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An Outcome-Based Competency Model for Systems Engineering Trainees

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ABSTRACT

AN OUTCOME-BASED COMPETENCY MODEL FOR SYSTEMS ENGINEERING TRAINEES

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Dominant theories relating to outcome-based learning and workforce competency were synthesized into a singular outcome-based competency model to evaluate systems engineering training. A baseline model was developed using leading theories from the academic literature pertaining to competencies for systems engineers across three categories: cognitive, skill-based, and behavioral. The model was further refined via qualitative and quantitative analysis of formal interviews of subject matter experts in the field of systems engineering workforce management. The refined model classifies 28 critical competencies for systems engineers into three tiers of workforce functionality: foundational, specialized, and leadership. The resultant theoretical model is both grounded in robust theory and is validated by subject matter experts and is suitable to drive practical evaluations of systems engineering training programs.

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CHAPTER 1

INTRODUCTION

1.1 Background of the Problem

What is the measurable value added by systems engineering in professional organizations? Where research has been completed, it paints a bleak picture. According to Buede (2009, p. 43), "there is very little empirical data about the value being added by systems (and software) engineering." Specifically pertaining to the United Kingdom and United States' civil information technology field, what little empirical data that have been compiled suggests that systems and software engineering initiatives experience more failure than success. Even with the implementation of traditional systems engineering practices within the surveyed programs, complete project failure occurred 30-40% of the time (Cook, 2000).

One brief, macro-level qualitative summary paints a more optimistic picture, positing that better/more systems engineering correlates to lower development costs and shorter schedules by 30% and 40% or more, respectively (Honour, 2006). However, the same research explains that the systems engineering field as a whole lacks "specific evidence regarding the right amount of systems engineering to bring about the best results [in large complex engineering systems], as well as the correct timing for the application of system engineering and the identification of those [systems engineering] tools that are most effective" (Honour, 2006, p. 1).

Within an organization, the efforts that guide and control systems engineering are defined by Honour (2004) as "systems engineering management." Where traditional program management is focused on financial and schedule concerns, systems engineering management is focused more heavily on technical analysis and emphasizes technical quality. According to Honour (2004, p. 15), increasing the level and quality of systems engineering management among a technical workforce improves development quality by "… [having] a positive effect on cost compliance, schedule compliance, and subjective quality of the projects." Furthermore, "the data analysis… suggests that there is a strong case to be made for a quantitative relationship between systems engineering investment and the quality of project performance."

There are a small number of studies in the literature which report efficacy of systems engineering management at a case-study level. The literature does not include case studies across a wide range of systems engineering enterprises that help determine the general value and efficacy; it is possible that such studies are being conducted at engineering organizations for internal purposes, though not much can be gained by the greater community without publication of methodology and results. Accordingly, it would be imprudent to make generalizable claims about the measurable value of systems engineering enterprises, other than to state that the literature is presently lacking.

Public and private technology organizations make substantial investments toward systems engineering enterprises, though there is insufficient published research which demonstrates the efficacy of these enterprises. In particular, the investment in systems engineering training is substantial among government and private industry organizations. For example, the United States Department of Defense (DoD) has invested millions of taxpayer dollars in professional systems engineering training since the enactment of the Defense Acquisition Workforce

Improvement Act (DAWIA) in 1991. Are the investments adding measurable value to the organizations or to specific technology programs? It is the prerogative of a private organization to make investments with or without justification. In the case of public organizations, and especially organizations funded entirely with tax-payer dollars, there is a gap in the research regarding the value added by these investments.

When performing an evaluation of a training program, it is imperative that the evaluation model be rooted in robust theory relating to critical competencies which are to be delivered and/or improved upon as a result of the training. Only then can an organization make assertions about how the training affects workforce competencies, and ultimately, workforce performance. Ineffectual or altogether absent training evaluations is a pervasive problem. The Van Buren (2001) American Society for Training and Development Annual State of the Industry Report indicates that reduced training budgets in the previous year were due to the training function’s inability to demonstrate the value of the firm’s investment in training. Phillips & Phillips (2001) suggests that to counter this trend, training organizations must develop and execute comprehensive evaluations of their programs.

Kotnour (2011) supports the notion that meaningful evaluation of a training system begins with the identification of and, subsequently, the continuous measurement of training system critical variables. Only when this has been achieved are organizations free to perform more rigorous training assessments. Kotnour (2011) recommends that “the organization receiving training develop evaluation systems that enable them to understand better the critical variables of their training systems.”

Brinkerhoff (1988) writes about the importance of demonstrable value in training and development programs:

> I believe that all [training and development] programs should be designed to produce beneficial results on an organizational level. A sales training program, for example, should not simply train sales people. It should increase sales volume, open new markets, or have some other positive effect on the company's goals. All [training] programs should share the same logic: trainees go through training in order to learn something that will eventually benefit the organization (p.67).

The American Society for Training and Development (ASTD) defines a training system as a set of coursework designed with the aim of improving workforce performance. Effective training systems improve relevant workforce competencies and promote the realization of organizational goals (Piskurich, 2005). When assessing the efficacy of a professional training program, demonstrable improvement in workforce competency is the final arbiter of value. In order to demonstrate improvement in workforce competency as a result of training, organizations must base their argument upon results of rigorous evaluations of the trained workforce which link outcome-based learning from the training and improved workforce performance.

1.2 Central Research Question

Creswell (2009) suggests that the central question be the broadest question that can be asked of the study so as not to limit the inquiry while maintaining a focus for data collection and analysis from multiple sources of evidence. This research shall be designed and executed to answer the following central research question for a specific context: *What is an appropriate outcome-based* *competency model which may drive a practical evaluation of a systems engineering training program?*

Alias (2005) identifies the biggest mistake common across all research methodologies which contributes to a fundamental reduction in validity and reliability: posing ambiguous research questions. Given that a central question is the crux of the formal research process, posing an ambiguous research question will prompt inescapable instability issues, and it would likely be impossible to demonstrate satisfactory validity and reliability in the subsequent design. The proposed research question has undergone extensive revision under the supervision of a proposal committee and is determined to be sufficiently unambiguous and appropriate for formal inquiry.

1.3 Research Methodology

The purpose of this research is to develop an outcome-based competency model for systems engineering trainees which is appropriate to drive practical evaluations of professional systems engineering training programs. A research methodology suitable for doctoral research consists of six steps: 1) define the research concept; 2) review the literature; 3) define research design & methods; 4) collect data; 5) analyze data; 6) interpret & report results. The research methodology, depicted in Figure 1, is designed to objectively gather information to answer the central research question.

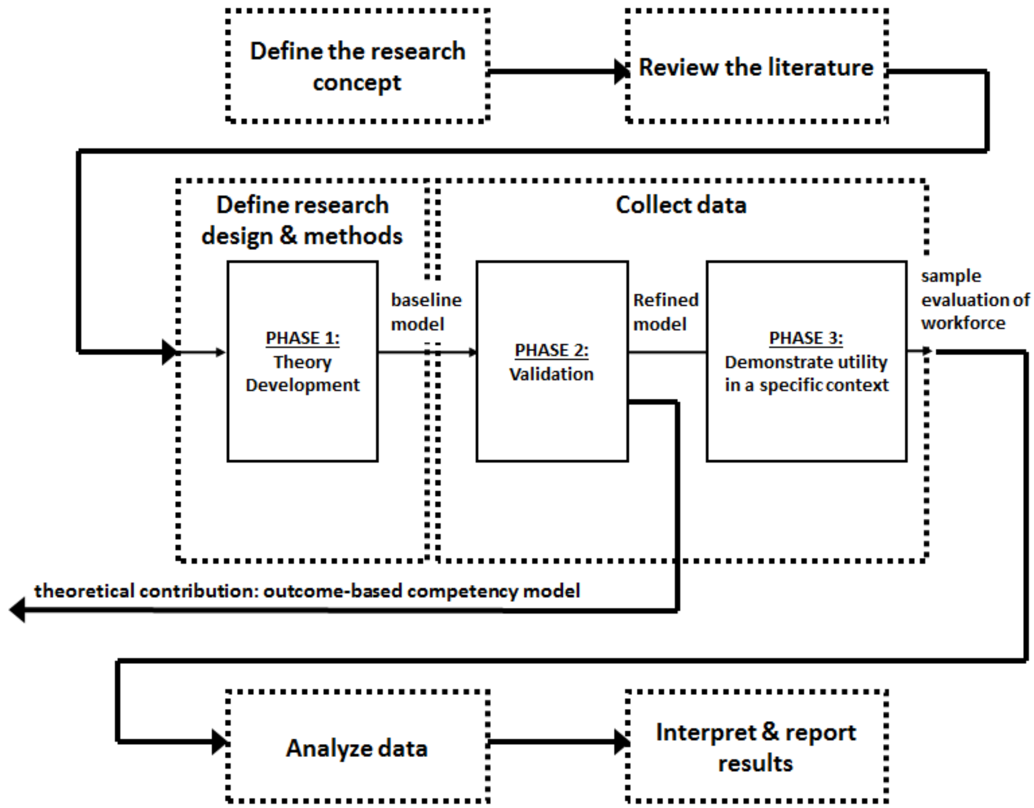

Figure 1. Research methodology.

A sufficient review of the literature, outlined in Chapter 2, has been conducted to provide the researcher a thorough understanding of the current bodies of knowledge relevant to the research concept. This chapter will introduce the research design, methods, data collection, and data analysis strategies. This chapter will also describe the study participants, considerations for data validity and reliability, and ethical considerations for the research project.

1.4 Research Design

The research effort was organized into three specific phases that systematically address the research question. The first two phases contribute to the general body of knowledge a new outcome-based competency model for systems engineers which is both grounded in robust theory relating to learning outcomes and critical competencies, and it was validated by subject matter experts. The final phase demonstrates the utility of the theoretical contribution by documenting the process by which the model was used to perform an evaluation on a sample of a trained workforce.

- Phase 1: Leverage existing theories related to learning outcomes and workforce competency to develop a baseline theoretical model;
- Phase 2: Validate the theoretical model using insight from expert practitioners relative to the field of systems engineering workforce management;
- Phase 3: Demonstrate the feasibility of the theoretical model by performing an evaluation of a trained workforce.

The phenomenon under study is the lack of robust theoretical models appropriate to drive practical evaluations of trained workforces. An empirical enquiry will be developed to investigate the phenomenon within a real-world context and shall rely on multiple sources of evidence (Yin, 2008). This approach is particularly useful where research and theory exist at an early, formative stage and where the experiences of individuals and the context of actions are critical. This approach usually involves a combination of data collection techniques which use qualitative and quantitative data. Data are typically gathered via interviews, observation, questionnaires, and document/text analysis. Variables and measurements may be evolved from existing literature to develop foundational theory and hypotheses regarding the observed phenomenon rather than to test predefined theory or identify causality. The development of a theoretical model for this research is detailed in a later chapter.

Data was drawn from multiple sources and is both qualitative and quantitative in nature. In phase one, a baseline theoretical model was developed which leverages the dominant literature related to learning outcomes and workforce competency. The competencies were evaluated for appropriateness to the research problem and for the purpose of developing an outcome-based competency model for professionals who have participated in systems engineering training. The outcome of phase one was a baseline theoretical model which synthesizes dominant theories from the relevant academic literature. In order to justify that the model is appropriate to drive practical evaluations of a trained workforce, the model must be validated by subject matter experts. Systems engineering workforce managers were identified as appropriate experts to perform the validation via in-depth interviews. After the baseline model was developed in phase one, interview questions were drafted to present to workforce managers in the next phase.

Six systems engineering workforce managers participated in the interviews in phase two. All information exchanged was unclassified and non-proprietary. Managers were selected according to their expertise in managing systems engineers; they are sufficiently knowledgeable about the necessary workforce competencies for success in a systems engineering workplace. Each was confirmed to be an expert based upon their possession of the following criteria:

- He/she has completed professional training in systems engineering.
- He/she participated in formal continuous learning to maintain his/her skills in the area of systems engineering.
- He/she is employed in a supervisory/managerial position of a systems engineering workforce.

- As a supervisor/manager, he/she has completed at least one review cycle of his/her workforce.
- He/she supervises a workforce of employees whom have completed, or are in the process of completing, professional training in systems engineering.

Qualitative data was collected in phase two via workforce interviews either in person or over a telecommunications device (phone, video-conferencing software, etc.). The interviews were driven by non-threatening, open-ended questions; the questions posed to each manager are included in Appendix C. Interview questions guided the interviews through a discussion of workforce competency. According to the guidelines for interview questions offered by Yin (2008), the interviews in phase two included high-level questions for each individual manager. Asking the same high-level questions to each manager allows for the identification of patterns across multiple interviews. The theoretical model was revised according to the information obtained in these interviews.

All qualitative data were analyzed using NVivo, which is equipped to assist the researcher with identifying patterns and relationships from the data collected in phase two. This analysis technique codifies unstructured data from the manager interviews to uncover subtle connections with sufficient rigor. Additionally, pattern identification was depicted in tables or arrays which contain raw data with the aim of refining the baseline theoretical model.

In phase two, the competencies which make up the model were presented to expert practitioners, i.e. systems engineering workforce managers, via in-depth interviews. Six workforce managers were interviewed individually and were permitted to speak freely about the applicability of the model's competencies to a real-world context. Insight from these interviews further refined the model: competencies were altered, deleted, or added according to the manager's input. Additionally, the structure of the baseline model was refined to better organize the competencies. For example, the baseline model organized workforce competencies into three categories according to the assumption that learning is multi-dimensional, i.e. learning affects cognition, skills & knowledge, and behavior. The manager interviews yielded a structure that is more practical when using the model to perform evaluations of a workforce; competencies in the refined model were organized according to workforce functionality. This refined model represents the theoretical contribution of the research endeavor: an outcome-based competency model for systems engineering trainees which is appropriate to drive practical evaluations across multiple contexts, i.e. the model is not tied to any specific training program or organization.

In phase three, the model was used to develop evaluation metrics for a specific context: the systems engineering training mandated by DAWIA. An evaluation was performed via survey on a small sample of the trained workforce and quantitative data was analyzed to measure the impact of the DAWIA training on workforce competency among the participating individuals. Phase three represented a face validation of the refined theoretical model; given the primary contribution of this research endeavor is the theoretical model, the objective of phase three is not rigorous, time-consuming hypothesis testing. The contribution of phase three is specific in nature and represents preliminary data regarding the efficacy of a particular training program. Bowen (1995) states that surveys provide an opportunity to study a large number of groups and strengthen the external validity of the research, assuming the data samples include multiple organizations, settings, etc.

1.5 Scope and Limitations of the Study

The study was designed with three specific components which will fully address the research question.

- Synthesize relevant theories related to learning outcomes and workforce competency to develop a baseline theoretical model for systems engineering training;
- Validate the theoretical model using insight from expert practitioners relative to the field of systems engineering workforce management;
- Demonstrate the feasibility of the theoretical model by using the model to perform an evaluation of a trained workforce.

The validation method by which the refined model was developed presents a limitation to the generality of the model. Insight was collected from six managers who have relatively similar backgrounds, e.g. each have received systems engineering education at U.S. accredited institutions; each have participated in identical professional systems engineering training programs; and each are managers of DoD workforces, though not the same workforce and not workforces in the same DoD agency. This presents a limitation due the nature of their backgrounds and, potentially, their perspectives, which naturally drives their insights provided to the researcher during phase two. Follow-on research may be conducted to mitigate this limitation and reduce the restrictions on the generality of the contribution, for example, additional interviews may be conducted with managers with more diverse educational and professional backgrounds. The findings of the evaluation in phase three is entirely limited to the specific context: the systems engineering training mandated by DAWIA.

CHAPTER 2

LITERATURE REVIEW

This chapter summarizes the theories related to the research project. Following a review of the literature on the subject, the theoretical framework for the research project is presented. The following topics and dominant references are depicted in Figure 2. All topics are relevant to the background, theory development, and research design of the proposed project.

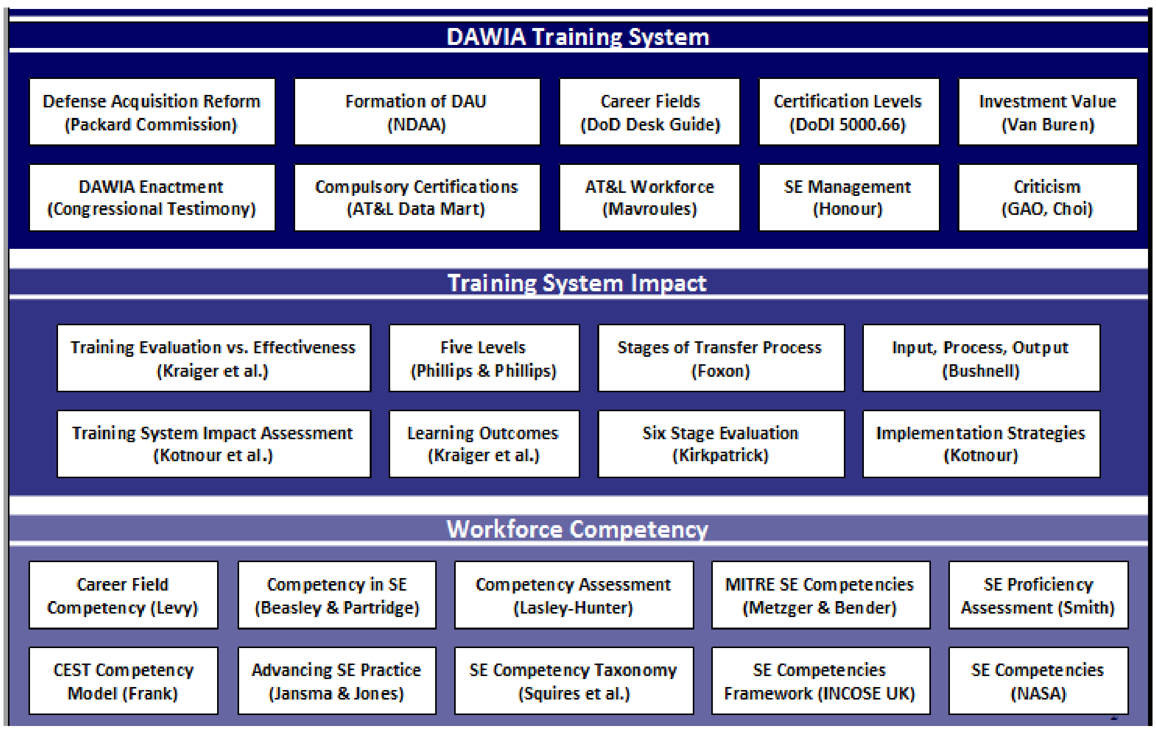

Figure 1. Literature review road map.

A review of the literature was performed according to three main topics of relevance. First, a review of the dominating theories in the field of training system impact and training system evaluation was performed. Theories were examined to ascertain their applicability to the research problem. Second, the prevailing literature on workforce competency, specifically as it pertains to the realm of professional systems engineering, was examined to better understand this domain. Finally, because the competency model developed by this research undertaking was planned to be exercised among a real-world context in phase three, a rigorous review of the development and implementation of the DAWIA and its professional systems engineering certification programs was performed to better understand the state of this particular training system; this information is included in a later chapter.

2.1 Training Evaluation vs. Training Effectiveness

In the literature regarding training system impact are two key terms which deserve distinction. Training evaluation and training effectiveness, sometimes written as training system efficacy, are often used interchangeably in the literature (Ostroff, 1991). However, each term represents very different perspectives and addresses different research questions. Issues of training effectiveness are broader and more mature than issues of training evaluation because they encompass the impact of training on the individual and the organization as a whole. Kraiger et al. (1993) make the distinction:

> Training evaluation refers to a system for measuring whether trainees have achieved learning outcomes. It is concerned with issues of measurement and design, the accomplishment of learning objectives, and the attainment of requisite knowledge and skills. In contrast, training effectiveness models seek to explain why training did or did not achieve its intended outcomes (p. 312).

2.2 Training System Impact Assessment

A training system impact assessment is defined by Kotnour et al. (2013) as a process to help an organization provide traceability from the identification of a training system, through the implementation of the system, and ultimately to defining and measuring the results of the system. Goldstein (1986) describes a similar term, training evaluation, which is defined as the systematic codification of data regarding the success of training programs. Specific to the topic of training evaluation, Kotnour et al. (2013, p. 2) posit "evaluating training [programs] is a process that is not completely understood and that can be suggested as being dynamically complex." However challenging, the need for an organization to conduct a thorough evaluation of any workforce training system they have chosen to implement is critical. These evaluations can be conducted either internally or via an external entity.

The critical motives for a rigorous impact assessment initiative are threefold (Phillips & Phillips, 2001):

1. Allow organization managers and workforce members to adequately and objectively understand the value of a training system.
2. Demonstrate to sponsoring managers the return on investment.
3. Troubleshoot in the event the training system is not producing the expected result.

2.2.3 Models for Training System Impact Assessment

The literature was further reviewed to identify potentially relevant models for training impact assessment and training evaluation. Models were studied which have a conceivable application as a theoretical framework for this research topic. Each model is a practice-based, comprehensive approach to evaluating workforce development programs.

2.2.3.1 Five Levels of Training Evaluation

Phillips & Phillips (2001) published a comprehensive measurement and evaluation process for practical application by executives and managers. The process includes indicators such as total investment in training, number of employee hours spent in training. Additionally, tangible evidence of training efficacy is included; evidence includes successful learning, improved workplace performance, changes in critical business measures, and return on investment (ROI). The Phillips & Phillips process expands upon the Kirkpatrick (1994) four-stage evaluation to include a fifth level, ROI. The addition of ROI converts training benefits to monetary value. However, ROI alone is an imperfect measurement (Hornegren, 1982). To ensure accuracy in calculating ROI, the Phillips model takes steps to isolate the effects of the training program and accounts for other factors that may influence the evaluation data. Table 1 lists the five levels of evaluation from Phillips & Phillips (2001).

Table 1. Five levels of training evaluation (Phillips & Phillips, 2001).

Level	Description
1. Reaction and satisfaction	Measures participant reaction to the training program and stakeholder satisfaction of the training program
2. Learning	Measures skills, knowledge, or attitude changes among participants which are related to the training program
3. Application and implementation	Measures changes in behavior in the workplace and the specific application and implementation of the training program
4. Business impact	Measures business impact changes related to the training program
5. Return on investment	Compares the monetary value of the business impact with the costs for the training program

2.2.3.2 Learning Outcomes Model

Training evaluation and impact assessment can only be constructive when outcome metrics are defined, measurable, and are conceptually linked to training program learning objectives. In an organization, constructive evaluation will identify transfer issues and demonstrate whether the training program enhanced organizational performance among those who participated in the training as it was intended. Kraiger et al. (1993) establish a classification scheme for evaluating training programs using cognitive, skill-based, and affective learning outcomes relevant to training. This classification scheme serves as a starting point for the development of a true training evaluation model. The model assumes that learning outcomes are multidimensional, i.e. evidentiary support of learning is measured by changes in cognitive, affective, and skill capacities. Figure 3 shows an overview of the three categories of learning outcome and the learning constructs most relevant for each category.

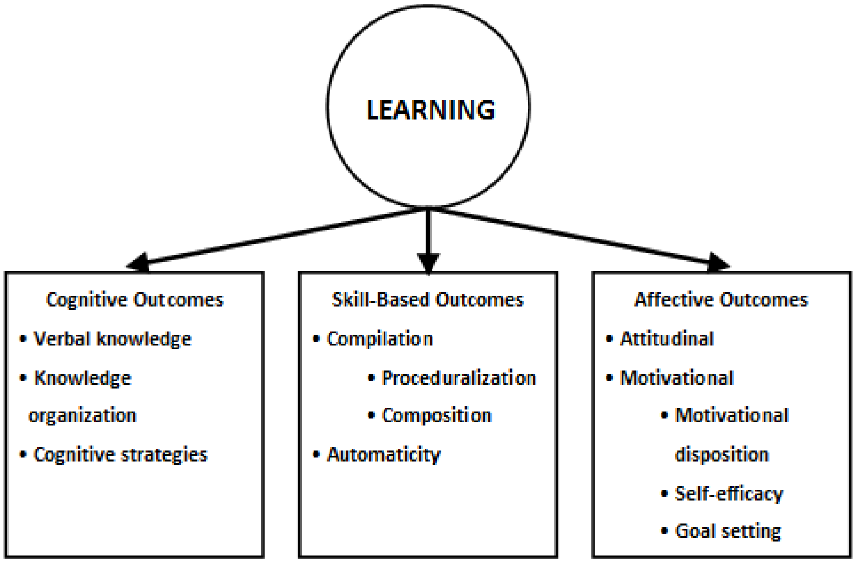

Figure 2. Learning outcomes model (Kraiger et al., 1993).

The Learning Outcomes model divides learning outcomes into three unique categories: cognitive outcomes, skill-based outcomes, and affective outcomes. With respect to evaluation, cognitive outcomes relate not only to the quantity and type of trainee knowledge but also the dynamic processes of knowledge acquisition, organization, and application (Kraiger et al., 1993). The second category, skill-based learning outcomes, concerns the development of technical or motor skills which, when developed in a trainee, include goal orientation and organization of job behaviors in a sequential and hierarchal manner (Weiss, 1990). The third and final category, affective learning outcomes, has been traditionally ignored as an indicator of learning by Kirkpatrick (1976, 1987) and other scholars in the training field. Kraiger et al. (1993) reason that attitudes and motivation are internal states that can affect behavior and on-the-job performance.

Among the three categories in the Learning Outcomes model are several subcategories depicted in Figure 3. Cognitive outcomes can be sorted into subcategories according to their characteristics: verbal knowledge, knowledge organization, and cognitive strategies.
Principally, *verbal knowledge* is task-relevant and verbally based which is a necessary component of higher order skill development. Such encoded knowledge exists in various forms. One form in particular, declarative knowledge (information about what) must first be acquired to allow the progression to higher order development.

Beyond the initial phase of declarative knowledge acquisition is the focus on procedural knowledge which, ultimately, creates a need for the development of meaningful structures for *knowledge organization*. The literature often describes numerous mechanisms for knowledge organization within an individual, including mental models, knowledge structures, cognitive maps, or task schemata. Many scholars emphasize that the importance of coherent knowledge organization is as at least equal to, and potentially greater than, the actual amount of knowledge being acquired (Rouse & Morris, 1986).

At the highest levels of knowledge acquisition, elegant *cognitive strategies* emerge to more rapidly and fluidly access and apply knowledge. The greater the knowledge internalization, the more cognitive resources become available for executive skills and strategy development. Evidence of high-order cognitive strategies has a place in a comprehensive training evaluation.

Skill-based outcomes from a training program occur beyond the initial phases of knowledge acquisition, though concurrently with procedural knowledge, and continue to mature with sustained practice of trained behaviors. At this stage, learning is translated into adaptive skills and individuals begin to become aware of the appropriate situations for the new skills. Skill-based outcomes are divided among two subcategories: compilation and automaticity.

Compilation describes a stage in which individuals' performance becomes more rapid and fluid. Knowledge is sufficiently assimilated and adaptive skills are exercised to the point that performance is enhanced and task-focused behaviors become routine. Production may become more complex as domain-specific routines are optimized and linked. At this stage, old knowledge and behaviors may begin to be modified to new task settings.

Sustained behavioral modification and optimization in the compilation phase evolves into individualized, and even more fluid, performance. This sophisticated, automatized performance is characterized by Kraiger et al. (1993) as *automaticity*. When behaviors and performance becomes automatic, cognitive resources are more readily available to cope with ancillary demands. Cognitive focus may lead to improved accuracy or skill "tuning."

Affectively based measures are disregarded in such prolific works as Kirkpatrick (1976, 1987, 2006) and others in the field of training effectiveness. Gagne (1984) posits that an absence of affective measurement provides an incomplete profile of the learning process; thus, it yields a curtailed training evaluation strategy. Kraiger et al. (1993) include affective outcomes in the Learning Outcomes model which are divided among two subcategories: attitudinal and motivational.

Attitudinal devices in a training program are often engineered into the curriculum for their recruitment, socialization, and indoctrination potential. Trainees may be expected to experience creative individualism, organizational commitment, inner growth, self-awareness, and most importantly, alignment of individual values to those of the organization. Attitude and value adjustment has the power to change behavior, performance, and allegiance.

Much like attitude, expectations regarding *motivational* changes may be engineered into a training program curriculum, although it is commonly a secondary outcome. Motivational disposition can propel task performance, and vice versa. As part of a training evaluation strategy, motivational measures may be a useful indicator or knowledge transfer and skill development.

Within each learning outcome category, and for each relevant learning construct, appropriate measurement techniques were summarized in a comprehensive classification scheme, shown in Table 2. Kraiger's research contributes a nomological and systematic framework which is appropriate for future research in training evaluation and training effectiveness. Moreover, the very intent of the classification scheme is to serve as a starting point for the development of a true training evaluation model. The Learning Outcomes model is a versatile theoretical framework for scholarly research. According to Kraiger et al. (1993, p. 325), "the ultimate criterion for such work is whether it spurs additional research in training that advances our understanding of training evaluation and training effectiveness."

Table 2. Learning outcomes classification scheme (Kraiger et al., 1993).

Category	Subcategory	Learning Construct(s)	Measurement Focus	Potential Training Evaluation Methods
Cognitive	Verbal knowledge	Declarative knowledge	Amount of knowledge Accuracy of recall Speed, accessibility of knowledge	Recognition & recall tests Power tests Speed tests
	Knowledge organization	Mental models	Similarity to ideal Interrelationships of elements Hierarchical ordering	Free sorts Structural assessments
	Cognitive strategies	Self-insight Metacognitive skills	Self awareness Self regulation	Probed protocol analysis Self-report Readiness for testing
Skill-based	Compilation	Composition Proceduralization	Speed of performance Fluidity of performance Error rates Chunking Generalization Discrimination Strengthening	Targeted behavioral observation Hands-on testing Structured situational interviews
	Automaticity	Automatic processing Tuning	Attentional requirements Available cognitive resources	Secondary task performance Interference problems Embedded measurement
Affective	Attitudinal	Targeted object Attitude strength	Attitude direction Attitude strength: accessibility, centrality, conviction	Self-report measures
	Motivation	Motivational disposition Self-efficacy Goal setting	Mastery vs. performance orientations Appropriateness of orientation Perceived performance capability Level of goals Complexity of goal structures Goal commitment	Self-report measures Free recall measures Free sorts

2.2.3.3 Stages of Transfer Process Model

Historically, training evaluation researchers and practitioners have attempted to measure training transfer, e.g. the use of learned skills, at a single snapshot in time. This perspective categorizes transfer as a product to be measured *ex post facto*. Foxon (1994) contributes the Stages of

Transfer model, described by Figure 4, which recognizes transfer as an ongoing process over five phases.

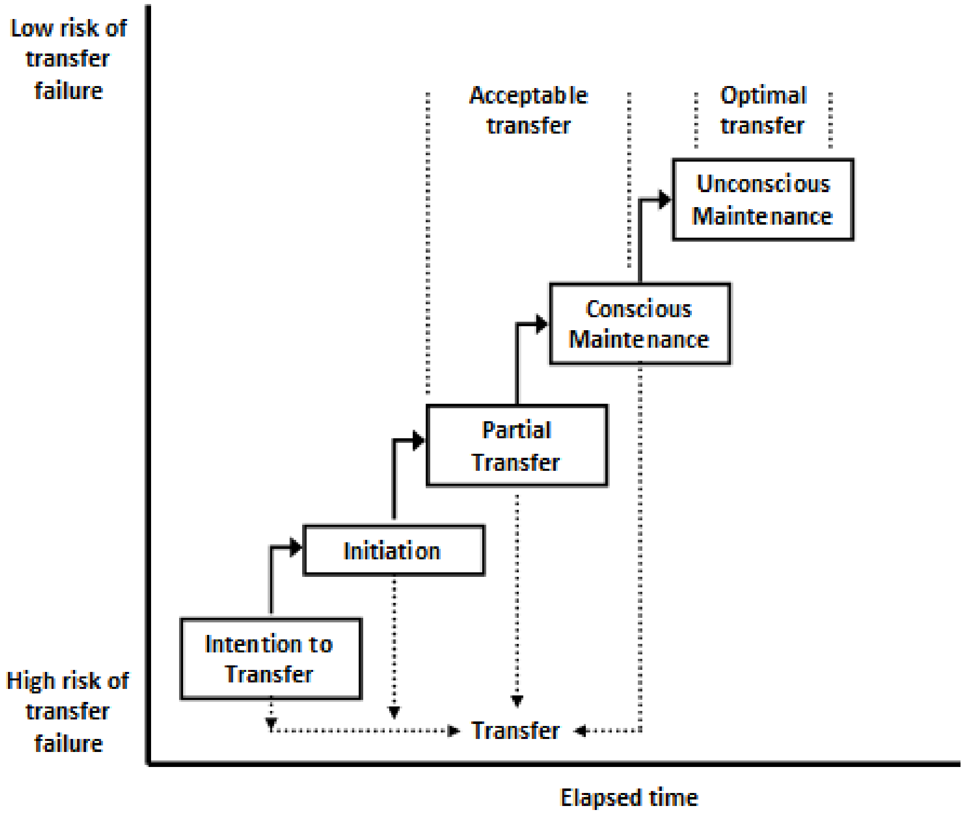

Figure 3. Stages in the transfer process (Foxon, 1994).

Huczynski & Lewis (1980) established that a high level of transfer intention will likely result in greater use of the training in the workplace. Optimal transfer is encouraged by perceived level of supervisor support for use of skills in the workplace. Foxon describes specific actions in each of the five stages which may be implemented in an organization as part of a comprehensive transfer strategy. Kraiger et al. (1993, p. 312) explain that “training effectiveness models seek to explain why training did or did not achieve its intended outcomes.” The model and subsequent implementation strategy put forth by Foxon is apposite as a training effectiveness research endeavor when much is already known about the training program's transfer issues. Furthermore, the strategies should be incorporated into the training program curricula to promote an even more favorable climate for transfer of skills.

2.2.3.4 Input, Process, Output Model

Bushnell (1990) describes training systems as having an input, a process, and an output. In order to maximize effectiveness of the training system, evaluations should occur at seven points. The input, process, and output (IPO) stages and the seven evaluation occurrences (E1 through E7) are shown in Figure 5.

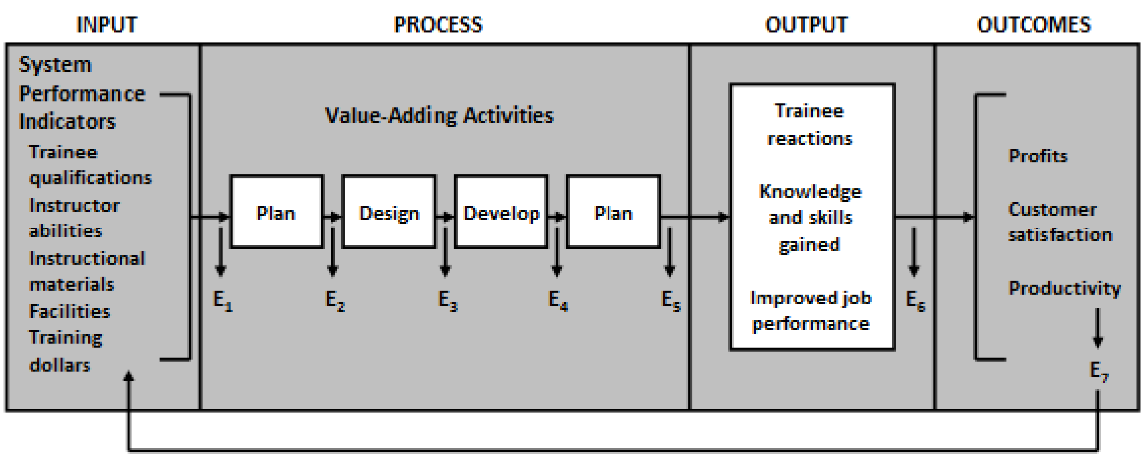

Figure 4. Input, process, output training evaluation model (Bushnell, 1990).

The input stage examines numerous system performance indicators (SPIs) to predict their contribution to the overall effectiveness of the training *a priori*. SPIs are separated into categories which include trainee qualification, instructor experience, training budget, etc. The process stage directs the training curriculum delivery according to predetermined instructional objectives, instructional strategies, and training materials. Five evaluations take place at different periods during the execution of the process stage. At the output stage, evaluators systematize information pertaining to the short-term impacts of the training on the participating students: their reaction, any skills or knowledge gained, and any improvement in on-the-job performance. A final evaluation is made to assemble information on any long-term outcomes associated with workforce participation in the training: improvement in the organization's profitability and competitiveness, for example. Research which applies the IPO model must have intimate access to the training curricula and training execution. Evaluations are made in-the-loop and the training system design is subject to corrective adjustment based on the evaluator's findings and suggestions.

2.2.3.5 Six Stage Evaluation Model

Dissatisfied with the prolific but nonetheless inadequate Kirkpatrick (1976) four level model, Brinkerhoff (1988) proposed a six stage evaluation model for Human Resource Development (HRD). Rather than focusing entirely on the outcome of a training program, the six stage model evaluates HRD programs as they occur and encourages program designers to revise or abort poorly conceived or poorly executed components. Each of the six stages, listed in Table 3, is accompanied in the literature by key evaluation questions and useful data collection procedures.

Table 3. Six stage model for evaluating HRD (adapted from Brinkerhoff, 1988).

Evaluation Stage	Governing Question
1. Goal Setting	What is the need?
2. Program Design	What will work?
3. Program Implementation	Is it working?
4. Immediate Outcomes	Did the trainees learn it?
5. Intermediate or Usage Outcomes	Are the trainees keeping it and/or using it?
6. Impacts and Worth	Did it make a worthwhile difference?

The model is based on traditional HRD logic—that training should not be delivered simply for training's sake but for the purpose of producing beneficial results at an organizational level—and emphasizes in-the-loop evaluation to facilitate decision making. Evaluation strategies vary according to the stage at which they are implemented.

2.2.4 Training System Impact Assessment Case Study

Kotnour et al. (2013) provide an exhaustive review of existing training impact assessment models and proposes a six-step process to perform balanced impact assessments from a stakeholder perspective. The six step process as defined by Kotnour (2009) is Programme-management Understanding, Measurement, and Assessment (PUMA). The PUMA process hinges on the clear definition and utilization of performance measurement-based objectives. These are derived from training objectives set by instructors or training curricula designers, as well as performance objectives set forth by organizational managers. This process was demonstrated using a case study approach at the Office of Naval Research (ONR) Next Generation Expeditionary Warfare Intelligent Training (NEW-IT) project. Table 4 outlines the PUMA process.

Table 4. PUMA process (adapted from Kotnour, 2009).

1. Develop a common understanding of measurement concepts and language.
2. Understand environment.
3. Understand stakeholders.
4. Convert stakeholder desired outcomes into measurement dimensions.
5. Convert conceptual measurement dimensions into specific measures.
6. Develop specific measure data collection & analysis tools.

The NEW-IT workshop was comprised of academia, industry, and government members. Many of these members were not co-located and each was responsible for performing different functions, including basic research, prototype testing, and program management. NEW-IT has built within itself impact assessment and has included this key feature since the project's inception. Outcome data have been collected throughout its lifecycle and reports a 25% improvement in observed training efficiency and a 71% improvement in training efficacy. The PUMA process was applied to improve upon the existing training impact assessment measures. An important gap in the knowledge was identified in Kotnour (2011) which brings attention to the need for continuous measurement of critical variables associated with a training system. Training system impact assessment requires not merely pre- and post-tests, but intermittent evaluations using descriptive statistics to track the changes of critical variables throughout the system's life-cycle (Hite, 1999).

2.3 Workforce Competency

With the growing popularity of the human capital field of study, more organizations are defining standardized metrics for workforce proficiency to better assess the economic value of proficiency improvement efforts. Proficiency is defined as the advancement in knowledge or skill (Merriam-Webster, 2014). The Office of Personnel Management (OPM) provides a more detailed description: "an observable, measurable pattern of skills, knowledge, abilities, behaviors and other characteristics that an individual needs to perform work roles or occupational functions successfully" (Lasley-Hunter, 2011, p. 8). At the individual level, proficiency is demonstrated when the individual's knowledge or skills advance. This concept can also be applied at the workforce level where the knowledge and skills of many individuals is advanced for improved workforce functionality. The definition of workforce functionality will vary among organizations.

Levy (2011) asserts that in order for an organization to fully benefit from a workforce proficiency assessment, that organization must first implement job-specific competency models. A competency model is defined as a set of competencies, e.g. behaviors, skills, that promote successful performance in a specific work setting (Levy, 2011). From these models, the current level of workforce proficiency can be fully understood. Such an effort would yield substantial dividends because not only does it provide rich insight into the knowledge and skill deficiencies of an organization's workforce, it also yields actionable data that can be used for strategic workforce analysis and planning.

2.3.1 Career Field Competency

Most organizations define career field competencies generally. Workforce managers often use generic ratings to assess generic proficiency; these ratings are typically based on subjective judgments of supervisors and are not supported by relevant and up-to-date observable criteria. This generic approach, according to Levy (2011, p. 2), "does not provide the specificity necessary to accurately assess [workforce] competencies at different organizational levels." A more effective and career field-specific approach must be taken to define workforce competencies before an improvement mechanism, e.g. a certification training, can be applied. Only then can the impact of training expenditures be measured by quantifying to the degree to which previous competency levels have advanced following training. Further, Levy (2011) asserts that competency advancement can be used to calculate the return on investment (ROI) from training expenditures.

2.3.2 Systems Engineering Competency

An extensive review of the literature was conducted to identify the critical characteristics of successful systems engineering practitioners and the process by which these characteristics are acquired. An individual's competency in the field of systems engineering is wholly built upon his or her capacity for *systems thinking* (Beasley & Partridge, 2011). Senge (1994) defines systems thinking as a discipline wherein a systems engineering practitioner has the ability to "see wholes." Frank (2000, p. 273) coins a more specific adaptation, *engineering systems thinking*, as a "high-order thinking skill that enables individuals to successfully perform systems engineering tasks." Systems engineering practitioners must possess a high Capacity for Systems Engineering Thinking (CEST) to be proficient in the workplace (Frank, 2012). CEST is most often a consistent personality trait among individuals, although it is possible for CEST to be developed and improved via well designed and taught training courses (Davidz & Nightingale 2008; Kasser, 2011). Furthermore, CEST within an individual or among individuals comprising a workforce can be assessed (Frank, 2010).

2.3.3 CEST Competency Model

The Capacity for Systems Engineering Thinking (CEST) Competency Model (Frank, 2012) is a model by which each element of systems thinking can be assessed separately. This model is uniquely useful in research designs which use surveys as a data collection tool, as survey questions can be constructed according to a specific competency element and thus mapped clearly. The model was derived from a theoretical framework constituted by General Systems Theory wherein field research was conducted via interviews, lectures, and observation sites to compile 83 systems engineering competency categories (Frank, 2000). The model has matured over nearly two decades and a total of 35 CEST elements relating to systems thinking remain, and are divided into categories: 16 cognitive competencies, nine skills/abilities, seven behavioral competencies, and three relating to knowledge and experience. Table 5 lists the 16 cognitive competencies and provides a description of the associated characteristics of an individual possessing the competency. The nine skills/abilities are all related to the 16 cognitive competencies of successful systems engineers; these are listed in Table 6. The seven behavioral competencies of systems engineers according to the CEST Competency Model are listed in Table 7. The three competencies relating to knowledge and experience for successful systems engineers according to the CEST Competency Model are listed in Table 8.

Table 5. CEST cognitive competencies (Frank, 2012).

Competency	Associated Characteristics
1. Understand the whole system and see the big picture	Multi-faceted understanding of the system beyond its elements, sub-systems, assemblies, and components; possess a generalist's perspective.
2. Understand interconnections	Consider the interconnections, interdependencies, and the mutual interrelations among system elements.
3. Understand system synergy (emergent properties)	Able to identify the synergy and emergent properties of combined subsystems within a higher-order system.
4. Understand the system from multiple perspectives	Avoid adopting a unidimensional view; able to describe the system from all relevant perspectives.
5. Think creatively	Capable of creative-lateral-divergent-heuristic thinking as well as logic-convergent-algorithmic-analytical thinking; can transform a creative concept into a realizable idea.
6. Understand systems without getting stuck on details	Tolerance for ambiguity and uncertainty; can functionally understand the system and solve systems problems without necessarily understanding all the system's minutiae.
7. Understand the implications of proposed change	Can anticipate and manage the impact of proposed changes to a system.
8. Understand a new system and/or concept immediately upon presentation	Quickly comprehends information about the operation, purpose, applications, advantages, and limitations of a new system or concept.
9. Understand analogies and parallelism between systems	Interdisciplinary understanding; make inferences and apply conclusions between different disciplines.
10. Understand limits to growth	Able to identify and accept limitations to performance improvement.
11. Ask the right questions	Strategic and constructive questioning of information as a managerial tool and a tool for improving understanding of the system or problem.
12. Are innovators, originators, promoters, initiators, curious	Curious and open-minded; have broad interests beyond the limits of their expertise; accepting of the unknown; searching for emergent opportunities.
13. Are able to define boundaries	Identify proper boundaries and delegate appropriately.
14. Are able to take into consideration non-engineering factors	Consider ecological/environmental, marketing, political, organizational, economical, and personal issues when preparing proposals or design solutions.
15. Are able to "see" the future	Forecasting; sense of vision and imagination beyond the immediate domain for planning purposes.
16. Are able to optimize	Consider optimization in three dimensions: engineering, cost and schedule, and operational.

Table 6. CEST skills/abilities (Frank, 2010).

1.	Analyze and develop the needs and mission statement, and the goals and objectives of the system.
2.	Understand the operational environment and develop the concept of operation (CONOPS).
3.	Perform requirements analysis: capturing requirements, defining requirements, formulating requirements, avoiding sub-optimization, generating System Requirements Documents (SRD), translating the CONOPS and the requirements into technical terms and preparing systems specifications, validating the requirements, tracing the requirements, ensuring that all needs, goals and external interfaces (context diagram) are covered by the requirements, and allocating the system requirements into lower levels.
4.	Conceptualize the solution.
5.	Generate the logical solution – functional analysis.
6.	Generate the physical solution – architecture synthesis.
7.	Use simulations and systems engineering tools.
8.	Manage systems processes including interface management, configuration management, risk management, knowledge/data management, resource management, integration, testing, verification and validation.
9.	Conduct trade studies, provide several options and rate them according to their cost-effectiveness.

Table 7. CEST behavioral competencies (Frank, 2010).

1.	Be a team leader.
2.	Perform technical management: build, control, and monitor the project.
3.	Possess ancillary management skills, e.g. negotiation, conflict resolution.
4.	Possess effective communication, collaboration, and interpersonal skills among team and stakeholders.
5.	Be capable of autonomous and independent self-learning.
6.	Possess a strong desire/will to deal with systems projects.
7.	Possess a tolerance for failure.

Table 8. CEST competencies related to knowledge and experience (Frank, 2010).

1.	Expert in at least one science or engineering core discipline.
2.	Possess ancillary interdisciplinary or multidisciplinary knowledge.
3.	Experience of several years working as a systems engineer on several systems projects.

2.3.4 Other Systems Engineering Competency Models

The literature is rich with systems engineering-specific competency models which can be used to measure and assess competency of an individual or a systems engineering workforce. Listed is a variety of competency models from the literature review:

- INCOSE UK SE Competencies Framework (INCOSE UK, 2010).
- MITRE Systems Engineering Competency Model (Metzger & Bender, 2007).
- Advancing the Practice of Systems Engineering at JPL (Jansma & Jones, 2006).
- NASA Systems Engineering Competencies (NASA, 2009).
- Systems Engineering Competency Taxonomy (Squires et al., 2011).

2.4 DAWIA Training System

Per the terms of DAWIA legislation, the DAU is responsible for developing and delivering a training system for the defense AT&L workforce. The DAU established a training system which mandates classroom instruction toward the completion of career field certifications.

2.4.1 Participation

DAU has categorized the training system participants within the defense AT&L workforce into career fields based on occupational specialties which are enumerated in Table 9. As specified by the DAWIA implementation policy (DoD Desk Guide, 2006), workforce members, including managers, across all career fields are required by law to participate in DAWIA training to earn and maintain career field certification. Training and certification requirements are tailored according to these career field designations. Four of the career fields identified in Table 9, program management and three subfields of Systems Planning, Research, Development, and Engineering (SPRDE), correspond with the Congressional instruction that DAWIA pay special attention to acquisition employees which fulfill program management and systems engineering functions (Congressional Testimony, 1997).

Defense acquisition workforce and training data are gathered and maintained in the AT&L Data Mart. These data are analyzed for a variety of purposes and are used by DAU to determine training system participation, course demand, and certification status of participating acquisition workforce members. The GAO has independently assessed the reliability of these data by reviewing data query information and collection techniques and determined that the data were sufficiently reliable (GAO, 2010a). Table 10 shows the total number of acquisition workforce members in each of the 15 career fields as of 2013 (AT&L Workforce Data Mart, 2013) whose participation in the DAWIA training system is mandatory. The FY2008 NDAA No. 110-181 §852 established the Defense Acquisition Workforce Development Fund to provide additional funds for use by the DAU for recruitment, training, and retention of DoD acquisition personnel

(NDAA, 2008). According to DAU data, it was reported that 90% of acquisition personnel receive required training within required time frames using current funding levels (GAO, 2010b).

Table 9. DAU career fields (DoD Desk Guide, 2006).

Acquisition Career Fields
(1) Program management
(2) Contracting
(3) Industrial/contract property management
(4) Purchasing
(5) Facilities engineering
(6) Production, quality, and manufacturing
(7) Business—cost estimating
(8) Business—financial management
(9) Lifecycle logistics
(10) Information technology
(11) Systems planning, research, development, and engineering—systems engineering
(12) Systems planning, research, development, and engineering—program systems engineer
(13) Systems planning, research, development, and engineering—science and technology manager
(14) Test and evaluation
(15) Auditing

As of 2013, the SPRDE-SE career path is comprised of 39,176 individuals (AT&L Workforce Data Mart, 2013). This research will focus only on the portion of the defense AT&L workforce which has undergone certifications in SPRDE-SE; because the greatest number of workforce personnel is represented by the SPRDE-SE career path, it is expected that case study participation and data collection efforts will be more attainable as compared to the other career paths.

Table 10. AT&L membership in 2013 (AT&L Workforce Data Mart, 2013).

Career Field	Army	Navy/ Marine Corp	Air Force	Defense Agencies	Total
Auditing	0	0	0	4,424	**4,424**
Business—cost estimating & financial management	2,399	2,438	2,266	86	**1,305**
Contracting	8,618	5,686	8,429	7,529	**30,262**
Facilities engineering	1,674	5,363	4	31	**7,072**
Industrial/contract property management	55	61	20	271	**407**
Information technology	2,270	2,086	1,146	448	**5,950**
Lifecycle logistics	8,326	5,568	2,848	599	**17,341**
Production, quality, & manufacturing	1,658	2,486	355	5,176	**9,675**
Program management	3,409	5,931	5,493	1,387	**16,220**
Purchasing	368	518	97	318	**1,301**
Science & technology manager	258	428	2,527	123	**3,336**
SPRDE—systems engineering	9,486	19,426	8,339	1,925	**39,176**
SPRDE—program systems engineer	55	62	287	59	**463**
Test & evaluation	2,098	3,107	3,076	395	**8,676**
Unspecified	12	22	22	14	**70**
Total	**40,686**	**53,182**	**34,909**	**23,415**	**152,192**

2.4.2 Certifications

Certification is defined as an operational designation which provides confirmation of a workforce member's competency in a specified profession or occupational specialty, and it is a formal process issued by a professional organization (INCOSE, 2014). INCOSE specifies that certifications may be part of the hiring and promotion process, though are not mandatory. In the DAWIA training system, these certifications are mandatory for specific career fields. The certifications are a tool for discriminating professional competence and are a requirement for filling key acquisition positions. Certification curricula for each occupational specialty are identified in §1746 (NDAA, 1991).

2.4.2.1 Certification Levels

Within the DAWIA training system, three certification levels are assigned to each AT&L career field: Basic (Level 1), Intermediate (Level 2), and Advanced (Level III). At the Basic level, certification participants must attend required education and training courses and develop required career field competencies through on-the-job experience, which often include rotational assignments. The Intermediate level includes additional training courses which emphasize functional specialization; additionally, the participant will engage in career broadening experiences which will prepare him/her for positions of greater responsibility in his/her career field. The Advanced level is designed to equip the participant with appropriate skills and competencies to fill Critical Acquisition Positions (CAPs) which comprise the pool to fill Key Leadership Positions (KLPs) (DoDI 5000.66, 2005). Table 11 specifies required certification levels for civilian and military AT&L workforce individuals.

Table 11. AT&L workforce certification level (DoD Desk Guide, 2006).

DAU Certification Level	Civilian AT&L Workforce		Military AT&L Workforce	
	All except Purchasing	Purchasing	Officer	Enlisted
Level I	GS-5 to GS-8	GS-5	O-1 to O-2	Per component direction
Level II	GS-9 to GS-12	GS-6 to GS-8	O-3 to O-4	
Level III	GS-13 & above	GS-9	O-5 & above	

2.4.3 Applying a Competency Model for Workforce Assessment

In the years since its implementation, the DAWIA training system has not been adequately demonstrated to have improved the participating acquisition workforce members (Choi, 2009; GAO, 2009a; GAO, 2010b). Ambiguity regarding the term "improvement" may be the critical issue. At issue are how training systems positively impact the participating workforce and how this improvement is demonstrated or measured with appropriate metrics. This is a gap specific to this particular context: no adequate evaluation has been conducted and reported to the GAO to demonstrate that DAWIA career field certifications have a measurable improvement on the participating workforce.

The literature indicates two DoD-funded studies which utilize competency models to perform workforce competency assessments. These were performed to assess the competency of workforce members in the systems engineering career field.

2.4.3.1 Lasley-Hunter Study

In 2011, the Director of Human Capital Initiatives (HCI) for the DoD acquisition workforce supported a study to develop competency models and perform competency assessments of defense AT&L workforce members in each of the major DAWIA career fields. Lasley-Hunter (2011) developed and validated a model of performance consisting of critical competencies for systems engineers. The model was used to perform a competency assessment of 10,000 SPRDE workforce members and to ultimately report proficiency ratings on each competency element in the model. The model separates competency metrics into three categories: analytical, technical, and professional. The competencies under each category are listed in Table 12.

The report included proficiency ratings for each participating organization which provides a snapshot of the proficiency of the SPRDE workforce based on the SPRDE competency model. The report also included a recommendation to the HCI AT&L leadership ((Lasley-Hunter, 2011, p. 6): “Given that no proficiency standards currently exist, we strongly encourage the leadership to set proficiency standards based on this baseline for future investments in [workforce proficiency] gap closure strategies.” Though the assessment was submitted to the DoD in August 2011, the literature review does not indicate follow-on reports as a result of their findings or recommendations.

Table 1. SPRDE competencies (Lasley-Hunter, 2011).

Competencies in the Analytical Unit of Competence	Competencies in the Technical Management Unit of Competence	Competencies in the Professional Unit of Competence
1. Technical basis for cost	14. Decision analysis	26. Communications
2. Modeling and simulation	15. Technical planning	27. Problem solving
3. Safety assurance	16. Technical assessment	28. Strategic thinking
4. Stakeholder requirements definition (requirements development)	17. Configuration management	29. Professional ethics
5. Requirements analysis (logical analysis)	18. Requirements management	
6. Architectural design (design solution)	19. Risk management	
7. Implementation	20. Technical data management	
8. Integration	21. Interface management	
9. Verification	22. Software engineering	
10. Validation	23. Acquisition	
11. Transition	24. System engineering leadership	
12. System assurance	25. System of systems	
13. Reliability, availability, and maintainability (RAM)		

2.4.3.2 Smith Study

Barbara Smith, Dean of the Defense Acquisition University (DAU) Mid-Atlantic Region, proposed a pilot program to develop acquisition workforce proficiency metrics (Smith, 2012). The pilot program is proposed for study at a variety of defense acquisition organizations across three DAWIA career fields: SPRDE, life-cycle logistics, and contracting. Specifically for the

SPRDE workforce, one proficiency metric was identified with associated on-the-job tasks; these are shown in Table 13.

Table 2. SPRDE proficiency metrics proposed by DAU (Smith, 2012).

Proficiency	Tasks
Configuration Management	• Describe the purpose, inputs, and outputs of the configuration management process • Explain the configuration management baselines by when they are established and why they are important • Summarize the activities of a configuration control board • Summarize the technical support for developing acquisition program baselines

Smith (2012) went on to propose that rubrics be created by regional DAU faculty which includes scoring criteria for the assessment of each workforce member's performance. The desired outcomes from the pilot program include a comprehensive set of proficiency metrics for each of the three career fields, as well as useful rubrics for assessing workforce performance. Naval Air Systems Command (NAVAIR) was identified as a candidate organization for the SPRDE pilot program. However, to date, the pilot program has not progressed beyond the proposal phase.

2.5 Gap Analysis

Two principle topics were examined in this literature: training system evaluation theory and workforce competency. Each was scrutinized according to their relevance to the research problem and to ultimately identify a gap which the research project will attempt to fill. A gap was identified during the review of the literature: an adequate outcome-based competency model does not exist which is suitable for driving practical evaluations of professional systems engineering trainees. This research contribution resolves this gap by developing an outcome-based competency model which is appropriate to drive a practical evaluation of a systems engineering training program.

CHAPTER 3

THEORY DEVELOPMENT

This chapter describes the theory development which is drawn from the information and concepts in the literature review. The theory developed serves as a foundation for practical research.

3.1 Relevant Theoretical Models

The literature review for this proposal mentions the prolific Kirkpatrick (2006) model for evaluating training programs. Indeed, most models in this particular field of study utilize Kirkpatrick's four levels as a theoretical framework and often build upon the levels for other applications. Kirkpatrick's levels provide adequate pedigree which allows modern scholars in the field of training program evaluation to tailor their models for specific purposes. Researchers may survey the models in the literature and select one which most closely fits their endeavor. Numerous authors have pointed out a number of conceptual flaws in the Kirkpatrick model (Alliger & Janak, 1989; Clement, 1982; Snyder, Raben, & Farr, 1980). Most notable, according to this research topic, is that the model does not sufficiently define how learning outcomes should be assessed during a training evaluation.

In order to perform a rigorous and meaningful review of a training system, evaluators must first develop comprehensive outcome-based metrics. This echoes a fundamental issue of evaluation posed in the literature by Campbell (1988) of whether trainees have learned the material covered in training and, furthermore, whether it has ultimately improved their on-the-job productivity within an organization. Kraiger et al. (1993) assert that outcome-based metrics must be defined, measurable, and conceptually linked to training program learning objectives in order to perform constructive training evaluation and impact assessment.

In their Learning Outcomes Model, Kraiger et al. (1993) propose cognitive, skill-based, and affective learning outcomes relevant to training for the development of evaluation measures, which are collated into a classification scheme. The objective of this classification scheme is to serve as a starting point for the development of a true training evaluation model. The Learning Outcomes model is a versatile theoretical framework. Learning outcomes are arranged into three multidimensional categories which can be easily applied to a variety of training programs under evaluation. The classification scheme for learning outcomes includes such broad subcategories as verbal knowledge, motivation, automaticity, and attitude strength. With each subcategory is listed a variety of potential training evaluation methods and measurement foci. The model and classification schema are sufficiently generalizable. Nevertheless, the authors always intended for their work to be the foundation for subsequent evaluation models which would be tailored to a specific practice. As Kraiger et al. (1993, p. 325) states, “the value of our construct-oriented approach is that it provides a systematic framework for conducting training evaluation research. The ultimate criterion for such work is whether it spurs additional research in training that advances our understanding of training evaluation and training effectiveness.”

The Learning Outcomes model will not be used exclusively, but it will be used as the overarching theoretical framework for this research project. This research proposes a synthesis of the Learning Outcomes model and the CEST Competency model (Frank, 2012). The CEST

Competency model was derived from a theoretical framework constituted by General Systems Theory and is uniquely useful in case study and survey research designs. This synthesis will ultimately yield a state-of-the-art training program evaluation model for a relevant application which is both grounded in robust theory and useful to modern, practical research. Evaluation metrics shall be gleaned out of this overarching model.

The Learning Outcomes model divides learning outcomes into three unique categories: cognitive outcomes, skill-based outcomes, and affective outcomes. With respect to evaluation, cognitive outcomes relate not only to the quantity and type of trainee knowledge but also to the dynamic processes of knowledge acquisition, organization, and application (Kraiger et al., 1993). The second category, skill-based learning outcomes, concerns the development of technical or motor skills which, when developed in a trainee, include goal orientation and organization of job behaviors in a sequential and hierarchal manner (Weiss, 1990). The third and final category, affective learning outcomes, has been traditionally ignored as an indicator of learning by Kirkpatrick (1976, 1987) and other scholars in the training field. Kraiger et al. (1993) reason that attitudes and motivation are internal states that can affect behavior and on-the-job performance.

The CEST Competency model divides systems engineering competencies into categories which are similar to the three Learning Outcomes model categories: cognitive, skills/abilities, and behavioral. The CEST Competency model has an additional category relating to knowledge and experience. Table 14 lists these categories and highlights their alignment across the Learning Outcomes model and the CEST Competency model. Among the three categories in the Learning Outcomes model are several subcategories depicted in Figure 3. Cognitive outcomes can be sorted into subcategories according to their characteristics: verbal knowledge, knowledge organization, and cognitive strategies.

Table 3. Learning outcomes & CEST competency model categories.

Learning Outcomes Model		CEST Competency Model
Cognitive	⟷	Cognitive
Skill-based	⟷	Skills/Abilities
Affective	⟷	Behavioral
		Knowledge & Experience

Skill-based outcomes are divided among two subcategories: compilation and automaticity. Affective outcomes are divided among two categories: attitudinal and motivational. Each subcategory is sufficiently broad and further research on training evaluation should focus on identifying specific metrics within each subcategory according to the research endeavor.

3.2 Baseline Model for Research

Synthesizing the CEST competency model with the Learning Outcomes model will provide specialized metrics across three categories: cognitive, skill- & knowledge-based, and affective/behavioral. In the CEST Competency model, the cognitive category is comprised of 16 competencies of successful systems engineers; these are listed in Table 5. Each competency can be mapped to a subcategory in the Learning Outcomes model and thus may be integrated into the classification scheme.

The skills/abilities category is comprised of nine competencies of successful systems engineers; the behavioral category is comprised of seven competencies. As in the cognitive category, these skill/abilities and behavioral competencies can be mapped to the skill-based and affective outcome subcategories in the Learning Outcomes model. Because the knowledge and experience category, comprised of three competencies, does not directly map to a Learning Outcomes model category, it is omitted from this theoretical framework. The baseline model for research is depicted in Figure 6. Following the guidance from Kraiger et al. (1993), this framework will yield a comprehensive model for the evaluation of a modern systems engineering training program. The model will be coherent, useful, and sufficiently grounded in theory.

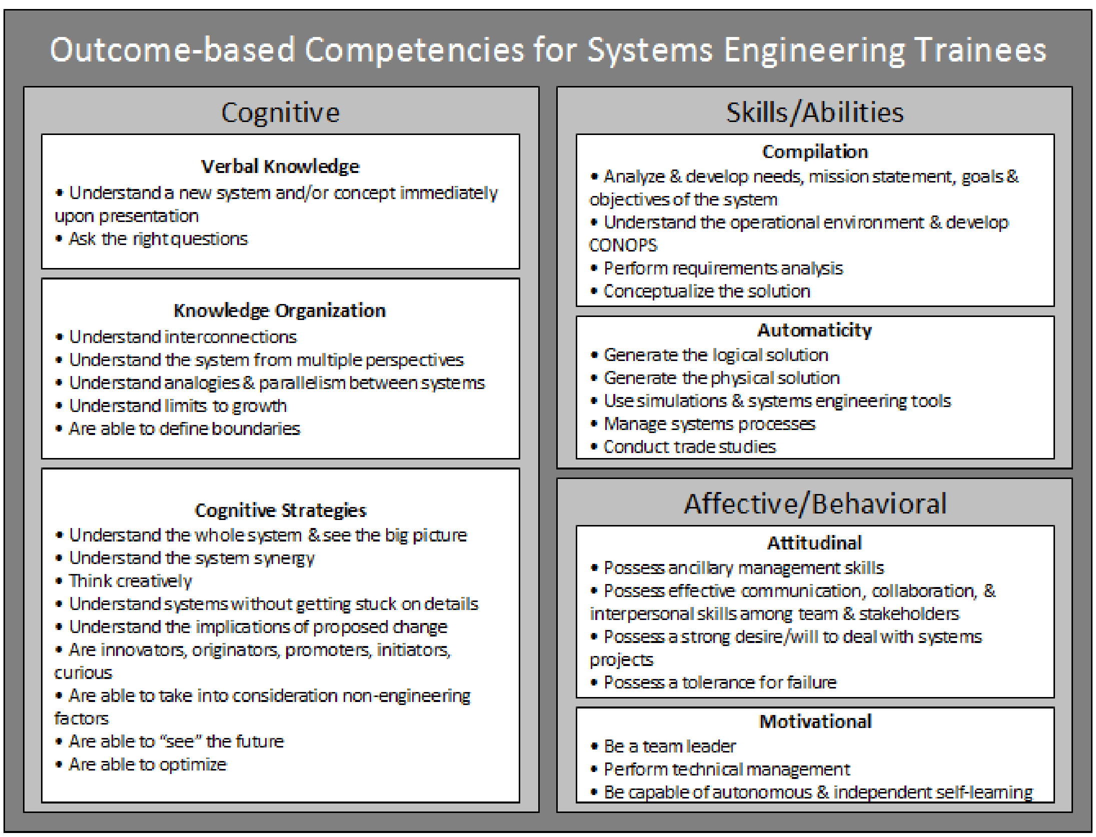

Figure 6. Baseline model for research.

CHAPTER 4

REFINED MODEL

The previous chapter presented the theory development and a baseline outcome-based competency model for systems engineering trainees. This chapter contains a detailed discussion of the process by which the baseline model for research was revised to develop a refined outcome-based competency model for systems engineering trainees which is both rooted in robust theory and validated by subject matter experts.

4.1 Phase 2 Interviews

Six practicing experts in the field of systems engineering were interviewed in phase two. After providing consent prior to the start of the interview, each manager reviewed the 32 outcome-based competencies for systems engineers in Figure 6. During the individual interviews, each manager was asked to think of the competencies as a set of professional skills that are needed for individuals to be successful in the workplace. They provided verbal responses regarding the applicability of each competency to their workforce, e.g. “system synergy” is not a necessary skill for employees to be successful in my workforce; or “requirements analysis” is identified in the workplace mission statement as a critical skill.

In addition to the narratives, managers were asked to rate the level of importance of each competency among their workforce on a scale of 1 to 5: 1, not at all important; 2, somewhat unimportant; 3, neither important or unimportant; 4, somewhat important; 5, very important. For example, “requirements analysis” is rated “5” because it is a critical skill for employees to be successful in the workplace and is therefore very important for employees to have. The average rating on importance for each of the 32 competencies are contained in Figure 7.

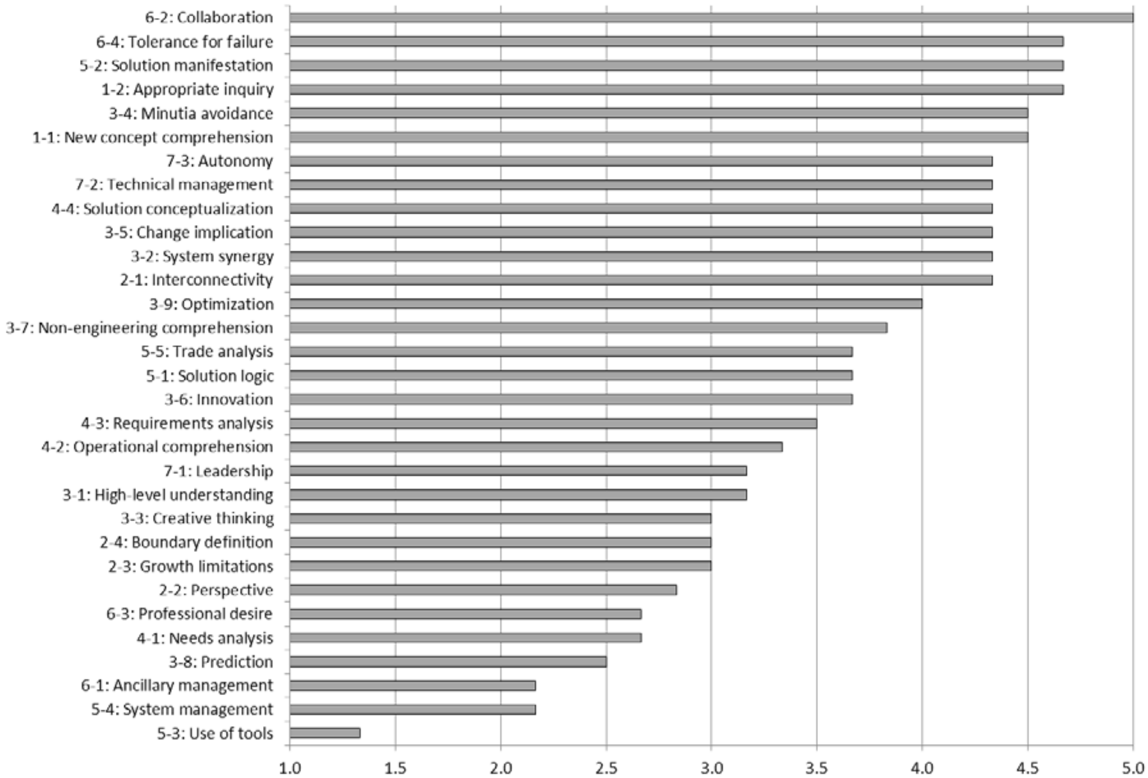

Figure 7. Average rating by managers of the importance for the systems engineering workplace (n=6).

The following seven competencies received average ratings below 3, falling in the realm of “not at all important” or “somewhat unimportant” in the manager’s professional workplace: use of tools, system management, ancillary management, prediction, needs analysis, professional desire, and perspective. However, the interview narratives suggested that while these seven competencies were rated low on the given scale when considering a traditional systems engineering workplace, they are not entirely unimportant to working professionals generally. For example, ancillary management was described in multiple interviews as a skill that many professionals must have simply due to the nature of a busy workplace, though it is not “very important” specifically for systems engineers. Use of tools, the lowest rated competency with an average rating of 1.33 ($\sigma = 0.516$, $n = 6$), was described by multiple managers as a desirable skill, but lacking this competency would not inhibit an individual’s success in a systems engineering workplace.

Narratives describe other competencies in terms of their importance to workplaces generally, while the ratings may vary. Tolerance for failure, the second highest rated competency, was described by all managers as necessary for engineers generally and is essential for driving toward a solution in spite of trial and error; one manager explained that this competency is a selection criterion when interviewing new members to their workforce. The narratives were analyzed for language which would categorize competencies according to their relevance either generally or specifically. Many competencies were described as foundational and non-specific to systems engineering workplaces; others were described as critical only for individuals in leadership and/or management roles, or for those who work on complex system-of-systems comprised of interdisciplinary teams. Some competencies were described as neither foundational nor associated with managers, but are most relevant for systems engineers in a journeyman role in the organization, or who work on sub-systems of a larger system-of-systems.

Managers were also asked to comment on the potential redundancy and ambiguity of specific competencies given the definitions provided prior to the interviews. For example, three managers commented that the definitions for growth limitations and boundary definition were similar enough that the competencies could not be fully differentiated. Additionally, all six managers declared independently that, as defined, new concept comprehension and appropriate inquiry were similar enough to be combined into a single competency. All qualitative narratives regarding potential redundancies were compiled; the results and actions from this analysis are captured in Table 15:

Table 15. Redundancy and ambiguity from interview narratives.

Narrative Feedback	**Actions**
"New concept comprehension" and "appropriate inquiry" are redundant	Combine and update the definition
"Needs analysis" definition does not match title	Change title to "understand training needs"
"Solution conceptualization" and "solution logic" are redundant	Combine and update the definition
"Innovation" is redundant with "creative thinking"	Eliminate innovation and leave only the definition regarding integration and update the title to "implementation;" combine innovation with "creative thinking" and update definition and title
"Interconnectivity" and "system synergy" are redundant	Combine and update the definition

4.2 Updates to Competencies

Twenty-eight outcome-based competencies remained following the actions taken in Table 15 based on the qualitative data from manager narratives. New concept comprehension and appropriate inquiry were combined into a single competency with an updated definition. The title for needs analysis was changed to understand training needs and the definition was left unchanged. Solution conceptualization and solution logic were combined into a single competency with an updated definition. Innovation was changed to implementation and the definition was updated. The definition for creative thinking was updated to include language for innovation. Interconnectivity and system synergy were combined into a single competency with an updated definition. Updated definitions and examples for the competencies impacted by the actions listed in Table 15 are listed in Table 16.

Table 16. Updated competency definitions & example based upon manager interviews.

Competency	**Definition**	**Example**
New concept comprehension	An individual's ability to describe the operation, purposes, applications, advantages, and limitations of a new system/concept immediately upon receiving an initial explanation.	An individual may demonstrate comprehension via recalling facts about the concept.
Appropriate inquiry	An individual's ability to pose relevant questions regarding the information they are given.	An individual poses questions regarding a particular system to an expert of that system, which may verify that the question is relevant and useful.
Interconnectivity	The state or quality of being connected together; as in a system, each component interacts with the other and cannot be analyzed if considered alone.	An individual demonstrates an understanding of the mutual influences among system elements; considers system's interactions, interrelationships, and interdependencies.
Perspective	A particular attitude toward or way of regarding something; a point of view.	An individual possesses a generalist's perspective and is able to consider issues from a wide range of points of view.
Growth limitations	The bounded conditions for a system's growth potential.	When considering ways for improving performance, an individual takes into account factors and processes which limit and balance the performance growth.
Boundary definition	Accounting for all relevant boundaries when considering a system.	An individual successfully assigns proper boundaries when considering a system while maintaining functionality.
High-level understanding	The ability to understand something beyond a superficial level.	The individual possesses a sophisticated understanding of the system as a whole.

Table 16. Continued.

Competency	Definition	Example
System synergy	The interaction or cooperation of two or more components within a system.	An individual demonstrates an ability to derive the synergy of a system from the integration of subsystems.
Creative thinking	An approach to thinking which is innovative and potentially risky.	An individual creates unusual ideas and innovative thoughts, and are able to put things together in new and imaginative ways.
Minutia avoidance	The practice of avoiding details which are unimportant.	An individual can identify which details are beyond the scope of the conversation or issue at hand, and can reroute.
Change implication	Impacts, definite or potential, of an imposed change to a system.	When a change to a system is proposed, an individual can analyze the impact of the change and are capable of anticipating and dealing with all implications of change to the system.
Innovation	A new method or idea; beginning.	An individual has the capability to plan and successfully integrate a novel design into an existing system.
Non-engineering comprehension	The ability to understand a concept or idea from a non-technical point of view.	An individual considers ecological/environmental, marketing, political, economic, etc. factors when managing a system.
Prediction	The action of predicting or forecasting something.	An individual possesses a vision for the future and are able to imagine how a system will develop over time and can plan accordingly.
Optimization	An act or process of making a system as fully functional or effective as possible.	An individual understands optimization efforts over multiple dimensions – engineering, cost, schedule, and operational.
Needs analysis	The identification of individuals in need of training and what kind of training is appropriate.	While performing requirements analysis, an individual assesses the human factors element, e.g. training requirements.
Operational comprehension	An understanding of the ways in which a system or organization operates.	An individual can develop a concept of operations (CONOPS) for a system or organization.
Requirements analysis	The process of defining and managing quantifiable, relevant features of a system in sufficient detail.	Via standardized means, an individual can capture all relevant requirements of a system.
Solution conceptualization	To create and communicate an idea for a solution to a problem.	An individual has the ability to design a solution to a problem and to communicate that design effectively.

Table 16. Continued.

Competency	Definition	Example
Solution logic	An explanation of the reasoning behind a proposed solution.	When designing a solution, the individual assesses its viability according to strict principles of validity.
Solution manifestation	The act of communicating or visually depicting a solution concept.	The individual can transform an abstract solution idea into an implementable plan.
Use of tools	The utilization of a device used to carry out a specific function.	An individual possesses a working knowledge of modern, relevant tools such as systems engineering simulations and software.
System management	Useful administration of a system.	An individual understands the management needs of a particular system and how they may be addressed.
Trade analysis	Examining the trade-off effects in a system.	An individual understands a system's relevant tradespace and can initiate and/or conduct trade studies.
Ancillary management	Useful administration of non-primary elements of a system or organization.	Without sacrificing primary functionality in a system, an individual may manage secondary functions.
Collaboration	Imparting information to another person or system for the purpose of creating something.	An individual demonstrates successful communication and demonstrates an ability to work with others to achieve a common goal.
Professional desire	A strong feeling of wanting something in a person's career.	The individual demonstrates a strong desire to deal with systems projects.
Tolerance for failure	The ability or willingness to tolerate defeat or a lack of success.	After experiencing a failure, an individual doesn't view the situation as an "end of the road."
Leadership	The act of leading a group of people or an organization.	An individual has succeeded in a leadership role in the workplace.
Technical management	Planning, design, and control of technical systems.	An individual possesses the ability to manage the technical steps necessary to implement or maintain a technical system.
Autonomy	Freedom from external control or influence.	An individual is capable of autonomous and independent self-learning.

4.3 Refined Model for Research

A revised model was developed to include the 28 outcome-based competencies for systems engineers based on the results from the manager interviews. The revised model organizes the competencies from the outcome-based competency model into three tiers which represent on-the-job experience level and job function:

- Tier 1: Foundational competencies required to be an effective member of a systems engineering workforce at the entry-level.
- Tier 2: Competencies which are necessary for members of a systems engineering workforce to be effective beyond a foundational level, i.e. at a mid-grade level. Members perform specialized tasking on a sub-system or component of a larger system, which requires little to no interface control; tasking would not likely extend to other disciplines, e.g. little to no management of contracts, budgets, or interdisciplinary teams. Tier 2 competencies are most critical to workforce members who lead a small team of 1-3 people or do not lead a team at all; the member and his/her team perform functions related to their subsystem or component, and a holistic view of the larger systems in not critical.
- Tier 3: Competencies necessary for senior-level workforce members who have a leadership and/or management role comprised of many individuals across multiple disciplines, not limited to technical fields (e.g. budget, policy, etc.) and/or for individuals managing a complex engineering system.

A revised theoretical model for research, which contains categorized outcome-based competencies for systems engineers, is shown in Figure 8.

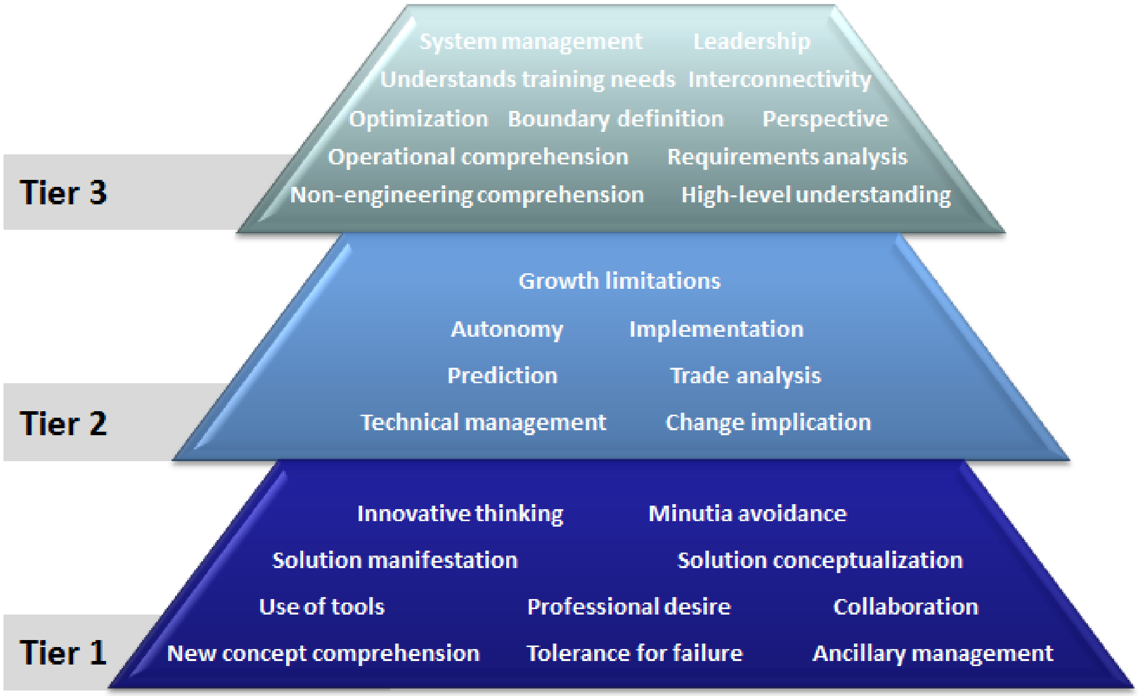

Figure 8. Revised model for research includes the competencies deemed important for success at each of the three tiers.

4.4 Validity and Reliability

Denzin (1995) insists that there is only one way to judge the quality of a formal scientific inquiry: the criteria of reliability and validity. The purpose of formal research is to enhance our understanding of phenomena which is often achieved by discovering and quantifying relationships between variables. Even if there is a distinct relationship between variables to describe a relevant phenomenon, a researcher won't necessarily recognize this relationship via formal inquiry if the research method has poor validity and reliability.

Research methods may have inherent degrees of validity (internal and external) and reliability. Additionally, the chosen measurement and analysis techniques within the research design will impact the overall validity and reliability of the research undertaking. A good research design will carefully consider the inherent characteristics and limitations of the chosen research method, and will include apposite strategies to enhance validity and reliability wherever possible.

Yin (2008) provides a framework for validity and reliability in which the data are used to make inferences involving analytical (as opposed to statistical) generalization. Yin's framework, shown in Table 17, hinges the quality of research design on four principles: construct validity, internal validity, external validity, and reliability. His framework can be used to guide researchers through the issues of reliability and validity in the process of formal inquiry.

This research followed the protocol set forth by Yin (2008) to ensure construct validity by first developing operational definitions of the competencies that are identified for study, as well as how they will be measured in the study; measurement of the competencies is described in Chapter 5. The operational definitions were used to develop the protocol for interview and survey questions for a practical evaluation of a training system, also shown in Chapter 5.
This research follows another guideline set forth by Van de Ven (2007) and Yin (2008) to further enhance the validity and reliability of qualitative data collection, both of which both involve the involvement of another person aside from the principle researcher. Incidents from raw data may be coded by two or more researchers to reach consensus; consensus will increase the consistency of interpretations. Additionally, incident coding can be reviewed by key informants at the case study sites; these individuals can identify if any incidents are absent or poorly interpreted. As this

project was conducted by a single researcher, interviewees in phase two were permitted to examine transcripts from the interviews and make changes to enhance validity.

Table 17. Framework for validity and reliability [adapted from Yin (2008)].

Quality principle	Strategy for research design	Phase of research
Construct validity	• Collect data from multiple sources; provide multiple measures of identical phenomenon • Establish triangulation of interview questions • Establish a chain of evidence • Peer review	Research design; data collection and analysis
Internal validity	• Incorporate pattern-matching, explanation-building, opposing explanations, and logic models for information richness	Research design; data analysis
External validity	• Application of theory (for single-case studies) • Use of replication logic (for multiple-case studies)	Research design
Reliability	• Case study protocol or guide for the collection of data • Structured process for interpretation of convergent interviews • Use of a steering committee • Use of quantitative data, when possible, to confirm qualitative findings • Application of triangulation techniques (multiple data sources, multiple observations, etc.)	Research design; data collection and analysis

The study design offers an enhancement of external validity. This technique is defined by Yin (2008) as replication logic. Replicating the study among genuine practitioners in the field of study and at multiple distinct locations, e.g. performing interviews of subject matter experts (managers) at differing organizations, employs the strategy set forth by Leedy & Ormrod (2010) for increasing external validity generally:

1. Perform research in a real-world setting to achieve broader applicability to other real-world contexts;
2. Collect data from a representative sample of interest;
3. Replicate the research in diverse context and situations to provide evidence that the conclusions have widespread validity and applicability.

This research was designed to perform steps one and two by interviewing subject matter experts in a real-world setting and collecting data from a representative sample of a systems engineering workforce. Future work can improve the overall results by continuing to interview managers outside the DoD domain, i.e. replicate the research in a diverse context.

Content validity is the degree to which elements of an assessment instrument are relevant to and representative of the targeted construct for a particular assessment purpose (Haynes et al., 1995). Data from an invalid instrument can over-represent, omit, or under-represent some of the facets of the construct and reflect variables outside the construct domain. A content-invalid assessment instrument could drive erroneous inferences about the construct because estimates of shared variance would be based on erroneous measures. Content validation is a multi-method, quantitative, and qualitative process that is applicable to all elements of an assessment instrument. Appendix B contains the questionnaire which was deployed to collect data, as described in Chapter 5; Appendix B also contains a description of the process by which content validity was established for the questionnaire. Considering the major contribution of this research was the theoretical model and not the evaluation performed by the questionnaire, a rigorous content validation was outside the scope of this research endeavor; this represents a limitation to the results obtained from the questionnaire in Chapter 5 as well as the inferences drawn in Chapter 6.

CHAPTER 5

A PRACTICAL EVALUATION USING THE REFINED MODEL

The following chapter demonstrates how the outcome-based competency model for systems engineering trainees was used to drive a practical evaluation of a real-world training program. Relevant background to the context of the problem is provided, as well as a description of the problem statement, the training program, and the sampled workforce. This chapter also contains a description of the detailed methodology by which the refined model was used to develop evaluation metrics to perform a survey of a trained workforce. The chapter concludes with the findings of the practical evaluation.

5.1 Context

The United States DoD has made considerable effort in the last thirty years to implement robust systems engineering initiatives that will meet the demands of increasingly complex defense weapon systems. The investments are significant and are funded entirely by tax revenue. Specifically for major weapons systems, the DoD spent $157 billion in fiscal year 2006 and $188 billion in fiscal year 2008 (Miller, 2008). The acquisition investment continues to rise dramatically from year to year, totaling $388 billion in fiscal year 2009, making the DoD the largest buying enterprise in the world (GAO, 2009a). A review of the literature shows a multitude of policies, public laws, and budgetary adjustments to implement systems engineering initiatives across DoD agencies, though very little research is published which defines or discerns measurable value from the considerable investment of taxpayer dollars.

In particular, the realm of DoD acquisitions has made major investments in systems engineering. This investment was meant to be the solution to decades of frustration over repeated and costly failures to meet cost, schedule, and performance goals by the defense acquisition community. These failures have been well-documented in numerous Government Accountability Office (GAO) and Office of the Secretary of Defense (OSD) reports, congressional panels, and presidential commissions. A special report to President Ronald Reagan identified significant problems at all levels in the DoD and explicitly targeted DoD acquisitions, issuing bold recommendations for change: "[the DoD] requires radical reform of the acquisition organization and procedures…" and "…requiring concerted action by the executive branch and Congress, and full support of the defense industry," (Packard Commission, 1986, p. 52). In response, the GAO designated the DoD management of major weapons system acquisitions a high risk area, and one cited cause for the numerous and costly failures is insufficient investment in systems engineering and program management (GAO, 2009b).

Following these widely-publicized reports, attention was turned to the DoD acquisition workforce as the critical target for fundamental reform. A congressional report (U.S. Congress, 1990) concluded that a comprehensive program is needed to ensure required improvement in the quality and professionalism of those individuals working in acquisition positions throughout the DoD. It was and still is believed that the DoD acquisition workforce is the most important asset to assure effective defense acquisition system reform, mitigate over-expenditures, and ensure that the best weapons systems are available to the warfighter. The term "acquisition workforce" has been replaced by the term "Acquisition, Technology, and Logistics (AT&L) Workforce," to more accurately portray the functions of those individuals targeted for reform in the acquisition community (DoD Desk Guide, 2006).

The plan for DoD AT&L workforce improvement prioritized the hiring of systems engineering experts in key AT&L leadership positions. Additionally, the current workforce was targeted for improvement and reform via employee training and development. In a letter to United States Congress, the GAO issued a call-to-action which still resonates today: "[Federal] agencies will need to invest resources, including time and money, to ensure that employees have the information, skills, and competencies they need to work effectively in a rapidly changing and complex environment" (GAO, 2004, p. i).

5.1.1 Defense Acquisition Workforce Improvement Act

The mechanism for defense AT&L workforce reform became the Defense Acquisition Workforce Improvement Act (DAWIA) which was enacted by public law in November 1990. Legislation was introduced by Congressman Mavroules (D-MA), Chairman of the House Armed Services Subcommittee on Oversight and Investigations in the U.S. House of Representatives. He explained that the fundamental mission of DAWIA was the professionalization and career management of the defense AT&L workforce via training, education, and experience (Mavroules, 1991). In particular, Congress testified that DAWIA should focus on individuals working in specialized acquisition positions who perform functions which include program management and systems engineering (Congressional Testimony, 1997). DAWIA was enacted by Title XII in the 1991 National Defense Authorization Act (NDAA).

Section 1205 §1746 of the 1991 NDAA prescribes the establishment of a Defense Acquisition University (DAU) and issues to it the responsibility of educating and training the defense AT&L workforce in systems engineering and program management career fields. DAU began as a consortium of 16 Army, Navy, Air Force, and DoD schools with the mission of developing and delivering appropriate certification curricula to AT&L workforce members. Currently, DAU campuses are located in Virginia, Maryland, Ohio, Alabama, and California.

DAU serves the acquisition community by providing a training system with a variety of modalities, including traditional classroom environments, on-site training workshops, and online education. Career field certification is the benchmark which demonstrates a defense AT&L employee is sufficiently trained to meet the legislative requirements set forth by DAWIA and its subsequent implementation plan, DoD Directive 5000.52. Participation in this training system, with the ultimate goal of earning career field certifications, is compulsory for all AT&L workforce members.

5.1.2 Criticism of DAWIA Certifications

In 2001, one decade after the legislation which established the DAU and the career field certifications, the GAO listed the training system, as an initiative under federal human capital management, a government-wide high risk item (GAO, 2010a; GAO, 2013), and it remains so today. In March 2004, the GAO issued a guide for assessing federal training programs and discusses key attributes and metrics of effective training and development that should be present to demonstrate effectiveness (GAO, 2004).

In a 2008 update, the GAO reported despite years of initiatives and investment to improve the defense AT&L workforce competency, it was still inconclusive whether the changes have had any impact (GAO, 2008). Insufficient and ambiguous objectives in the training and development programs were cited specifically as key failures. The GAO (20091, p. 6) remarked: "Specifically, AT&L [leadership] does not have key pieces of information regarding its in-house acquisition workforce, such as complete data on skill sets, which are needed to accurately identify its workplace gaps." Lacking this critical information hinders the DoD's ability to demonstrate value in its training initiatives thus justifying the enormous investment.

In 2010, the GAO issued an update as well as another letter to key Congressional members of the Committee on Armed Services and the Subcommittee on Defense Appropriations which concluded that "while the DoD has demonstrated some progress in addressing the legislative requirements related to its [AT&L] workforce plan, several key elements continue to be missing from the process," and furthermore, "… DoD may not be able to determine whether its investment in strategies to improve the [AT&L] workforce is effective and efficient" (GAO, 2010a, p. 7).

In October 2010, the GAO published an investigation targeted specifically at the efficacy of the DAWIA training system as measured by the attributes and metrics from the 2004 guide. The investigation concluded that while the training system is effective in some ways, it is lacking in two critical areas: (1) DoD lacks complete information on the existing skill sets of the AT&L workforce, and (2) DoD does not use outcome-based metrics to assess the efficacy of its mandatory training system (GAO, 2010b). The GAO report identified two recommendations for key Congressional committees based on the findings: (1) The DoD must establish milestones for developing metrics to measure how certification training improves acquisition workforce capability, and (2) the DoD must establish a time frame for acquiring and implementing an integrated, enterprise-wide student information system.

In a letter of response, the DoD concurred with the latter recommendation and did not concur with the former. The DoD cited that the reason for non-concurrence with the first recommendation is that developing milestones is unnecessary and existing metrics provide sufficient insight into the efficacy of the training system. Five metrics were noted which measure the size and composition of the AT&L workforce as well as the education, training, and experience levels of the individuals that comprise it (GAO, 2009a).

1. Annual increase in DoD personnel in acquisition positions.
2. Annual increase in DoD personnel authorizations as a result of in-sourcing acquisition functions.
3. Annual percent increase of acquisition personnel achieving mid-level career field certification.
4. Annual percent increase of acquisition personnel achieving top-level career field certification.
5. Meet or exceed government benchmarks for classroom and online course delivery and student satisfaction surveys.

In response to the DoD non-concurrence, GAO issued a Recommendation for Executive Action to the Secretary of Defense which explains that the existing metrics are valuable though uncomprehensive. The GAO (2009a, p. 9) explained: "At a fundamental level, workforce gaps are determined by comparing the number and skill sets of the personnel that an organization has with what it needs. However, [the DoD] lacks information on both what it has and what it needs." Collecting demographic data on acquisition personnel merely provides insight into the degree to which required workforce personnel are completing the certification programs and filling essential acquisition positions. However, complete training effectiveness must be measured against organizational performance after the personnel have earned the certifications (GAO, 2010b). A Naval Postgraduate School study echoes the GAO recommendation: "a comprehensive study should be conducted to examine and review the defense [AT&L] workforce competency level… and development consistent with the concept of DAWIA" (Choi, 2009, p. 86).

5.2 A Practical Evaluation of DAWIA SPRDE Training

The evaluation in this chapter demonstrates the utility of the model for a practical context wherein the DAWIA SPRDE training is evaluated among a sample of the trained workforce. The results of the evaluation provide insight regarding the efficacy of the DAWIA training by measuring the perceived improvement of critical systems engineering competencies as a result of training.

5.2.1 Using the Refined Model to Develop Evaluation Metrics

The term "metric" is traditionally defined as a system or standard of measurement. More specifically, evaluation metrics, sometimes called performance metrics, are standards of measurement used to evaluate the effectiveness of a system and to justify the pragmatic development of the system (Pehcevski & Piwowarski, 2007). Evaluation metrics are employed as a component of a larger system evaluation process for evaluating training programs, known in the literature as an evaluation model.

A list of competencies and their corresponding definitions and examples is shown in Table 16. The process by which an evaluation metric is developed to measure the perceived improvement on a particular competency is as follows:

1. Key phrases that compose the definition of the metric are identified (each will become a separate survey question);
2. Each phrase is preceded with the training context under evaluation; and
3. The specific skill that is impacted is identified.

Figure 9 shows this process for new concept comprehension as a result of DAWIA training. As shown in the figure, the "new concept upon presentation" is the key phrase of the definition being assessed, "participation in DAWIA training" is the specific training context, and the "ability to describe" is the specific skill that is impacted.

Survey questions were written to measure the effectiveness of DAWIA training on improving the 28 competencies using a Likert scale. Table 18 contains an example of a single metric which is associated with the Tier 1 competency, “new concept comprehension,” and three questions which were developed to collect a measurement via the questionnaire. Note that the three questions are all derived from the same competency definition, but evaluating the different key phrases that compose the definition.

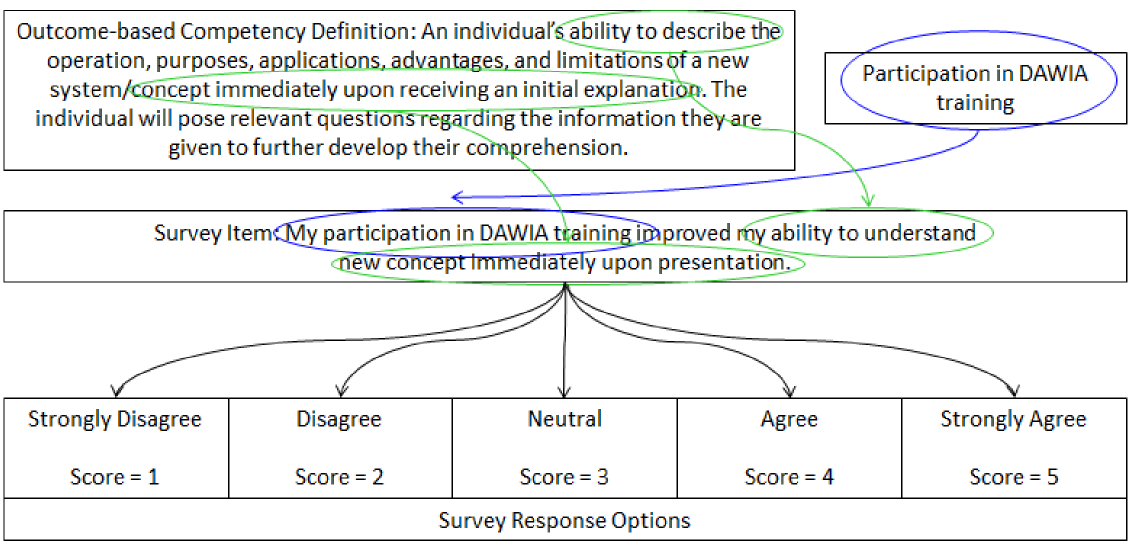

Figure 9. Metric for new concept comprehension.

According to Parsons (2004, p. 42), the “optimal number of survey questions per variable is between three and five.” Hatcher (1994) maintains that surveys should include at least five questions per variable so that at least three will remain after the researcher verifies internal consistency. Composing multiple questions per evaluation metric promotes internal validity of the research. For each of the 28 competencies, three survey questions were composed by repeating the process in Figure 9. The three survey questions for new concept comprehension are included in Table 18.

Table 18. Survey questions to measure perceived improvement of new concept comprehension.

Metric: DAWIA training impact on new concept comprehension				
Question 1: My participation in DAWIA training improved my ability to understand new concepts immediately upon presentation.				
Strongly disagree	Disagree	Neutral	Agree	Strongly agree
Question 2: My participation in DAWIA training improved my ability to formulate relevant questions when discussing a project in the workplace.				
Strongly disagree	Disagree	Neutral	Agree	Strongly agree
Question 3: My participation in DAWIA training improved my ability to formulate relevant questions, without relying on the guidance of others, to promote my understanding of a new concept.				
Strongly disagree	Disagree	Neutral	Agree	Strongly agree

Survey questions were composed to dutifully measure the impact of the DAWIA training program on survey participants. The Likert scale provided a method by which training impact on specific competencies could be measured according to the scale: strongly disagree = 1; disagree = 2; neutral = 3; agree = 4; strongly agree = 5. For example, Table 18 identifies the three questions related to a single metric associated with new concept comprehension. A response of “strongly disagree” to each question would yield an average numerical value of 1 for the metric, i.e. the response indicates that DAWIA training was not at all effective in improving new concept comprehension in the participant. Given a response of “strongly agree” to each question, the average numerical value would equal 5; thus, the participant has indicated that DAWIA training was extremely effective at improving the competency.

Additional data were collected via questions not related to the competencies identified in the model, e.g. educational background, highest level of certification achieved, frequency to which the DAWIA training material was revisited, continuous learning to maintain DAWIA certification, date and career level when DAWIA certification was conferred, totaling 94 survey questions in all. A full list of survey questions is provided in Appendix D.

5.2.2 Performing the Evaluation

The survey instrument was generated using surveymonkey.com and included each of the 94 questions drafted by the process shown in Figure 9. The survey was distributed to members of the defense AT&L workforce, in the systems engineering career field, and who have participated in the DAWIA SPRDE-SE certification training. For a SPRDE-SE population of 39,167 at a 95% confidence level and 15% margin of error, an acceptable sample size for the simple statistics is 43. The total number of survey responses, n, was 52.

The survey results obtained in phase three were largely quantitative in nature. The data consist of objective, quantified responses where questions associated with each research variable were constructed to address the research question. Traditional quantitative data analysis techniques were employed once the survey results were collected. Scheuren (2004, p. 10) suggests, “All of the survey’s results should be presented in completely anonymous summaries, such as statistical tables and charts.” Statistical analyses were used to interpret and convey the meaning of the quantitative data and to sufficiently demonstrate the feasibility and utility of the metrics as a tool for evaluation.

Numerical values were assigned for all Likert responses and descriptive statistics were compiled for the 52 survey responses. Results were organized to demonstrate the effectiveness of DAWIA training on improving each of the 28 competencies listed in the revised model for research.

5.2.3 Improvement of Competencies

The average rating for DAWIA SPRDE-SE training impact on individual competencies is shown in Figure 10. All 28 competencies are depicted in descending order of average ratings from the surveyed population. For an individual competency, an average numerical value below 3 indicates DAWIA training was not effective in improving the competency among the sample workforce. The sample shows that of the 28 competencies evaluated, the averages for 22 competencies were below this threshold; thus, they were not improved as a result of DAWIA training among the surveyed workforce. The averages for six competencies were above 3, indicating that DAWIA training was effective in improving the competency among the surveyed workforce. The six competencies which rated 3 or higher are requirements analysis, operational comprehension, non-engineering comprehension, boundary definition, technical management, and system management. Five of these six competencies are categorized in Tier 3, i.e. are competencies required by workforce members who are in a leadership or management role in the organization.

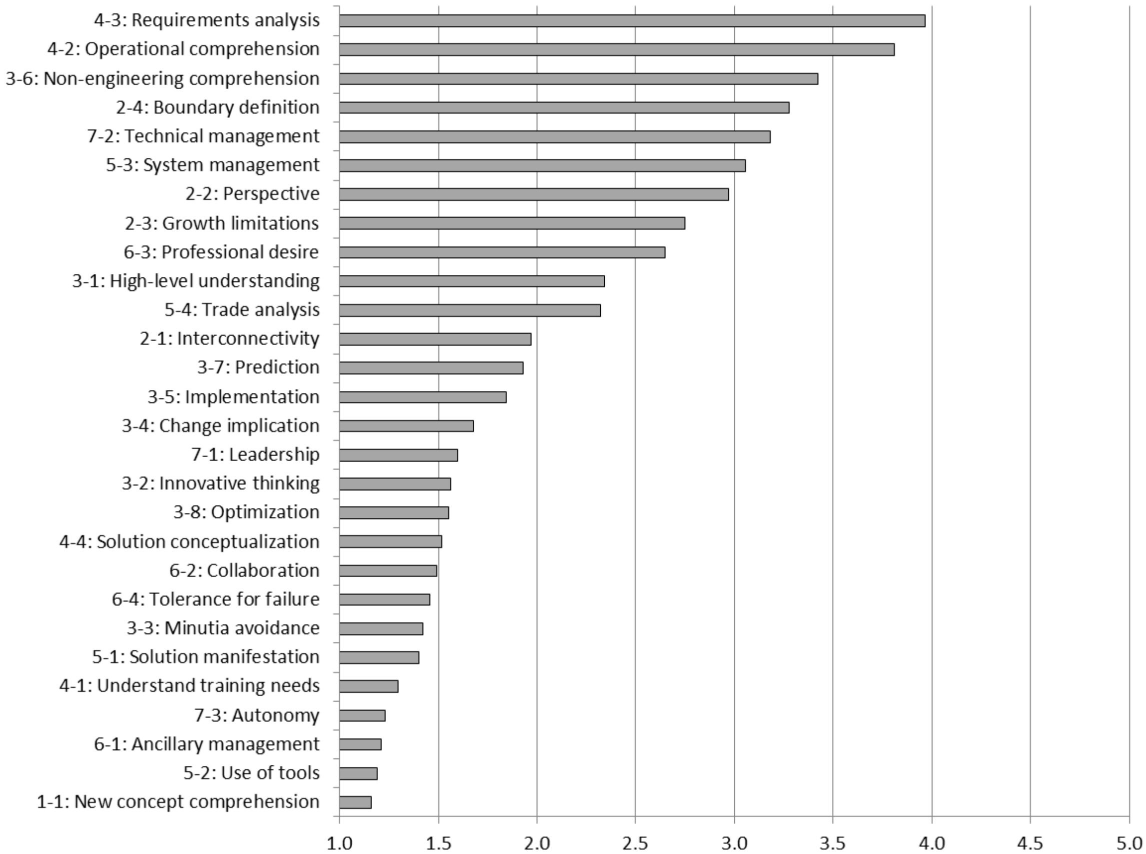

Figure 10. Average rating for each competency (n=52).

5.2.4 Improvement Among Categorized Competencies

The revised model for research, Figure 8, categorizes individual competencies into three tiers based on on-the-job experience level and job function. An average of the individual competency ratings in each tier was computed; these are shown in Figure 11. These averages represent the effectiveness of DAWIA SPRDE-SE training on improving critical systems engineering competencies according the tiered structure from the revised model for research. These data show a positive trend in training efficacy for competencies when arranged in the three-tiered structure; i.e. DAWIA SPRDE-SE training is not effective at improving Tier 1 (foundational) competencies in trainees, while comparatively, the training is more effective at improving Tier 2 (specialized) competencies, and more effective still at improving Tier 3 (managerial) competencies.

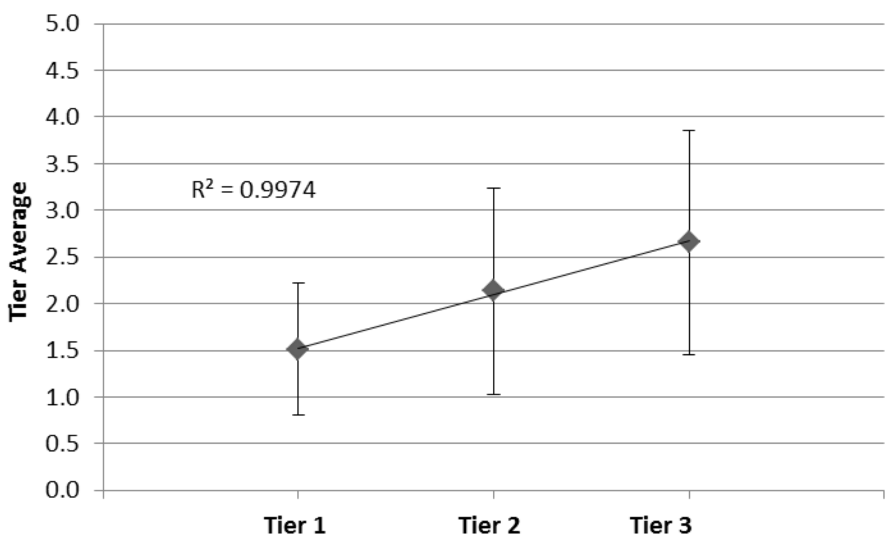

Figure 11. Average rating per tier (n=52).

5.2.5 Results for Additional Variables

The survey contained questions to gather data for additional variables beyond the impact of DAWIA SPRDE-SE training on specific systems engineering competencies, specifically:

- Highest level of DAWIA SPRDE-SE certification earned;
- Estimated calendar date and time-in-career when highest level of DAWIA SPRDE-SE certification was earned;
- Current professional duties;
- Professional duties during the time of DAWIA SPRDE-SE training;
- Continuous learning to maintain DAWIA SPRDE-SE certification;
- Frequency to which DAWIA SPRDE-SE training material is referenced and/or reviewed;

- Educational background.

Questions relating to each variable are listed in the full questionnaire in Appendix D. The responses to these questions were examined to identify potential trends and may guide future efforts of confounding variables related to this research. Figures 12, 13, 14, and 15 depict the responses to survey questions relating to each of the confounding variables.

Figure 12 indicates that 98 percent of survey participants had earned the highest level of training. To perform a valid test of the improvement of DAWIA training on a sample workforce, it is important to confirm that each of the respondents are familiar with the training; this figure indicates that all survey respondents are sufficiently familiar with the training.

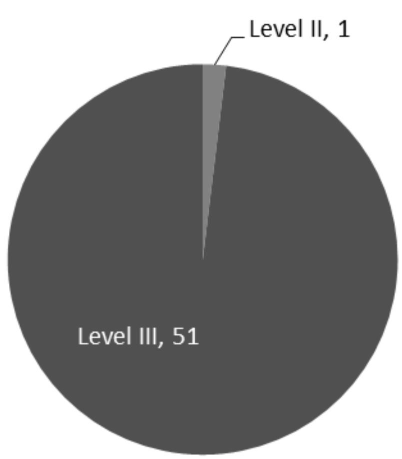

Figure 12. Highest level of DAWIA SPRDE-SE certification earned (n=52).

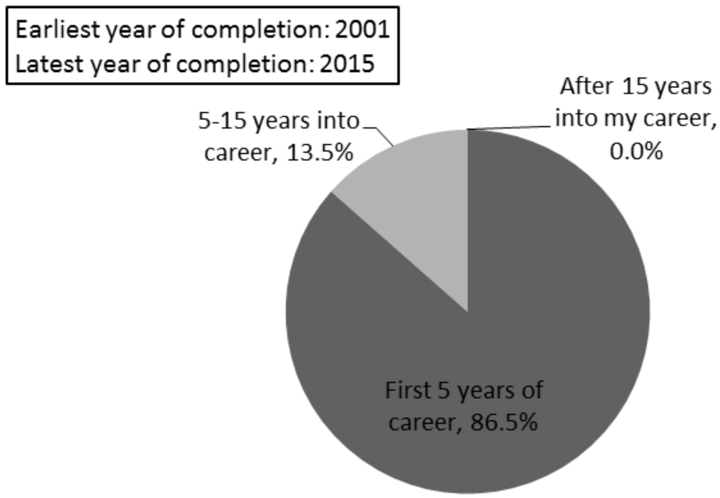

Figure 13. Date and time-in-career at DAWIA SPRDE-SE certification (n=52).

Figure 13 indicates that 86.5 percent of respondents completed DAWIA SPRDE-SE certification in the first five years of their career, i.e. when they were entry-level members of the systems engineering workforce. The figure also indicates that 13.5 percent of respondents completed DAWIA SPRDE-SE certification between their fifth and fifteenth year, i.e. when they were journeyman members of the systems engineering workforce. In the previous section, Figure 11 indicated that DAWIA SPRDE-SE training was least effective at improving Tier 1 (entry-level) competencies in trainees; however, the majority of the surveyed workforce completed the training while they were entry-level employees. This infers a critical mismatch between the perceived effectiveness of the training and the time-in-career at which the training is mandated. Tier 1, “entry-level” employees must possess entry-level competencies to perform their jobs effectively; however, the mandatory training is least effective at improving entry-level competencies. Figure 11 indicates DAWIA training is most effective at improving Tier 3 (managerial) competencies, yet zero respondents indicated that they completed the training 15+ years into their career, i.e. when they are beyond the journeyman level.

Figure 14 depicts additional information regarding the types of duties at the time of the respondent's participation in DAWIA SPRDE-SE training. This information is useful because it describes the types of competencies which were required at the time of training. For example, one trainee may have participated in the training during the first five years of his career when he had no managerial responsibilities; this would indicate that he did not require Tier 3 (managerial) competencies to perform his job effectively at the time he participated in the training. Descriptions for professional duties in Figure 14 map to the definitions:

A. I have a leadership / management role and I am responsible for a team which is comprised of individuals from multiple disciplines. In my work, I must focus on the management of a complex system which has many sub-systems and interfaces; it is critical that I have a holistic understanding of the system. I am also responsible for program management duties, such as budget formulation, contract execution, policy adherence, etc.

B. I am mostly responsible for myself at work, or I am responsible for a small team of engineers and scientists. I work on a subsystem of a larger, more complex system; it is not critical that I have a holistic view of the larger system. My job duties rarely, or never, include program management activities such as budget formulation, contract execution, and policy adherence.

C. Neither A nor B.

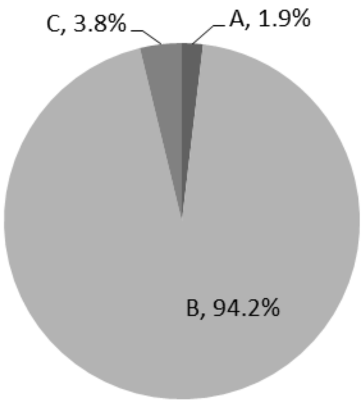

Figure 14. Professional duties at time of DAWIA SPRDE-SE certification (n=52).

Figure 14 indicates that 94.2 percent of the respondents were in a journeyman position at the time they participated in the DAWIA SPRDE-SE training. This further confirms the inference that there is a mismatch between the perceived effectiveness of the training and the time-in-career at which the training is mandated. Employees in journeyman positions must possess Tier 2 (journeyman) competencies to perform their jobs effectively. However, the survey results indicate that DAWIA SPRDE-SE training was not effective at improving journeyman competencies. Figure 11 indicates DAWIA training is most effective at improving Tier 3 (managerial) competencies, yet only 3.8 percent of respondents indicated that they completed the training when they were in managerial positions.

Of the 52 responses, 100% of survey participants answered that they were currently up-to-date with the required continuous learning to maintain their DAWIA SPRDE-SE certification. A separate question provided a narrative box to describe the nature of the continuous learning they have completed to meet the requirement. Responses were consolidated and included:

- Qualifying coursework for academic degree;
- Mandatory professional and functional training at workplace;
- Qualifying participation at conferences, information meetings, and test events;
- Additional systems engineering DAU training modules;
- Training and coursework for additional DAWIA career field certification;
- Qualifying coursework for professional engineering license.

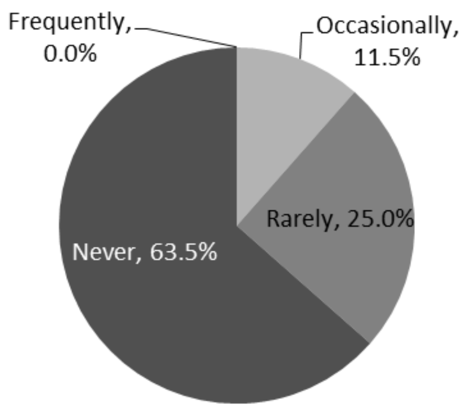

Figure 15. Frequency at which DAWIA SPRDE-SE material is reviewed (n=52).

Figure 15 indicates that while respondents are continuing their education to maintain their DAWIA SPRDE-SE certifications, 63.5 percent are never referring back to DAWIA materials. It may be inferred that, due to the overall perceived ineffectiveness of the training, trainees do not consider the DAWIA material a useful reference to maintain their critical professional skills.

5.3 Ethical Considerations

Regarding the contextual evaluation of the DAWIA training in phase three, full disclosure is appropriate: the researcher has completed the training which is under evaluation. Efforts have been taken to eliminate research bias and provide valid results commensurate with the strategies set forth by Yin (2008) to maximize validity and reliability. Regarding research bias, Schmitt (1994, p. 394) comments, “the relevant question is whether the method(s) of measurement and the research design allow one to derive appropriate conclusions.” The research is designed such that unbiased and objective results will be obtained to maintain neutrality in the research and data analysis.

5.3.1 Protection of Intellectual Property & Identity

Identities of surveyed workforces will not be disclosed in any written artifact, discussions, or briefings associated with this research project. All data exchanged in phases two and three are unclassified and non-proprietary. All physical notes were transferred to electronic documents and the remaining physical pages were destroyed. Electronic documents were saved to password protected files; the research was the only person with the password to access the files. All password protected files were saved to a personal computer which must be accessed with the researcher’s chip-enabled card and PIN. Survey responses were saved to the principle investigator’s secure account on surveymonkey.com; the password to access the account was not shared with anyone.

5.3.2 Human Subjects Protection

This research endeavor was conducted using the highest ethical standards for the protection of human subjects. The researcher has successfully completed the Collaborative Institutional Training Initiative (CITI) Social and Behavioral Responsible Conduct of Research Curriculum.

The completion report is on file at ODU and accessible via the CITI website. The completion report is included in the Appendix A.

Consent for research using human subjects was obtained separately for phase two and phase three. An application was submitted with ODU to classify phase three of the research, the survey instrument, as being exempt from an Internal Review Board (IRB) process according to Federal Regulations 45CFR46.101(b) section 6.2. This instruction permits exemption for proposed research that involves the use of survey procedures that will be conducted and reported in a manner such that the human subjects cannot be identified, directly or through identifiers linked to the subjects. The University College Committee granted consent for the exempt research on April 28, 2016; the interviews in phase two were not exempt from the full review of the IRB. The phase two research protocol and supporting material was submitted to the ODU IRB and, following a full review, the IRB granted consent for research on July 6, 2016. Approval letters were obtained from the review committee for phase two and phase three, and are included in Appendix B.

Consent of all study participants was paramount. Research such as this, which involves the study of a modern social phenomenon in a real-life context, requires that measures be taken to protect the rights of all participating individuals. Workforce managers participating in phase two interviews were approached by the researcher individually to request their informed consent. Informed consent was obtained from all individuals prior to their participation in the study via a signed consent form. Consent forms advised participating individuals of the nature of the study and formally solicited their consent for participation. The consent form, containing the name of the participating individual, was scanned and uploaded by the researcher into a password protected file, and stored on a laptop hard drive which requires a chip-enabled card and PIN to access. Only the researcher has the password and access PIN. The chip-enabled card remains in the researcher's possession.

All interviews were conducted in a one-on-one private setting or via phone with a single direct line from the researcher to the interviewee. Participant names were not recorded nor coded on the interview records. Following all interviews, participating workforce managers were provided with a transcript of the interview via encrypted email for their review and to request changes if necessary. Digital files, e.g. interview transcripts and interview notes, remain in a password protected file on the researcher's computer; only the researcher has the password. In the event the interview transcripts were printed to allow the manager to review a hard-copy, the hard-copies and all physical notes taken during the interviews were destroyed once all relevant data was consolidated in the digital notes and transcript. All reports associated with this research project will not include any means to identify the individual participants, nor the identity of the participating organizations.

The survey instrument is the sole data-collection method for phase three. The survey questions were used to generate a digital survey instrument via surveymonkey.com and the survey web link was distributed to potential participants via email. IP addresses for users accessing the surveymonkey.com web link were not stored. The first question of the survey instrument presented the opportunity for users to provide consent:

“By completing and submitting this questionnaire, you are agreeing to participate in a formal research study of the efficacy of systems engineering training enacted by the Defense Acquisition Workforce Improvement Act (DAWIA). Participation in this study is anonymous; please do not write your name or any other personally identifiable information in the one survey item which provides a comment box for a response in your own language. This survey is configured such that your response will remain anonymous, e.g. your IP address will not be tracked. All responses to the completed questionnaire will be transferred from surveymonkey.com and saved in a password protected folder on the researcher’s computer and will not be shared with anyone. Do you consent to participate in this questionnaire?”

The question allowed a multiple choice response: “I consent” and “I do not consent.” The survey was configured such that, should the “I do not consent” option be selected, the survey results would not be included in the surveymonkey.com compilation of responses for review by the researcher.

CHAPTER 6

IMPLICATIONS & FUTURE RESEARCH

This research endeavor set out to fill a critical gap and resolving the central research question: *What is an appropriate outcome-based competency model which may drive a practical evaluation of a systems engineering training program?* Figure 8 shows the outcome-based competency model for systems engineering trainees which is both theoretically grounded and validated by interviews with experts. Furthermore, the findings in Chapter 5 demonstrate the utility of the model via a practical evaluation of a small sample of a trained systems engineering workforce. The central research question was answered satisfactorily.

Generally, this research contribution resolves a gap in the literature by developing a theoretical model which synthesizes the prevailing theories relating to outcome-based learning and workforce competencies. The model contains 28 outcome-based competencies for systems engineers who were refined via interviews from subject matter experts as a measure to enhance the external validity and practical utility of the model. The revised model organizes the competencies into three tiers which represent a workforce member's on-the-job experience level and job function. This tiered structure implies that the criticality of on-the-job competencies has a temporal dimension, i.e. certain competencies are essential at specific times in an individual's career and others are non-essential. For example, the leadership/managerial competencies are not critical to the success of an entry-level workforce member who is not employed in a leadership or managerial position.

Moreover, because the outcome-based competency model was specifically developed for systems engineering trainees, this implication can be further applied to training systems which are employed to develop workforce competencies. Forethought regarding training outcomes, e.g. workforce competencies, must be applied when mandating when an employee must participate in the training. For example, in the evaluation of DAWIA SPRDE certification training in Chapter 5, the training was shown to be most effective at improving leadership/managerial competencies. However, over 90% of the trainees reported that they were entry-level or journeymen, i.e. not in leadership or managerial positions, at the time they participated in the training. This implies that DAWIA SPRDE training was most effective at improving competencies which were not critical to the trainees at the time in which they participated in DAWIA SPRDE training. To maximize training value, the training should develop and/or improve upon the competencies which are critical to the trainees' role in the workplace, and should deliver skills which can be immediately applied to increase workplace functionality. This can only be achieved if the time at which the training is delivered is matched with the competencies which are identified as critical to the trainees.

The model is not merely academic in nature but also is appropriate for export to practical applications where an evaluation of a trained workforce is needed. Guidelines for generating appropriate metrics to evaluate the perceived improvement in systems engineering competencies resulting from training events are described. When utilized for a specific context, the model is demonstrated to be appropriate for filling specific organizational gaps. As detailed in Chapter 5, this research makes a more specific contribution by answering the Congressional call to action for the development of robust, theoretically grounded evaluation metrics by which the impact of

DAWIA certification can be measured among a workforce of professional systems engineers. The results of the evaluation in Chapter 5 imply two major impacts of DAWIA training:

- Training is effective at improving six individual competencies: requirements analysis, operational comprehension, non-engineering comprehension, boundary definition, technical management, and system management.
- Training efficacy increases among competencies when grouped in the tiered structure in the revised model for research; i.e. training is most ineffective at improving foundational competencies, is less ineffective at improving specialized competencies, and is least ineffective at improving leadership competencies.

Regarding the limitations of the study as it relates to the model validation by subject matter experts, it was noted in Chapter 1 that while each manager had varying experience at differing organizations, increasing the level of diversity among the subject matter experts interviewed should be pursued in the event this research is replicated. This method employs the strategy set forth by Leedy & Ormrod (2010) for increasing external validity generally, e.g. "replicate the research in diverse context and situations to provide evidence that the conclusions have widespread validity and applicability." With more diverse contribution from subject matter experts, the resultant model would not only be rooted in theory and validated by practicing experts but also would also have enhanced external validity.

It is recommended that the practical evaluation in Chapter 5 be replicated to collect a larger sample of data and understand whether the trend shown in Figure 11 changes. It is recommended that the questionnaire deployed to collect data for this widespread evaluation be constructed with additional rigor beyond what was accomplished by this research endeavor. Appendix B contains a discussion on the additional steps which should be taken to ensure maximum content validity.

For a population of 39,167 workforce members, 99% confidence and 2% margin of error, a sample size of 3,761 is necessary. Given a future researcher can enlist broad participation, a longitudinal study may be conducted on a large population of the systems engineering workforce, yielding sufficient data to analyze with traditional statistical methods. A full report from such a study would provide the DoD evidence regarding the statistical significance of DAWIA certification on the participating workforce. Return on investment (ROI) studies may follow to compare the economic investment to workforce improvement gains, offering further opportunities for study in the realm of human capital management among the DoD workforce.

Chapter 5 contains data regarding potential confounding effects, such as the mismatch between the time-in-career at which DAWIA training is mandated and the tiered competencies which the training attempts to improve. For example, the majority of workforce members complete DAWIA training when they are entry-level employees, but the training is least effective at improving entry-level competencies. The workforce members invest considerable time to earn a DAWIA certification, but the skills delivered by the training will not be immediately useful to their jobs; this may contribute to the poorly perceived effectiveness of the training overall. Additional questions arise when considering the confounding effects identified in this study, such as:

- Does time-in-career affect the impact of DAWIA training on workforce competency?
- Do professional duties at the time of DAWIA career field certification affect the impact of DAWIA training on workforce competency?
- Do participants who refer back to DAWIA training material after earning their certification experience a higher competency improvement as a result of the training?
- Has the impact of DAWIA training on workforce competency changed over the 20+ years since the inception of career field certification?

Each question can be pursued via formal inquiry to better understand the nature of DAWIA training impact on workforce competency and is not limited to a specific career field competency.

Opportunities for additional study based on this research are not limited to the training initiatives identified in Chapter 5. As stated previously, the most important contribution of this research is the general competency model described in Chapter 4. While many follow-on studies related to the evaluation in Chapter 5 can and should be pursued by the defense acquisition community, the model in Chapter 4 is appropriate to drive practical evaluations of any systems engineering training program. Professional training in the field of systems engineering is popular among other agencies, including government and private industry, and the training investment ought to be scrutinized for evidence of its value to an organization. The evaluation metrics developed in this study are suitable for export; the survey instrument must only be tailored to identify the training program under scrutiny, e.g. “My participation in Company X Systems Engineering training improved my ability to understand new concepts immediately upon presentation.” A rigorous study of the training impact in terms of critical competencies may provide preliminary input to follow-on investigations of ROI and human capital management among many organizations.

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APPENDIX A: SOCIAL & BEHAVIORAL RESEARCH COURSE COMPLETION REPORT

The following appendix contains the completion report for the Social & Behavioral Research – Basic/Refresher curriculum organized by the Collaborative Institutional Training Initiative (CITI Program). Completion of this course is mandatory to apply for an Internal Review Board (IRB).

COLLABORATIVE INSTITUTIONAL TRAINING INITIATIVE (CITI PROGRAM)

COURSEWORK REQUIREMENTS REPORT*

* NOTE: Scores on this Requirements Report reflect quiz completions at the time all requirements for the course were met. See list below for details. See separate Transcript Report for more recent quiz scores, including those on optional (supplemental) course elements.

- **Name:** Vanessa Lent (ID: 2655419)
- **Email:** vlent001@odu.edu
- **Institution Affiliation:** Old Dominion University (ID: 1771)
- **Institution Unit:** engineering management

- **Curriculum Group:** Social & Behavioral Research - Basic/Refresher
- **Course Learner Group:** Same as Curriculum Group
- **Stage:** Stage 2 - SBR 101 refresher
- **Description:** Choose this group to satisfy CITI training requirements for Investigators and staff involved primarily in Social/Behavioral Research with human subjects.

- **Report ID:** 17834196
- **Completion Date:** 02/15/2016
- **Expiration Date:** 02/14/2017
- **Minimum Passing:** 80
- **Reported Score*:** 90

REQUIRED AND ELECTIVE MODULES ONLY	DATE COMPLETED	SCORE
SBE Refresher 1 – Instructions (ID: 943)	02/15/16	No Quiz
SBE Refresher 1 – History and Ethical Principles (ID: 936)	02/15/16	2/2 (100%)
SBE Refresher 1 – Federal Regulations for Protecting Research Subjects (ID: 937)	02/15/16	2/2 (100%)
SBE Refresher 1 – Informed Consent (ID: 938)	02/15/16	2/2 (100%)
SBE Refresher 1 – Defining Research with Human Subjects (ID: 15029)	02/15/16	2/2 (100%)
SBE Refresher 1 – Privacy and Confidentiality (ID: 15035)	02/15/16	2/2 (100%)
SBE Refresher 1 – Assessing Risk (ID: 15034)	02/15/16	2/2 (100%)
SBE Refresher 1 – Research with Prisoners (ID: 939)	02/15/16	2/2 (100%)
SBE Refresher 1 – Research with Children (ID: 15036)	02/15/16	2/2 (100%)
SBE Refresher 1 – Research in Educational Settings (ID: 940)	02/15/16	2/2 (100%)
SBE Refresher 1 – International Research (ID: 15028)	02/15/16	0/2 (0%)

For this Report to be valid, the learner identified above must have had a valid affiliation with the CITI Program subscribing institution identified above or have been a paid Independent Learner.

CITI Program
Email: citisupport@miami.edu
Phone: 305-243-7970
Web: https://www.citiprogram.org

COLLABORATIVE INSTITUTIONAL TRAINING INITIATIVE (CITI PROGRAM)

COURSEWORK TRANSCRIPT REPORT**

** NOTE: Scores on this Transcript Report reflect the most current quiz completions, including quizzes on optional (supplemental) elements of the course. See list below for details. See separate Requirements Report for the reported scores at the time all requirements for the course were met.

- **Name:** Vanessa Lent (ID: 2655419)
- **Email:** vlent001@odu.edu
- **Institution Affiliation:** Old Dominion University (ID: 1771)
- **Institution Unit:** engineering management

- **Curriculum Group:** Social & Behavioral Research - Basic/Refresher
- **Course Learner Group:** Same as Curriculum Group
- **Stage:** Stage 2 - SBR 101 refresher
- **Description:** Choose this group to satisfy CITI training requirements for Investigators and staff involved primarily in Social/Behavioral Research with human subjects.

- **Report ID:** 17834196
- **Report Date:** 02/15/2016
- **Current Score**:** 90

REQUIRED, ELECTIVE, AND SUPPLEMENTAL MODULES	MOST RECENT	SCORE
SBE Refresher 1 – History and Ethical Principles (ID: 936)	02/15/16	2/2 (100%)
SBE Refresher 1 – Federal Regulations for Protecting Research Subjects (ID: 937)	02/15/16	2/2 (100%)
SBE Refresher 1 – Informed Consent (ID: 938)	02/15/16	2/2 (100%)
SBE Refresher 1 – Research with Prisoners (ID: 939)	02/15/16	2/2 (100%)
SBE Refresher 1 – Research in Educational Settings (ID: 940)	02/15/16	2/2 (100%)
SBE Refresher 1 – Instructions (ID: 943)	02/15/16	No Quiz
SBE Refresher 1 – International Research (ID: 15028)	02/15/16	0/2 (0%)
SBE Refresher 1 – Defining Research with Human Subjects (ID: 15029)	02/15/16	2/2 (100%)
SBE Refresher 1 – Assessing Risk (ID: 15034)	02/15/16	2/2 (100%)
SBE Refresher 1 – Privacy and Confidentiality (ID: 15035)	02/15/16	2/2 (100%)
SBE Refresher 1 – Research with Children (ID: 15036)	02/15/16	2/2 (100%)

For this Report to be valid, the learner identified above must have had a valid affiliation with the CITI Program subscribing institution identified above or have been a paid Independent Learner.

CITI Program
Email: citisupport@miami.edu
Phone: 305-243-7970
Web: https://www.citiprogram.org

APPENDIX B: INTERNAL REVIEW BOARD APPROVAL FOR HUMAN SUBJECTS RESEARCH

OLD DOMINION UNIVERSITY

OFFICE OF THE VICE PRESIDENT FOR RESEARCH

Physical Address
4111 Monarch Way, Suite 203
Norfolk, Virginia 23508
Mailing Address
Office of Research
1 Old Dominion University
Norfolk, Virginia 23529
Phone(757) 683-3460
Fax(757) 683-5902

DATE:	July 6, 2016
TO:	Vanessa Pietrzyk
FROM:	Old Dominion University Institutional Review Board
PROJECT TITLE:	[870967-2] Phase 2 Interviews: "A framework for systems engineering competency metrics: Conceptualized for the Defense Acquisition Workforce"
REFERENCE #:	16-060
SUBMISSION TYPE:	New Project
ACTION:	APPROVED
APPROVAL DATE:	July 6, 2016
EXPIRATION DATE:	April 21, 2017
REVIEW TYPE:	Full Committee Review

Thank you for your submission of New Project materials for this project. The Old Dominion University Institutional Review Board has APPROVED your submission. This approval is based on an appropriate risk/benefit ratio and a project design wherein the risks have been minimized. All research must be conducted in accordance with this approved submission.

This submission has received Full Committee Review based on the applicable federal regulation.

Please remember that informed consent is a process beginning with a description of the project and insurance of participant understanding followed by a signed consent form. Informed consent must continue throughout the project via a dialogue between the researcher and research participant. Federal regulations require each participant receive a copy of the signed consent document.

Please note that any revision to previously approved materials must be approved by this office prior to initiation. Please use the appropriate revision forms for this procedure.

All UNANTICIPATED PROBLEMS involving risks to subjects or others (UPIRSOs) and SERIOUS and UNEXPECTED adverse events must be reported promptly to this committee. Please use the appropriate reporting forms for this procedure. All FDA and sponsor reporting requirements should also be followed.

All NON-COMPLIANCE issues or COMPLAINTS regarding this project must be reported promptly to this committee.

This project has been determined to be a Minimal Risk project. Based on the risks, this project requires continuing review by this committee on an annual basis. Please use the appropriate forms for this procedure. Your documentation for continuing review must be received with sufficient time for review and continued approval before the expiration date of April 21, 2017.

Please note that all research records must be retained for a minimum of three years after the completion of the project.

If you have any questions, please contact Adam Rubenstein at 757-683-3686 or arubenst@odu.edu. Please include your project title and reference number in all correspondence with this committee.

This letter has been electronically signed in accordance with all applicable regulations, and a copy is retained within Old Dominion University Institutional Review Board's records.

OFFICE OF THE VICE PRESIDENT FOR RESEARCH

Physical Address
4111 Monarch Way, Suite 203
Norfolk, Virginia 23508
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1 Old Dominion University
Norfolk, Virginia 23529
Phone(757) 683-3460
Fax(757) 683-5902

DATE:	April 28, 2016
TO:	Holly Handley
FROM:	Old Dominion University Engineering Human Subjects Review Committee
PROJECT TITLE:	[870980-2] Phase 3 Questionnaire: "A framework for systems engineering competency metrics: Contextualized for the Defense Acquisition Workforce."
REFERENCE #:	ENGR 16-04
SUBMISSION TYPE:	Amendment/Modification
ACTION:	DETERMINATION OF EXEMPT STATUS
DECISION DATE:	April 28, 2016
REVIEW CATEGORY:	Exemption category # *6.2*

Thank you for your submission of Amendment/Modification materials for this project. The Old Dominion University Engineering Human Subjects Review Committee has determined this project is EXEMPT FROM IRB REVIEW according to federal regulations.

Please note that your method of administering the survey by email (and email response) or by accepting paper copies is highly unusual and will significantly increase your data entry time. Additionally, people may not want to participate because they may not have confidence that there data are anonymous. Please consider using tools such as survey monkey, Qualtrics (ODU has a site license for this), or a Google form to set up your survey. There is no need to submit a modification if you choose an electronic survey method in an exempt study.

We will retain a copy of this correspondence within our records.

If you have any questions, please contact Stacie Ringleb at 757-683-6363 or sringleb@odu.edu. Please include your project title and reference number in all correspondence with this committee.

This letter has been electronically signed in accordance with all applicable regulations, and a copy is retained within Old Dominion University Engineering Human Subjects Review Committee's records.

APPENDIX C: MANAGER INTERVIEW QUESTIONS

General

1. Were you able to read through and understand the evaluation metrics that were provided to you prior to this interview?
2. Do you require clarification on any of the metrics before the interview continues?
3. What is your educational background? For example, do you have a college degree and if so, in what field is your degree?

DAWIA Experience

4. When did you complete the DAWIA SPRDE-SE Level III certification?
5. At what point in your career did you participate in training for DAWIA SPRDE-SE Level III certification: beginning (first 5 years of your career), mid-level (5-15 years into your career), or later (15 years or more into your career)?
6. Have you pursued additional DAWIA career field certifications and, if so, was it a requirement for your employment?
7. Aside from DAWIA training for a SPRDE-SE career field certification, have you completed any coursework or professional training in systems engineering? Please identify if any coursework or professional training was completed as part of the continuous learning requirement to maintain the DAWIA SPRDE-SE Level III certification.
8. Would you describe your experience as a DAWIA training participant as constructive, not constructive, or neither? Please elaborate on your choice.

Evaluation Metrics

9. Think of the 32 metrics as a set of professional skills that are needed for individuals in your workforce to be successful in the workplace. Describe the applicability of the 32 metrics to your workforce. For example, metric 4-3 is not a necessary skill for employees to be successful in my workforce; or metric 6-1 is identified in the workplace mission statement as a critical skill.

Evaluation Metrics – Coupled with DAWIA

10. Considering again that the metrics are a set of professional skills, did your participation in DAWIA SPRDE-SE training contribute to the development and/or improvement of any of these skills? Which skills in particular? For example, DAWIA training greatly improved my ability to define the boundaries of a system, which is the definition of metric 2-4.
11. When members of your workforce participate in DAWIA training, do you notice a change in their professional output, attitude, or performance that is either positive or negative? Do any of the changes align with the metrics? For example, I notice that employees return from DAWIA training with an improved ability to understand a system as a whole, rather than just understand and focus on their piece of the system; this aligns with the definition of metric 3-1.

APPENDIX D: QUESTIONNAIRE

Metric Description	Survey Question	Response Options
	By completing and submitting this questionnaire, you are agreeing to participate in a formal research study of the efficacy of systems engineering training enacted by the Defense Acquisition Workforce Improvement Act (DAWIA). Participation in this study is anonymous; please do not write your name or any other personally identifiable information in the one survey item which provides a comment box for a response in your own language. This survey is configured such that your response will remain anonymous, i.e. your IP address will not be tracked. All responses to the completed questionnaire will be transferred from surveymonkey.com and saved in a password protected folder on the researcher's computer and will not be shared with anyone. Do you consent to participate in this questionnaire?	Y/N* N turns off survey
Highest level of certification	What is the highest DAWIA SPRDE-SE certification level you have completed? A) None. B) Level I. C) Level II. D) Level III.	Multiple choice
	What approximate date did you complete your highest level DAWIA certification?	MM/DD/YYY
New concept comprehension	My participation in DAWIA training improved my ability to understand new concepts immediately upon presentation.	Five level Likert scale
	My participation in DAWIA training improved my ability to formulate relevant questions when discussing a project in the workplace.	Five level Likert scale
	My participation in DAWIA training improved my ability to formulate relevant questions, without relying on the guidance of others, to promote my understanding of a new concept.	Five level Likert scale
Interconnectivity	My participation in DAWIA training improved my ability to understand the importance of synergy among sub-systems.	Five level Likert scale
	My participation in DAWIA training improved my ability to understand and appreciate the interconnectivity of system components.	Five level Likert scale
	My participation in DAWIA training improved my ability to understand how separate systems can be interrelated.	Five level Likert scale
Perspective	My participation in DAWIA training improved my ability to appreciate perspectives that may be different than my own when performing systems analysis.	Five level Likert scale
	My participation in DAWIA training improved my ability to consider multiple perspectives when dealing with a	Five level Likert scale

	project decision.	
	My participation in DAWIA training improved my ability to consider the perspectives of other experts when making decisions in the workplace.	Five level Likert scale
Growth limitations	My participation in DAWIA training improved my ability to understand the limits to system growth.	Five level Likert scale
	My participation in DAWIA training improved my ability to acknowledge the limitations of a growing technology or capability.	Five level Likert scale
	My participation in DAWIA training improved my ability to consider a system's limitations for growth when making design decisions.	Five level Likert scale
Boundary definition	My participation in DAWIA training improved my ability to identify boundaries of a new system concept.	Five level Likert scale
	My participation in DAWIA training improved my ability to acknowledge relevant boundaries when considering the scope of a problem or project.	Five level Likert scale
	My participation in DAWIA training improved my ability to acknowledge the pre-defined boundaries when making design decisions.	Five level Likert scale
High-level understanding	My participation in DAWIA training improved my ability to consider the whole system, beyond what my singular duties may be.	Five level Likert scale
	My participation in DAWIA training improved my ability to take a holistic approach to system design and maintenance.	Five level Likert scale
	My participation in DAWIA training improved my ability to comprehend the "big picture" when working on a systems project.	Five level Likert scale
Innovative thinking	My participation in DAWIA training improved my ability to think creatively while still acknowledging relevant boundaries and limitations.	Five level Likert scale
	My participation in DAWIA training improved my ability to be innovative, when given the opportunity.	Five level Likert scale
	My participation in DAWIA training improved my ability to contribute creative solutions with confidence.	Five level Likert scale
Minutia avoidance	My participation in DAWIA training improved my ability to understand a system or concept without getting stuck on minor details.	Five level Likert scale
	My participation in DAWIA training improved my ability to manage minor tasks and problems without interrupting system productivity.	Five level Likert scale
	My participation in DAWIA training improved my ability to comprehend system concepts even if minor details are vague or missing.	Five level Likert scale
Change implication	My participation in DAWIA training improved my ability to understand the implications of a proposed change.	Five level Likert scale
	My participation in DAWIA training improved my ability to forecast the impact of a proposed change.	Five level Likert scale
	My participation in DAWIA training improved my ability to adapt if a system or design change is implemented.	Five level Likert scale

Implementation	My participation in DAWIA training improved my ability to create a plan for introducing new concepts, ideas, and/or technology into an existing project or system.	Five level Likert scale
	My participation in DAWIA training improved my ability to successfully execute a plan for innovation or change into an existing system or project.	Five level Likert scale
	My participation in DAWIA training improved my ability to create new plans in a professional project with confidence.	Five level Likert scale
Non-engineering comprehension	My participation in DAWIA training improved my ability to consider non-engineering factors.	Five level Likert scale
	My participation in DAWIA training improved my ability to understand that non-engineering factors may be relevant to my system.	Five level Likert scale
	My participation in DAWIA training improved my ability to welcome the opportunity to integrate non-engineering factors into a system, if necessary.	Five level Likert scale
Prediction	My participation in DAWIA training improved my ability to "see" the future of a system or concept.	Five level Likert scale
	My participation in DAWIA training improved my ability to make predictions about future needs when I understand a system well.	Five level Likert scale
	My participation in DAWIA training improved my ability to predict future needs and objectives regarding a system so that I may prepare myself.	Five level Likert scale
Optimization	My participation in DAWIA training improved my ability to take advantage of an opportunity for optimization when one arises.	Five level Likert scale
	My participation in DAWIA training improved my ability to consider optimization even in the initial stages of a system design.	Five level Likert scale
	My participation in DAWIA training improved my ability to implement optimization strategies if they are relevant and achievable.	Five level Likert scale
Understand training needs	My participation in DAWIA training improved my ability to identify the training needs for a group of employees.	Five level Likert scale
	My participation in DAWIA training improved my ability to compose an appropriate training plan for a workforce.	Five level Likert scale
	My participation in DAWIA training improved my ability to identify training opportunities which would deliver the skills that employees are lacking in a workplace.	Five level Likert scale
Operational comprehension	My participation in DAWIA training improved my ability to understand the operational environment of a system.	Five level Likert scale
	My participation in DAWIA training improved my ability to develop a concept of operations (CONOPS).	Five level Likert scale
	My participation in DAWIA training improved my ability to consider a system's operational environment and CONOPS when making decisions.	Five level Likert scale
Requirements analysis	My participation in DAWIA training improved my ability to perform requirements analysis.	Five level Likert scale
	My participation in DAWIA training improved my ability to account for system requirements when working on a	Five level Likert scale

	system.	
	My participation in DAWIA training improved my functional knowledge of requirements analysis software.	Five level Likert scale
Solution conceptualization	My participation in DAWIA training improved my ability to conceptualize an achievable solution to a systems problem.	Five level Likert scale
	My participation in DAWIA training improved my ability to generate the logical solution when faced with a systems problem.	Five level Likert scale
	My participation in DAWIA training improved my ability to consider logical constraints when developing an achievable solution to a problem.	Five level Likert scale
Solution manifestation	My participation in DAWIA training improved my ability to generate a physical solution after developing a solution concept.	Five level Likert scale
	My participation in DAWIA training improved my confidence that I am capable of generating physical solutions to systems problems.	Five level Likert scale
	My participation in DAWIA training improved my ability to confidently bring a solution plan to fruition.	Five level Likert scale
Use of tools	My participation in DAWIA training improved my functional knowledge of various simulation tools to perform system engineering duties.	Five level Likert scale
	My participation in DAWIA training improved my ability to comfortably use a variety of system engineering software tools.	Five level Likert scale
	My participation in DAWIA training improved my ability to select the appropriate software to solve a systems engineering problem.	Five level Likert scale
System management	My participation in DAWIA training improved my ability to understand each of the processes at play within a system.	Five level Likert scale
	My participation in DAWIA training improved my ability to understand the relationship between multiple processes within a system.	Five level Likert scale
	My participation in DAWIA training improved my ability to effectively manage critical system processes.	Five level Likert scale
Trade analysis	My participation in DAWIA training improved my ability to perform effective trade analyses.	Five level Likert scale
	My participation in DAWIA training improved my ability to identify critical trade analyses that must be completed.	Five level Likert scale
	My participation in DAWIA training improved my functional knowledge of the software tools to conduct trade analyses.	Five level Likert scale
Ancillary management	My participation in DAWIA training improved my ability to manage ancillary duties in addition to my primary duties.	Five level Likert scale
	My participation in DAWIA training improved my ability to manage my time effectively to allow for the successful completion of extraneous duties, in addition to primary duties.	Five level Likert scale

	My participation in DAWIA training improved my ability to effectively prioritize primary and ancillary duties.	Five level Likert scale
Collaboration	My participation in DAWIA training improved my ability to comfortably collaborate with team members and external stakeholders.	Five level Likert scale
	My participation in DAWIA training improved my ability to communicate effectively in the workplace.	Five level Likert scale
	My participation in DAWIA training improved my ability to successfully communicate my ideas and work with team members and stakeholders.	Five level Likert scale
Professional desire	My participation in DAWIA training increased my desire to work with systems projects.	Five level Likert scale
	My participation in DAWIA training improved the alignment of my professional goals and the position I currently maintain.	Five level Likert scale
	My participation in DAWIA training improved my belief that my skills are well-suited for working with systems projects.	Five level Likert scale
Tolerance for failure	My participation in DAWIA training improved my ability to tolerate failure.	Five level Likert scale
	My participation in DAWIA training improved my ability to accept failure when it occurs and continue to work toward a solution.	Five level Likert scale
	My participation in DAWIA training improved my ability to perform failure analysis to learn from past failures.	Five level Likert scale
Leadership	My participation in DAWIA training improved my ability to lead teams.	Five level Likert scale
	My participation in DAWIA training increased my confidence as a team leader.	Five level Likert scale
	My participation in DAWIA training increased my suitability for leadership positions.	Five level Likert scale
Technical management	My participation in DAWIA training improved my ability to perform effective technical management.	Five level Likert scale
	My participation in DAWIA training improved my ability to understand the unique demands of performing technical management, as opposed to non-technical management.	Five level Likert scale
	My participation in DAWIA training improved my ability to manage technical teams and projects.	Five level Likert scale
Autonomy	My participation in DAWIA training improved my ability to operate autonomously when working on a project.	Five level Likert scale
	My participation in DAWIA training improved my ability to perform independent self-learning.	Five level Likert scale
	My participation in DAWIA training improved my ability to working effectively with minimal or no oversight from management.	Five level Likert scale

Tier (now)	Select one of the following which most accurately describes the nature of your current job. A) I have a leadership / management role and I am responsible for a team which is comprised of individuals from multiple disciplines. In my work, I must focus on the management of a complex system which has many sub-systems and interfaces; it is critical that I have a holistic understanding of the system. I am also responsible for program management duties, such as budget formulation, contract execution, policy adherence, etc. B) I am mostly responsible for myself at work, or I am responsible for a small team of engineers and scientists. I work on a subsystem of a larger, more complex system; it is not critical that I have a holistic view of the larger system. My job duties rarely, or never, include program management activities such as budget formulation, contract execution, and policy adherence. C) Neither A nor B accurately describe my current job.	Multiple choice
Tier (at time of DAWIA)	Select one of the following which most accurately describes the nature of your job at the time you participated in coursework for DAWIA SPRDE-SE certification: A) I have a leadership / management role and I am responsible for a team which is comprised of individuals from multiple disciplines. In my work, I must focus on the management of a complex system which has many sub-systems and interfaces; it is critical that I have a holistic understanding of the system. I am also responsible for program management duties, such as budget formulation, contract execution, policy adherence, etc. B) I am mostly responsible for myself at work, or I am responsible for a small team of engineers and scientists. I work on a subsystem of a larger, more complex system; it is not critical that I have a holistic view of the larger system. My job duties rarely, or never, include program management activities such as budget formulation, contract execution, and policy adherence. C) Neither A nor B accurately describe the nature of my job at the time I participated in coursework for DAWIA SPRDE-SE certification.	Multiple choice
Continuous learning	Are you currently up-to-date with the required continuous learning to maintain your DAWIA SPRDE-SE certification? A) Yes. B) No. C) I have not yet earned a DAWIA SPRDE-SE certification and thus, the continuous learning requirement does not apply to me.	Multiple choice
	Describe the continuous learning activities you have completed in order to maintain your DAWIA SPRDE-SE certification.	Comment box
Revisit DAWIA material	How often do you refer back to the material presented in the coursework for the DAWIA SPRDE-SE certification? A) Frequently. B) Occasionally. C) Rarely. D) Never.	Multiple choice
DAWIA at time in career	Select one of the following which most accurately describes your time-in-career level at the time you participated in coursework for DAWIA SPRDE-SE certification: A) In the first 5 years of my career. B) 5-15 years into my career. C) After 15 years into my career.	Multiple choice

Educational background	Check all that apply to the nature of your educational background: 1) Academic degree in systems engineering. 2) Professional training in systems engineering. 3) Academic degree in an engineering program that is NOT systems engineering. 4) Academic degree in a technical/scientific/mathematics field that is NOT engineering. 5) Academic degree in a field other than engineering or any technical/scientific/mathematics field.	Multiple options

B.1 Content Validity for Questionnaire

Content validity is the degree to which elements of an assessment instrument are relevant to and representative of the targeted construct for a particular assessment purpose (Haynes et al., 1995). Construct refers to the concept, attribute, or variable that is the target of measurement. The construct for this research is the degree to which training improves critical systems engineering competencies. The construct domain is the refined outcome-based competency model for systems engineering trainees. Data from an invalid instrument can over-represent, omit, or under-represent some competencies in the model and reflect variables outside the construct domain. A content-invalid assessment instrument could drive erroneous inferences about the impact of training on critical competencies for systems engineering trainees because estimates of shared variance would be based on erroneous measures of the construct. This section discusses the process by which content validity was established for the questionnaire administered in Chapter 5.

Content validation is a multi-method, quantitative, and qualitative process that is applicable to all elements of an assessment instrument. Haynes et al. (1995) identify a 24-step sequence for content validation which can be applied for a self-report questionnaire from the perspective of educational and personnel assessment. Considering the major contribution of this research was the theoretical model and not the evaluation performed by the questionnaire, a rigorous content validation was not performed; this is identified as a limitation of the research. Of the 24 steps, 19 were completed prior to deployment of the questionnaire; the remaining five steps require additional interviews with subject matter experts and multiple rounds of evaluations of the questionnaire among a targeted population and are outside the scope of the research effort. Future research, wherein a widespread evaluation of the SPRDE-SE workforce is performed to examine the efficacy of DAWIA certification, should include additional rigor when constructing and validating an assessment instrument.

1. Specify the construct targeted by the instrument.
    a. The construct is the degree to which DAWIA SPRDE-SE certification training improves critical systems engineering competencies.
2. Specify the domain of the construct.
    a. The construct domain is the refined outcome-based competency model for systems engineering trainees; the development of this model is described in Chapter 3 and Chapter 4.
3. What is to be included?
    a. All 28 competencies in the theoretical model, linked to the DAWIA SPRDE-SE training impact;
    b. Details regarding the participation in DAWIA SPRDE-SE training, i.e. time, job-function, level of completion, and frequency of review of course material after training is complete.
    c. Certification maintenance.

4. What is to be excluded?
    a. All information that is not listed in Step #3.
5. Specify the facets and dimensions of the construct factors to be covered.
    a. The participant’s perceived improvement of each of the 28 competencies from the refined model as a result of DAWIA SPRDE-SE;
    b. The participant’s highest level of DAWIA SPRDE-SE certification achieved;
    c. The participant’s estimated date at which the highest level of DAWIA SPRDE-SE certification was achieved;
    d. A description of the participant’s job functions and time-in-career at the time he/she participated in training for DAWIA SPRDE-SE certification.
    e. A description of the participant’s job functions at the time he/she is completing the questionnaire.
    f. Whether the participant is up-to-date on the continuous learning requirements to maintain his/her DAWIA SPRDE-SE certification.
    g. A description of the continuous learning that the participant has completed to maintain his/her DAWIA SPRDE-SE certification.
    h. The frequency to which the participant reviews DAWIA SPRDE-SE certification course material.
    i. A description of the participant’s educational background: academic and professional.
6. What are the dimensions?
    a. Magnitude of perceived improvement of competencies as a result of DAWIA SPRDE-SE training.

   b. Frequency to which training material is revisited.

7. What is the mode?
   a. Thoughts (perception of improvement and performance), behaviors.
8. What are the temporal parameters?
   a. There are no temporal parameters identified for this questionnaire.
9. Describe the relevant situations.
   a. A participant is or was a member of the defense acquisition workforce and has completed the coursework to achieve and maintain a DAWIA SPRDE-SE certification. The participant recalls enough about the training to provide information on their perceived improvement as a result of the training.
10. Specify the intended functions of the instrument.
    a. To perform an evaluation of the improvement of systems engineering competencies among a workforce as a result of DAWIA SPRDE-SE training.
11. Select the assessment method to match targeted construct and function of the assessment.
    a. Electronic questionnaire (surveymonkey.com).
12. Perform the initial selection and generation of items.
    a. Complete; process is described in Chapter 5.
13. Match items to facets and dimensions.
    a. Complete; process is described in Chapter 5.
14. Generate multiple items for each facet; ensure proportional representation of items across facets.
    a. Complete; process is described in Chapter 5.

15. Examine structure, form, topography, and content of each item, and appropriateness of each item for construct.
    a. Completed by the researcher.
16. Promote consistency and accuracy, specificity, and clarity of wording.
    a. Completed by the researcher.
17. Remove redundant items.
    a. Completed by the researcher.
18. Establish quantitative parameters, response format and scales, and time-sampling parameters.
    a. Complete; process is described in Chapter 5. Full questionnaire with response format and scales is contained in Appendix B.
19. Provide instructions to participants to match each item in the assessment instrument to domain and function.
    a. This step was not performed for this research.
20. Clarify language in assessment items and strive for specificity and appropriate grammatical structure.
    a. Completed by the researcher.
21. Have experts review the results of the quantitative evaluations of construct definition, domain, facets, mode, and dimensions. Instruct experts to provide qualitative evaluation of relevance and representativeness of assessment items, quantitative evaluation of response formats, scales, time-sampling parameters, data reduction, and aggregation.
    a. This step was not performed for this research.

22. Have a targeted population sample the results, review quantitative and qualitative evaluation of items. Modify the assessment instrument as appropriate.
    a. *This step was not performed for this research.*
23. Have experts and the targeted population re-review the modified assessment instrument.
    a. *This step was not performed for this research.*
24. Perform a psychometric evaluation and contingent instrument refinement using criteria related to construct validity and factor analysis.
    a. *This step was not performed for this research.*

VITA

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Doctor of Philosophy, Engineering Management & Systems Engineering, Old Dominion University, Norfolk, VA., 2016.

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Work Experience:

Dr. Pietrzyk is currently an engineer at Strategic Systems Programs in support of the Navy's Fleet Ballistic Missile program. She was formerly an Adjunct Faculty member in the Masters of Business Administration program at the University of Phoenix, Asia Military Campus, in Yokosuka, Japan. She also served as a Lecturer for the undergraduate campus at the University of Maryland University College in Yokosuka, Japan. She has over 10 years of experience as an aerospace and systems engineer for innovative DoD weapons systems, both in the science and technology phase and acquisition phase of development. She was awarded the 2011 Dr. Delores M. Etter Top Scientists and Engineers of the Year Award by the Assistant Secretary of the Navy.

Publications:

Outcome-based competency model for systems engineering training (co-author), *Symposium conducted at the 2016 IEEE International Symposium on Systems Engineering*, Edinburgh, 2016.

An investigation of the effectiveness of mandatory training among the U.S. Defense Acquisition Workforce (co-author), *Symposium conducted at the 2016 IEEE International Symposium on Systems Engineering*, Edinburgh, 2016.

Experimental detection & quantitative interrogation of damage in a jointed composite structure, *Journal of Intelligent Material Systems and Structures, 21*, 275-283, 2010.