skilled engineers.

IV. MEASURING SELF-EFFICACY: DEVELOPMENT OF A SELF-EFFICACY MEASUREMENT INSTRUMENT AND ANALYSIS OF NPS STUDY

A. HOW DO SELF-EFFICACY ITEMS IN THE SURVEY INSTRUMENT RELATE TO THE COMPOSE MODEL?

In the previous chapter, the implications for possible applications of the COMPOSE model as a source of self-efficacy related KSAs was discussed. This chapter is an extension of the research previously discussed, and aims to demonstrate how the survey instrument developed by the SE department at NPS can be used to 1) aid in the development of competent systems engineers and 2) be used as a tool to predict career performance. The *Systems Engineering Competency Survey* is a survey instrument initially designed with a composite of questions aimed to measure the level of self-efficacy perceived by entry level systems engineers. The self-efficacy items in the The *Systems Engineering Competency Survey* relate to the COMPOSE model in that they pose the cognitive and affective KSAs measures as questions. In other words, the survey items relay the KSAs exhibited in the model as measures of performance.

B. NPS SURVEY INSTRUMENT: BACKGROUND AND METHODOLOGY

The primary method utilized to measure self-efficacy in systems engineering students was via the *Systems Engineering Competency Survey*. The survey instrument had 65 items meant to measure the knowledge, skills and abilities that are directly related to meeting educational objectives one would expect of a master's systems engineering program. The survey items were developed by subject matter experts, using information collected during the development of a DOD competency model for the domain of systems engineering, and as such are believed to have face validity.

The survey items were written to measure self-confidence in performing systems engineering related tasks that included understanding the limits of systems engineering technology and techniques (critical thinking), translating user requirements into technical requirements (systems engineering), leading a team of technical professionals (teamwork), and being able to track and monitor the progress of a project (project

management). The *Systems Engineering Competency Survey* asked students to rate their level of self-efficacy on a linear scale of 0 to 100, with 0 representing "no confidence" and 100 being 'complete confidence' in being able to perform the skills. The expectation was that the survey items constituted tasks that graduates would be able to perform if they were to be successful in systems engineering work.

The survey was delivered in a pre- and post-mode to two consecutive SE cohorts (categorized as *RT19* and *RT19A*, respectively). The *RT19* pre-rendition of the *SE Competency Survey* was deployed to an SE cohort in 2011 during the middle of the students' first quarter. The *RT19A* cohort was given the pre-survey at the beginning of their program, in 2012. Then, each of the *RT19* and *RT19A* post-surveys were administered towards the end of the each of the cohorts' program.

1.   SE Competency Survey: Questionnaire Analysis Using Factor Analysis and Cronbach's Alpha

Following an example set by Lucas et al., NPS used the statistical technique of factor analysis (FA) to test for underlying dimensions of the self-efficacy items embedded in the survey (2009, 744). As defined by Fricker, Kulzy and Appleget:

> factor analysis is a method for identifying latent traits from question-level survey data. It is useful in survey analysis whenever the phenomenon of interest is complex and not directly measurable from a single question. In such situations, it is necessary to ask a series of questions about the phenomenon and then appropriately combine the resulting responses into a single measure or factor. Such factors, then, become the observed measures of the unobservable or latent phenomenon. (2012, 1)

If the FA results indicate that an established scientific reliability goal is achieved for each survey item, "the latent variables will have useful and interpretable meanings that provide additional insight into the characteristics of the populations being studied" (Fricker, Kulzy and Appleget 2012, 2).

For the purposes of our study, the latent phenomenon was defined to be the cognitive trait(s) of self-efficacy to perform each competency. We used the technique of FA as a method to extract and label each latent competency, which we then grouped into one of the four systems engineering domains. And, again following an example set forth

by Lucas et al., the criteria for establishing the scientific reliability goal was that the FA result for each survey item must be .6 or higher on its "primary component," and less than .4 on any other component. We define primary component as the domain we intended the competency to fall under. So, for instance we intended for each competency to fall under project management, teamwork, systems engineering or critical thinking. Factors were grouped together based on intended domain and the FA value obtained.

The purpose of the factor analysis was to determine which items of the *Systems Engineering Competency Survey*, if any, could be considered to be reliable indicators of self-efficacy, within one of the four specific domains of systems engineering. The factor analyses were run twice, once for each pre-survey rendition of the *SE Competency Survey*. The method of FA allowed the NPS research team to delineate and group the competencies, based on the value assigned to each competency from the survey results. As stated above, competencies that loaded with a value of .6 or higher in the primary component (domain) were retained for further analysis. Competencies less than .4 were excluded from the analysis to strengthen the identification of the four specific self-efficacy components.

Cronbach's alpha, a statistical measure used to test the validity and reliability of survey data, was then run for each of the 65 *RT19* and *RT19A* survey items, and again for each survey set as a whole. Cronbach's alpha was observed to be .989 and .985 for the *RT19* and *RT19A* surveys, respectively—suggesting that overall, the survey items have a relatively high internal consistency.

2.   Rotated Factor Analysis

The responses of each pre-rendition of the *RT19* and *RT19A* survey were used in the factor analysis to test for underlying dimensions within the self-efficacy survey items. In FA, the relationship of the factors to each other is determined by a rotation technique selected during the analysis. Following an example set forth by Lucas et al., we chose to rotate our FA results using the statistical rotation technique referred to as Varimax. In FA, the rotated component matrix displays the loadings, or value groupings, of variables on factors. Variables are grouped based on "high loadings" (.6 or higher) and similar

values across components. If the factor axes are rotated, the loading of a variable on one factor is maximized while its loading on the other factors is minimized, thereby making the factor structure easier to interpret (Daniel 2013). For the context of this paper, we define the phrase "loaded on" or "high loadings" to refer to the way in which FA results are displayed. Survey items with a value of .6 or higher are said to "load" strongly – meaning they can be assumed to reliably measure the latent construct one is examining. FA results display survey items within matrix columns. These columns are suggested as being domains.

The significance of using the Varimax rotation method after performing FA is that the Varimax rotation attempts to simplify the columns of the factor matrix, achieving the maximum simplification of component identification. This also results in factors that are independent of each other (Daniel 2013). For the purposes of our study, this was important to do as we aimed to 1) test the hypothesis that self-efficacy can be measured and improved upon by a rigorous education and training and 2) identify reliable measures of self-efficacy in each of the four systems engineering domains.

When the responses were subjected to rotated factor analysis, 11 components emerged both times, with the four expected domains of systems engineering (i.e., critical thinking, systems engineering, teamwork or project management) emerging as major components. Again, the component selection was determined using competencies that loaded on a .6 or higher within the intended systems engineering domain and excluding the competencies that loaded strongly (.6 or higher) on more than one domain, or scored a value lower than .4. Student data for each cohort set was then subjected to two sample t-tests, to examine if any statistically significant difference was observed between the mean pre- and post-self-efficacy scores.

C.   GENERAL RESULTS

Using the factor analysis results of the survey items tested against each other, it was observed that some survey items loaded on more than one component—thereby indicating that the items may need to either be re-evaluated (so as to measure one specific domain) or be eliminated from future renditions of the survey. A possible follow on

procedure, now that factor analysis has been performed twice, could be a cross analysis of each of the *SE Competency Survey* factor analysis results to determine which, if any, of the survey items can be used for further survey analysis. Taking into consideration each of the factor analysis results, we may re-combine certain survey items or re-write a survey to measure self-efficacy in the SE domains of teamwork, project management, systems engineering and critical thinking.

It is noteworthy to mention that the data reflected in Tables 1 and 2 are a subset of the 65 survey items that were originally presented to the students in the pre- and post-surveys. The survey items represented are those that, through factor analysis, were observed to load on a single, distinct SE domain.

Table 1.   Pre to Post Education Change in Levels of Self-Efficacy, AY 2011 Cohort

A. <u>Self-efficacy</u>: Current skill levels in **Teamwork**	Percent avg. across all responses		Response changes from pre- to post-event survey and sign test		
Response rate at post-test, 17/17=100%	Pre-education	Post-education	N	Percent increase	T value
Help two team members resolve serious personal differences so they can work effectively with the team.	74	79	17	5	-0.955
Help make sure your teammates deliver on the schedule that they agreed to support.	76	78	17	2	-0.457
Talk with your team members for the purpose of assessing their interests and skills in order to ensure needed team capabilities are included.	75	79	16	4	-0.716
Identify important personal relationships that must be considered to complete a project.	69	74	14	5	-0.920
Determine an operating plan once all team members understand their interests and skills.	66	75	14	9	-1.9316*
Get your team members at project start to make personal commitments to their responsibilities.	69	70	14	1	-0.143

Give constructive criticism to a poorly performing team member that helps them improve their performance.	72	74	14	2	-0.434
Facilitate a team to reach agreement when there had been conflicting views about what steps should be taken next.	71	72	14	1	-0.212

B. Self-efficacy: Current skill levels in **Critical Thinking**	Percent avg. across all responses		Response changes from pre- to post-event survey and sign test		
	Pre-education	Post-education	N	Percent increase	T value
Examine the statement of a problem to identify its key elements.	72	76	17	4	-1.005
Identify and, if necessary, challenge the assumptions in a problem statement.	73	71	17	-2	0.527
Examine what is known and unknown about a problem to create a logical argument for the best solution.	68	74	17	6	-1.102
Read a policy paper and identify any assumption that is unsupported by the evidence.	66	71	17	5	-0.838
Identify the critical questions of fact that are missing from a line of reasoning.	64	70	14	6	-1.020
Find an inconsistency in an argument the first time you read a document.	64	68	14	4	-0.714
Recognize any logical inconsistencies in a presentation by a speaker.	70	71	14	1	-0.078
Judge the strengths and weaknesses of the evidence supporting your logic.	70	74	14	4	-0.824

C. Self-efficacy: Current skill levels in **Systems Engineering**	Percent avg. across all responses		Response changes from pre- to post-event survey and sign test		
	Pre-education	Post-education	N	Percent increase	T value
Generate alternative system ideas to meet a stakeholder need.	73	76	17	3	-0.5669
Elicit requirements that a future stakeholder has for a system, service, or construct using direct interaction with them.	66	69	17	3	-0.575
Leverage features or elements of existing systems that can inform a new design.	62	69	17	7	-1.471

Use projected warfighting capability gaps to estimate the future need for a new system.	60	74	17	14	-2.9528**
Translate the system capabilities that you have co-developed with stakeholders into technical requirements.	64	71	17	7	-1.133
Determine whether a set of system requirements are feasible.	64	70	17	6	-1.0415
Create a feasible design that meets the system requirements.	65	67	17	2	-0.4564
Pick a technology for a system considering that the technology readiness level is estimated, and uncertain.	47	68	17	21	-3.8973***
Recognize when you can reduce the complexity of your completed system design.	59	68	17	9	-2.0062*
Prioritize the requirements that a future customer has for a system, service, or construct.	68	72	17	4	-0.7142
Design a system that fits within its desired total ownership cost.	55	66	17	11	-2.0505*
Determine what evidence is required as data to demonstrate that a system meets its requirements.	61	71	17	10	-1.9378
Meet with 20 stakeholders with very different needs and determine the design that serves them best.	55	70	16	15	-2.5056
Create a system architecture that has appropriate elements, attributes, and relationships to be able to be used for system development and decision making.	61	69	17	8	-1.3956
Formulate a methodology and approach for solving a systems engineering problem in an unfamiliar subject area.	62	70	17	8	-1.6069
Decompose a problem into its solvable parts.	76	74	17	-2	0.6378
Compare a number of proposals and identify the one with the strongest line of reasoning for how to solve the problem.	72	72	17	0	-0.1535
Listen to 20 stakeholders with very different needs and define a set of requirements that meet their needs.	61	69	14	8	-1.6897

Create a rough vision for a design solution in an hour for requirements that you have just received.	63	71	14	8	-1.3911
Know how and when to challenge the assumptions for a design.	63	67	14	4	-0.8112
Collect and interpret stakeholder needs related to a given project.	69	72	14	3	-0.6071
Use your technical knowledge to make contributions to a new design proposal.	69	69	14	0	-0.0454
Select the most appropriate initial design iteration to meet a given set of requirements.	64	71	14	7	-1.2259
Describe what resources will be necessary to conduct tests to demonstrate that a system meets its requirements.	58	71	14	13	-2.968**

D. Self-efficacy: Current skill levels in **Project Management**	Percent avg. across all responses		Response changes from pre- to post-event survey and sign test		
	Pre-education	Post-education	N	Percent increase	T value
Develop a time-phased budget for a multi-year project.	52	62	16	10	-1.485
Estimate quantitatively the likelihood and relative impact of events on a development project that represent the most pressing risks.	59	70	17	11	-2.022*
Create a work breakdown structure for your project.	62	71	17	9	-1.455
Identify risk events that could have an impact on timely development of your system.	69	71	14	2	-0.449
Recognize the important assumptions that need to be tested at the start of a new system development project.	65	69	13	4	-1.032
Identify and define the roles and responsibilities that will be needed to complete a project.	71	75	14	4	-1.032
Determine what measures must be taken in a risk mitigation strategy to assess if the likelihood or impact have been assuaged as development progresses.	68	71	14	3	-0.671

Identify in the development schedule when tests must be completed to demonstrate that a system meets its requirements.	63	70	14	7	-1.505
Prioritize events in a risk mitigation strategy and ideate corrective action.	68	72	13	4	-0.684

* p<.05; ** p<.01; *** p<.001. The t-test was used to estimate statistical strength of significance using the difference of means between the pre- and post-survey results.

Given a null hypothesis that any change found will be random and equally probable in either direction, the t-test calculates the probability that the number of changes is disproportionately in the hypothesized direction (one-tail test).

Table 2.   Pre to Post Education Change in Level of Self-Efficacy, AY 2012
Cohort

A. Self-efficacy: Current skill levels in **Teamwork**	Percent avg. across all responses		Response changes from pre- to post-event survey and sign test		
Response rate at post-test, 11/11=100%	Pre-education	Post-education	N	Percent increase	T value
Ensure team members follow agreed upon rules for meetings.	67	89	11	22	-5.6903***
Help two team members resolve serious personal differences so they can work effectively with the team.	59	81	11	22	-4.2807***
Help make sure your teammates deliver on the schedule that they agreed to support.	57	79	11	22	-5.3094***
Talk with your team members for the purpose of assessing their interests and skills in order to ensure needed team capabilities are included.	55	76	11	21	-5.0963***
Examine two design approaches and select the better one for your project to present as your alternatives to your team.	51	78	11	27	-6.3165***
Identify important personal relationships that must be considered to complete a project.	53	83	11	30	-6.3555***
Help ensure your team members understand the goals, scope, and deadlines at the project start.	55	84	11	29	-6.4187***
Get your team members at project start to make personal commitments	50	76	11	26	-5.4103***

to their responsibilities.					
Give constructive criticism to a poorly performing team member that helps them improve their performance.	54	71	11	17	-2.2975*
Facilitate a team to reach agreement when there had been conflicting views about what steps should be taken next.	50	78	11	28	-6.1914***
B. Self-efficacy: Current skill levels in **Critical Thinking**	Percent avg. across all responses		Response changes from pre- to post event survey and sign test		
	Pre-education	Post-education	N	Percent increase	T value
Analyze opposing positions on an issue and compare the quality of their evidence.	59	77	11	18	-4.199***
Examine an engineering problem and prepare a written and oral statement describing all essential elements included in the solution.	36	72	11	36	-8.477***
Evaluate data about an existing design problem to define its nature, boundaries, and scope.	40	73	11	33	-8.435***
Find an inconsistency in an argument the first time you read a document.	47	67	11	20	-4.307***
Recognize any logical inconsistencies in a presentation by a speaker.	48	68	11	20	-3.147**
Identify the critical questions that need to be answered before a feasible design can be selected.	39	73	11	34	-6.148***
Judge the strengths and weaknesses of the evidence supporting your logic.	45	75	11	30	-7.121***
C. Self-efficacy: Current skill levels in **Systems Engineering**	Percent avg. across all responses		Response changes from pre- to post-event survey and sign test		
	Pre-education	Post-education	N	Percent increase	T value
Generate alternative system ideas to meet a stakeholder need.	45	76	11	31	-6.955***

Elicit requirements that a future stakeholder has for a system, service, or construct using direct interaction with them.	39	73	11	34	-9.6184***
Leverage features or elements of existing systems that can inform a new design.	42	75	11	33	-8.6191***
Translate the system capabilities that you have co-developed with stakeholders into technical requirements.	35	70	11	35	-7.7072***
Create a feasible design that meets the system requirements.	40	72	11	32	-7.6047***
Pick a technology for a system considering that the technology readiness level is estimated, and uncertain.	33	68	11	35	-6.1698***
Design a system that fits within its allocated budget, trading off schedule, performance, and lifecycle issues.	37	68	11	31	-4.5292***
Recognize when you can reduce the complexity of your completed system design.	39	68	11	29	-4.6898***
Prioritize the requirements that a future customer has for a system, service, or construct.	40	74	11	34	-6.3318***
Design a system that fits within its desired total ownership cost.	30	61	11	31	-4.8887***
Determine what evidence is required as data to demonstrate that a system meets its requirements.	37	66	11	29	-6.8608***
Tailor a systems engineering process for your project.	31	76	11	45	-9.3137***
Apply functional analysis during system design.	36	75	11	39	-6.8608***
Identify what tests should be conducted to create data to demonstrate that a system meets its requirements.	36	68	11	32	-7.4133***
Create a system architecture that has appropriate elements, attributes, and relationships to be able to be used for system development and decision making.	29	70	11	41	-7.4799***

Formulate a methodology and approach for solving a systems engineering problem in an unfamiliar subject area.	32	73	11	40	-6.5519***
Respond to a change in the environment or stakeholder needs via modification of the requirements baseline.	32	61	11	29	-5.2495***
Explain the ramifications to a change in the environment or stakeholder needs based on modification of requirements.	33	65	11	32	-5.6638***
Select the most appropriate initial design iteration to meet a given set of requirements.	36	67	11	31	-6.8845***
Describe what resources will be necessary to conduct tests to demonstrate that a system meets its requirements.	38	68	11	30	6.1492***
D. Self-efficacy: Current skill levels in **Project Management**	Percent avg. across all responses		Response changes from pre- to post-event survey and sign test	
Recognize the important assumptions that need to be tested at the start of a new system development project.	37	67	11	31	-4.4662***
Determine what measures must be taken in a risk mitigation strategy to assess if the likelihood or impact have been assuaged as development progresses.	36	73	11	37	-8.2558***
Prioritize events in a risk mitigation strategy and ideate corrective action.	41	78	11	37	-8.0621***

* p<.05; ** p<.01; *** p<.001. The t-test was used to estimate statistical strength of significance using the difference of means between the pre- and post-survey results.

Given a null hypothesis that any change found will be random and equally probable in either direction, the t-test calculates the probability that the number of changes is disproportionately in the hypothesized direction (one-tail test).

NPS included only those items that were observed to load with a .6 or higher on a component, and loaded with items that were similarly *intended* to measure one of the abovementioned domains. And, again, following the model set forth by Lucas et al., items that loaded on more than one component were excluded from the analysis in order to have scales based on the items that capture the distinctness of the domains (2009, 744). However, as one can see, the two survey sets yielded different factor analysis results, and as such, reflect different survey items as markers of domain distinctness.

1. Survey Instrument Analysis Using Rotated Factor Analysis Results

Observations of the final data sets, as represented in Tables 1 and 2, led to examination of the similarities between the rotated factor analysis results to determine which survey items were more effective in capturing self-efficacy in the intended domains. The survey items to keep, based on the rotated factor analysis results of each survey, would be:

Teamwork

- Help two team members resolve serious personal differences so they can work effectively with the team.

- Help make sure your teammates deliver on the schedule that they agreed to support.

- Talk with your team members for the purpose of assessing their interests and skills in order to ensure needed team capabilities are included.

- Identify important personal relationships that must be considered to complete a project.

- Get your team members at project start to make personal commitments to their responsibilities.

- Give constructive criticism to a poorly performing team member that helps them improve their performance.

- Facilitate a team to reach agreement when there had been conflicting views about what steps should be taken next.

Systems Engineering

- Generate alternative system ideas to meet a stakeholder need.

- Elicit requirements that a future stakeholder has for a system, service, or construct using direct interaction with them.

- Leverage features or elements of existing systems that can inform a new design.

- Translate the system capabilities that you have co-developed with stakeholders into technical requirements.

- Create a feasible design that meets the system requirements.

- Pick a technology for a system considering that the technology readiness level is estimated, and uncertain.

- Recognize when you can reduce the complexity of your completed system design.

- Prioritize the requirements that a future customer has for a system, service, or construct.

- Design a system that fits within its desired total ownership cost.

- Determine what evidence is required as data to demonstrate that a system meets its requirements.

- Create a system architecture that has appropriate elements, attributes, and relationships to be able to be used for system development and decision making.

- Formulate a methodology and approach for solving a systems engineering problem in an unfamiliar subject area.

- Select the most appropriate initial design iteration to meet a given set of requirements.

- Describe what resources will be necessary to conduct tests to demonstrate that a system meets its requirements.

Critical Thinking

- Find an inconsistency in an argument the first time you read a document.

- Recognize any logical inconsistencies in a presentation by a speaker.

Project Management

- Recognize the important assumptions that need to be tested at the start of a new system development project.

- Determine what measures must be taken in a risk mitigation strategy to assess if the likelihood or impact have been assuaged as development progresses.

- Prioritize events in a risk mitigation strategy and ideate corrective action.

This subset of survey items represents the skills that were observed to load with a .6 or higher in a single component, within both the rotated factor analysis tests.

D.   RESULTS: ANALYSIS AND IMPLICATIONS

In general, there is some evidence to show that there was improvement in the systems engineering students as they progressed through the program, in their perceived level of self-efficacy to perform systems engineering skills. Although not all items displayed statistically significant differences between pre- and post-survey results, changes in mean scores (from pre- to post-) were generally reported to be higher, reflecting an overall enhanced perception of self-efficacy.

An interesting observation of the survey results is that the first cohort *(RT19)* generally marked their pre-scores to be much higher than those of the next cohort *(RT19A)*. This trend leads us to examine possible reasons for the difference in perceived levels of self-efficacy between cohorts, as there are potentially a couple of reasons for this observation. For instance, in a discussion with a lead faculty member who interviewed the *RT19* students about the scores, it was deemed that the students' relatively high perception of their own ability could have been affected by the preconceived notion that, prior to any formal education or training, they had an ability to accomplish many of the competencies because of the context of their military experiences. This point is supported in the research review discussed earlier, in which we describe the process by which mastery experiences (in our case, that of the students' having prior experience in performing SE related tasks, albeit through a military setting), can positively affect self-efficacy. It is meaningful to add to this discussion that there was a structured difference between the *RT19* and *RT19A* course format, but the change in structural format was not deemed to have affected the *RT19* cohort's pre-survey results—and in fact the NPS research team believes it would have impacted the post-survey results. It should be noted that the *RT19* pre-survey was deployed during the middle of the students' first quarter. So, they had essentially already received a fair amount of educational experience in fundamental SE concepts, compared to *RT19A*. The *RT19A* cohort was given their survey at the beginning of their curriculum. The decision of the lead faculty to deploy the *RT19A* pre-survey at an earlier point in the students' master's program came as a result of an informal review process with students. It was deemed that adjusting the process and procedure when deploying to the *RT19A* cohort would control for the way students understood the questions. Also, the project that was used for the basis of learning (and by which the students would have been expected to base their experiences), was pedagogically designed as an authentic-learning project.

To summarize, a general assessment of the high pre-scores of the *RT19* cohort is that the students may have misjudged (i.e., overestimated) their skills and abilities in the pre-test, as a result of them feeling like they had experience in performing the tasks in a

military environment, but not so much in an educational environment. Again, we stress the role of mastery experiences in enhancing a student's perceived level of self-efficacy.

1.   Teamwork

Relevant research has suggested that teamwork provides students with an opportunity to evaluate the skills of their peers (Ponton et al. 2001, 250). When a student observes his/her peers with competencies he/she values, then the individual student can believe him/herself equally competent in performing the same skill (Ponton et al. 2001, 250). As such, our hypothesis was that the survey results would indicate increased levels of self-efficacy in items relating to teamwork, as one would hope progressing through a master's program at university would enhance opportunities and skills necessary for working in teams. In general, results indicate mixed findings as the results for the first cohort did not show significant differences in the average response rates towards many of the teamwork aspects, while the second cohort seems to have improved at significant levels. An area of teamwork that seems to have been enhanced is the students' ability to *determine an operating plan once all team members understand their interests and skills.* This finding is indeed interesting as research has found teamwork in engineering has the advantage of solving complex problems (Ponton et al. 2001, 249).

Among the first cohort's results, the skill was observed to be significant at $p<.01$, with a percent increase in pre- and post-results of nine percent. The second cohort's percent increase between pre- and post-average was 30 percent and was statistically significant at $p<.001$. An interesting observation one immediately notices when studying the results is the difference in the percent increase of pre- and post-means between cohorts. The second cohort seems to have indicated lower levels of self-efficacy in their pre-survey and so display a larger mean difference in post results. It is noteworthy to mention that the statistical method of using a t-test accounts for the difference in sample sizes, and so the difference in mean percent increase across teamwork items between the first and second cohort provides interesting context for further study. It should be noted that a possible explanation for this observation is that lead faculty incorporated course work that addressed teamwork into the curriculum of the second cohort (*RT19A*), but not

the first cohort. This was because, for the first cohort, it was assumed the students could effectively work in teams. This structural method may have impacted the results.

2. Critical Thinking

Data analyses of the first cohort's results seem to indicate that the self-efficacy scores in critical thinking did not go up enough to exceed rejection criteria for traditional hypothesis testing, which would contend that there would be a significant difference between pre- and post-averages. All but two of the skills surveyed demonstrated higher averages in the post-survey results—meaning that even though the gains were not significantly different, there was at least a general sense of improvement among students.

An analysis of the second cohort yields markedly different results, with most of the post mean differences relating to critical thinking self-efficacy skills statistically significant from pre-survey results at $p<.001$.

The mixed results observed within the critical thinking items may be due to the social phenomenon that students are not aware of how well they can perform a certain task until they actually have to utilize the skill or knowledge set, in a work environment. Put in context, self-efficacy influences the level of accomplishment realized by people as they perform tasks (Bandura 1997, 3).

In reviewing the critical thinking results, it should be noted that the structural format in teaching the first cohort involved referring the students to textbooks on the topic of engineering reasoning, whereas the second cohort was more formally taught from lectures (i.e., through parts of course work and seminars) on what critical thinking is and how it is used. The NPS research team feels that this change in structure may have impacted the survey results.

3. Systems Engineering

Our hypothesis was that the survey results would indicate increased levels of self-efficacy in items relating to systems engineering, as it is expected SE students will, at the least, feel efficient and capable in performing standard systems engineering tasks as they progress through a master's program.

Contrary to results observed in the other systems engineering domains, the first cohort's results showed significant differences in several areas. Two skills in particular showed significant differences between pre- and post-results at $p < .01$. These were the student's ability to *use projected warfighting capability gaps to estimate the future need for a new system* and to *describe what resources will be necessary to conduct tests to demonstrate that a system meets its requirements.* One self-efficacy item in particular reflected statistically significant pre- and post-survey results at $p < .001$, which was the student's ability to *pick a technology for a system considering that the technology readiness level is estimated, and uncertain.*

The survey offered to the second cohort culminated in mean pre- and post-differences that went up enough to exceed rejection criteria for traditional hypothesis testing. There were significant differences in means observed in all self-efficacy items relating to systems engineering. These results may be due to the change in structural format of instruction delivery between that of the first and second cohort. The first cohort integrated their authentic project within each of the courses in the curriculum. The second cohort had an additional three consecutive project courses added to their curriculum in which the instructor reviewed all SE methods and processes in the context of the project. This facilitated near transfer of the learning of SE methods and processes to the authentic project context. So, in theory, key SE concepts were revisited a number of times. Therefore, the NPS team feels that this approach to teaching systems engineering concepts in context of authentic-learning projects seems to improve self-efficacy and is more effective in teaching. Also this finding supports our assumption that the systems engineering students would perceive higher levels of self-efficacy as they progressed through SE courses. As such, it can be assumed that the education provided to the students positively affected their ability to perform systems engineering tasks.

4. Project Management

Similar to results observed in the critical thinking self-efficacy items, most of the first cohort's results did not go up enough to exceed traditional rejection criteria for hypothesis testing. An exception to this observation was in the skill of *estimating quantitatively the likelihood and relative impact of events on a development project that*

represent the most pressing risks, which had an increase of 11 percent, and the difference in mean scores was statistically significant at p<.05.

Results of the second cohort's survey items relating to project management, showed statistically significant differences in the mean scores at p<.001—exceeding rejection criteria for traditional hypothesis testing. This finding supports our assumption that systems engineering education provided to the students improved their ability to perform tasks related to project management skills.

Similar to the analysis discussed on systems engineering, the project management results may be due to the change in structural format of instruction delivery between that of the first and second cohort. As in the case in the systems engineering domain, the second cohort was explicitly taught how SE skills relate to the project via learning activities. The NPS team feels that assisting them in near transfer of knowledge and ability to their project may have influenced the survey results to reflect an increase in self-efficacy.

E.   CHAPTER SUMMARY

The aim of this research was to determine whether self-efficacy in systems engineering could be reliably measured via a survey instrument among SE students at the Naval Postgraduate School.

Overall, the *Systems Engineering Competency Survey* instrument can be seen as an effective means to measure self-efficacy in systems engineering students. As discussed above, the survey was delivered in a pre- and post-mode to two consecutive SE cohorts and was designed to establish, with confidence, that the systems engineering program had a measurable influence in improving the knowledge, skills and abilities of students to perform standard systems engineering tasks. The results support the hypothesis that there was a general sense of improvement in the systems engineering students as they progressed through the program, in their perceived level of self-efficacy to perform domain specific systems engineering skills.

Several format structures could have biased the data and this should be strongly considered when assessing the results of the research. Perhaps the strongest bias was the sheer length of the survey. Offered as a paper questionnaire, the survey initially had 65 items. A bias that may have occurred due to the length of the first format was that students may have inadvertently or purposely circled answers on the scale, without considering the value, in an effort to quickly submit the lengthy survey. Despite this, we chose to keep all survey submissions as there is no way to prove that a student did or did not feel they could perform the skills at the level they indicated.

To address the possible areas of bias, the survey has since been divided up into two surveys, so as to lessen the load and time needed to take the survey. We used the method of rotated factor analysis with the data obtained from the first and second *SE Competency* surveys to observe which survey items, if any, loaded on multiple components, and took those survey items out that loaded on more than one component. This method aimed to ensure that each item would measure self-efficacy in a specific domain of systems engineering, and aided in reducing the length of the survey. Also, the two surveys are now offered online, and are paired: systems engineering/critical thinking ('systems thinking') and project management/teaming. Despite this, given that the factor analysis reports of each cohort's survey data set yielded different component loading results (as unique data sets were used as the basis to run the analysis), an important follow-on step would be to merge the results to create a survey instrument that can more effectively measure self-efficacy in systems engineering.

Finally, the NPS research team assessed possible implications of changes in the educational content and delivery structure between the cohorts (i.e., to explicitly go over key SE concepts via projects, course work and seminars). In examining the mean differences in pre- and post-scores, it was observed that statistically significant differences (particularly within the systems engineering and project management domains), could have been due to this structural changes in teaching, as assisting students in near transfer of knowledge and ability, and including authentic-learning projects seems to have increased the perception of self-efficacy in students.

V. CONCLUSIONS, RECOMMENDATIONS, SUMMARY AND AREAS FOR FURTHER RESEARCH

A. SUMMARY

In this chapter, we will discuss conclusions, recommendations and further areas of research based on the results of the *SE Competency Survey* analyses. We will also provide a relevant discussion on current areas of research that tie into the NPS study and can support our findings and the subsequent recommendations for further areas of research.

It can be observed from the survey research results previously discussed that self-efficacy can be used as an indicator of systems engineering competency level achievement. Self-efficacy, as it relates to research within systems engineering, was defined as an individual's belief that he or she can be proficient in skills necessary to become a systems engineering professional. System's engineering self-efficacy was also defined as the beliefs in one's ability to learn systems engineering skills. Relevant research suggests that self-efficacy is influenced by one's own sense of capability and by the education, training and support received by others. As such, self-efficacy can be used in systems engineering as a motivational predictor of how well an individual will perform tasks, and can be utilized and developed to leverage performance enhancing advantages (National Security Leadership Foundation n.d.).

Self-efficacy and cognitive/affective processes were shown to be integral in indicating performance in SE related careers. For instance, relevant research suggested that self-efficacy is a latent, psychological trait, which serves as a regulator across a broad range of functioning, as the key determinant for cognitive and affective processes. The NPS team cited Prawat's (1989) finding that cognitive and affective skills are determined to be vital in indicating performance in SE because having a broad range of KSAs enables knowledge acquisition and application. The NPS team theorized that the acquirement of domain specific knowledge has the advantage of allowing one to facilitate the performance of work.

A literature review of relevant studies on the topic of self-efficacy led the NPS team to believe that a gap exists between being able to assess SE KSAs and measure the competency of students/entry level engineers as a way to predict future career performance. It was stated that research by Lucas et al. (2009) that foundational, as it is in the development of survey models to measure self-efficacy, does not answer whether or not self-efficacy requires a higher level of cognition. Research conducted by NPS, which maps KSAs across SE competencies and categorizes the KSAs into SE domains, fills this gap. The NPS research team contends that the research aids in the identification of the characteristic experiences and knowledge students need to strengthen self-efficacy in technical and non-technical fields.

B.   CONCLUSIONS AND RECOMMENDATIONS

A conclusion the research team came to after reviewing the results of the *SE Competency Survey* was that self-efficacy can be used in systems engineering to highlight areas of potential educational/training gaps in the development of systems engineers. It was observed that teamwork, in particular, is a domain entry level systems engineers can feel generally less competent in. Critical thinking and project management had mixed results of self-efficacy levels between the two cohorts, with one cohort indicating statistically significant increases in competencies and the other cohort, at best, indicating a general sense of improvement (considering the difference in pre- and post-mean scores). Following Bandura's overarching recommendation that "a major goal of formal education should be to equip students with the intellectual tools, self-beliefs, and self-regulatory capabilities to educate themselves throughout their lifetime" (1993, 136) the research team would advise NPS faculty and program developers to focus on teamwork strategies. For instance, teamwork projects could be adjusted to include upper and lower classmen. Research has found that when teams are structured to include both upper and lower classmen, the lower classmen may develop a heightened sense of competency in regards to completing the education because they observe the upper classmen as models. This instills in them a "perseverant self-efficacy" (Ponton et al. 2001, 250).

Given the research findings, the NPS team further recommends survey methods to assess self-efficacy. As stated earlier, survey methods utilizing task specific measures in the form of a survey, might be superior to other approaches, such as ER, to self-efficacy assessment. Similarly, the NPS research team contends that alongside utilizing the COMPOSE model as a career development tool, the *SE Competency Survey* can be used to identify achievement of specific knowledge, skills and abilities as indicators of competency in performing systems engineering tasks.

Research on the identification of professional development KSA has suggested that industry knowledge, alongside EI, should be included as skill areas (Moore and Rudd 2005, 69). Given the fact that the NPS model does not include industry knowledge or EI as competency areas, a recommendation for future research would be to study the impact and feasibility of including the two constructs into the NPS model.

C. AREAS FOR FURTHER RESEARCH

The NPS's research team contends that the top recommendation for an area for further research would be to have an engineering organization validate the *SE Competency Survey* instrument. The NPS research team contends that if possible within time, participant, and resource constraints, the *SE Competency Survey* can be used by other engineering disciplines as a model to implement the self-efficacy based method. It can also be tailored to meet an organization's requirements with minimal effort/changes. In referencing Whitcomb, Khan and White (2013) and White's (2013) research discussed in Chapter III, it should be noted that the KSAs identified in the COMPOSE model have been validated by a couple of notable engineering organizations. As such, the validation of the *SE Competency Survey* would be a natural extension of the self-efficacy research. Doing so would provide necessary insight for those in academia involved in the education, training and development of systems engineers, as well as for those involved in the hiring of systems engineers. To address the concern of Moore and Rudd (2005, 75) cited earlier in the thesis, that students in a study such as this are not likely to perceive themselves to be poor in a competency area they think is very important, another area of research could be to develop a subjective SE exam for students to take upon graduation.

Or, students could be asked to relate the perceived level of importance of a competency alongside how competent they feel in being able to perform it, for a correlation analysis. Similarly, the NPS research team recommends further research to include a correlation analysis between achievement within a particular SE domain and self-efficacy, as research indicates that a "high sense of efficacy in a particular domain may not necessarily translate into having [a] similar level of efficacy in another domain" (Loo and Choy 2013, 86).

Finally, recalling the discussion on "high component loadings" and "domain specific KSAs" the *SE Competency Survey* can be further refined and the new survey sub-portions can be re-written to include KSAs that are representative of domains not currently addressed by the survey. For instance, the *SE Competency Survey* does not address EI skill areas such as time management and balancing personal and professional lives, so perhaps this can be an area for further research. Keeping in mind that "in such difficult budget times, demands on faculty time continue to increase" (Moore and Rudd 2005, 75), including EI competencies may prove beneficial in providing information on professional skills development given the current economic climate.

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