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Factors Influencing the Effectiveness of Systems Engineering Training and Education in the Department of Defense

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Preface & Acknowledgements

During his internship with the Graduate School of Business & Public Policy in June 2010, U.S. Air Force Academy Cadet Chase Lane surveyed the activities of the Naval Postgraduate School's Acquisition Research Program in its first seven years. The sheer volume of research products—almost 600 published papers (e.g., technical reports, journal articles, theses)—indicates the extent to which the depth and breadth of acquisition research has increased during these years. Over 300 authors contributed to these works, which means that the pool of those who have had significant intellectual engagement with acquisition issues has increased substantially. The broad range of research topics includes acquisition reform, defense industry, fielding, contracting, interoperability, organizational behavior, risk management, cost estimating, and many others. Approaches range from conceptual and exploratory studies to develop propositions about various aspects of acquisition, to applied and statistical analyses to test specific hypotheses. Methodologies include case studies, modeling, surveys, and experiments. On the whole, such findings make us both grateful for the ARP's progress to date, and hopeful that this progress in research will lead to substantive improvements in the DoD's acquisition outcomes.

As pragmatists, we of course recognize that such change can only occur to the extent that the potential knowledge wrapped up in these products is put to use and tested to determine its value. We take seriously the pernicious effects of the so-called "theory–practice" gap, which would separate the acquisition scholar from the acquisition practitioner, and relegate the scholar's work to mere academic "shelfware." Some design features of our program that we believe help avoid these effects include the following: connecting researchers with practitioners on specific projects; requiring researchers to brief sponsors on project findings as a condition of funding award; "pushing" potentially high-impact research reports (e.g., via overnight shipping) to selected practitioners and policy-makers; and most notably, sponsoring this symposium, which we craft intentionally as an opportunity for fruitful, lasting connections between scholars and practitioners.

A former Defense Acquisition Executive, responding to a comment that academic research was not generally useful in acquisition practice, opined, "That's not their [the academics'] problem—it's ours [the practitioners']. They can only perform research; it's up to us to use it." While we certainly agree with this sentiment, we also recognize that any research, however theoretical, must point to some termination in action; academics have a responsibility to make their work intelligible to practitioners. Thus we continue to seek projects that both comport with solid standards of scholarship, and address relevant acquisition issues. These years of experience have shown us the difficulty in attempting to balance these two objectives, but we are convinced that the attempt is absolutely essential if any real improvement is to be realized.

We gratefully acknowledge the ongoing support and leadership of our sponsors, whose foresight and vision have assured the continuing success of the Acquisition Research Program:

- Office of the Under Secretary of Defense (Acquisition, Technology & Logistics)
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James B. Greene, Jr.
Rear Admiral, U.S. Navy (Ret.)

Keith F. Snider, PhD
Associate Professor

Panel 16 – Contributions of Systems Engineering to Effective Acquisition

Thursday, May 12, 2011	
9:30 a.m. – 11:00 a.m.	**Chair: Rear Admiral John Clarke Orzalli,** USN, Vice Commander, Naval Sea Systems Command ***Control of Total Ownership Costs of DoD Acquisition Development Programs Through Integrated Systems Engineering Processes and Metrics*** Paul Montgomery and Ron Carlson, NPS ***Applying an Influencer Approach to Ingrain Systems Engineering into Pre-Milestone B Defense Programs*** Bob Keane, Ship Design USA, Inc. ***Factors Influencing the Effectiveness of Systems Engineering Training and Education in the Department of Defense*** William Fast, NPS

Rear Admiral Orzalli—Vice Commander, Naval Sea Systems Command (NAVSEA). Rear Admiral Orzalli is the son of a retired Navy captain. He graduated with distinction from the U.S. Naval Academy in 1978.

At sea, he served aboard USS *Snook* (SSN 592) as an engineering division and weapons officer; and as USS *Helena's* (SSN 725) engineering officer. Ashore, Orzalli has served at the U.S. Naval Academy, as well as tours at naval shipyards in Mare Island, Puget Sound, and Portsmouth.

Orzalli was the 45th shipyard commander at Puget Sound Naval Shipyard from 2002–2005. During his command tour, he assumed additional duties in establishing the Northwest Regional Maintenance Center. Following selection to flag rank, Orzalli was the deputy director, Fleet Readiness Division, OPNAV (N43B); commanding officer, Mid-Atlantic Regional Maintenance Center, then established commander, Regional Maintenance Centers.

Most recently, Orazalli was the director, Fleet Maintenance on the staff of commander, U.S. Fleet Forces Command. His service decorations include the Legion of Merit (with four stars), the Meritorious Service Medal (with two stars), Navy Commendation Medal (with star), Navy and Marine Corps Achievement Medal (with three stars) and various other unit and operational awards.

Orzalli holds a Bachelor of Science in Marine Engineering from the U.S. Naval Academy, Naval Engineer, a Master of Materials Science and Engineering from Massachusetts Institute of Technology, and a Master of Science in Systems Management from Golden Gate University.

Factors Influencing the Effectiveness of Systems Engineering Training and Education in the Department of Defense

William Fast—COL, USA (Ret.). COL Fast facilitates acquisition and program management courses at the Naval Postgraduate School. He also writes and speaks on various management topics and provides consultation services to defense acquisition programs. From 2006–2010, COL Fast taught program and financial management courses at the Defense Acquisition University.

Abstract

While current systems engineering certification courses within the Department of Defense appear to do a pretty good job of training and educating the workforce, improvements can be made. The use of more problem-based methods of learning would equip the students with better problem identification and reasoning skills needed to solve the complex problems they encounter on the job. Learning outcomes in some of these courses could be rewritten to target the *analyze, evaluate,* and *create* levels of Bloom's Taxonomy, thereby improving student critical thinking skills and ultimately improving far-transfer of learning to the job. Also, learning assessment methods in a few of the courses could be changed to focus more on the assessment of conceptual understanding, vice rote memorization, in order to promote deep learning. Recommendations are also presented for additional research into a more effective systems engineering andragogy.

Purpose

Competency-based training for defense acquisition workers in the systems engineering discipline is accomplished through a continuum of four courses developed and delivered by the Defense Acquisition University (DAU):

- SYS 101 Fundamentals of Systems Engineering; computer-based distanced learning; 35 hours.
- SYS 202 Intermediate Systems Planning, Research, Development and Engineering, Part 1; computer-based distance learning; 30 hours.
- SYS 203 Intermediate Systems Planning, Research, Development and Engineering, Part 2; resident course; 36 hours.
- SYS 302 Technical Leadership in Systems Engineering; a resident course; 68 hours.

The primary purpose of this research was to determine if the methods and objectives of these systems engineering certification courses encourage a deep approach to learning and far-transfer of that learning (i.e., the students are able to apply what they have learned on the job). Ultimately, the effectiveness of systems engineering training within the Department of Defense does affect the outcome of systems acquisition programs.

Method

A literature search revealed that a problem-based approach to teaching systems engineering, with the primary objective of developing the student's ability to reason and solve complex problems (i.e., develop critical thinking skills), would result in deep learning and promote skill transfer to the job. Therefore, I decided to study the current design of systems engineering courses to determine how much problem-based instruction was actually used. To gauge the stimulation of student critical thinking skills in these courses, I examined student learning outcomes for each of the systems engineering courses discussed above. I also examined the learning assessments for each course to determine if they had been designed to promote deep or surface learning by the students.

Student course materials and learning objectives from the four systems engineering certification courses discussed previously were analyzed in three ways. First, student materials were inspected to determine the time allocated to computer-based training (CBT), lectures, and problem-based exercises in each of the courses. These student course materials are available to the public on the DAU *iCatalog* website (DAU, 2011).

Second, the lesson objectives (expected student outcomes) for each of the four systems engineering certification courses were categorized according to their required levels of functional thought, using Bloom's Taxonomy (Bloom, 1956, updated in accordance with Figure 1). Specifically, the measureable action verb from each learning objective was placed into one of the six Bloom categories representing the cognitive activity required by the student to successfully demonstrate that objective. The lesson objectives are available to the public on the DAU *iCatalog* website (DAU, 2011).

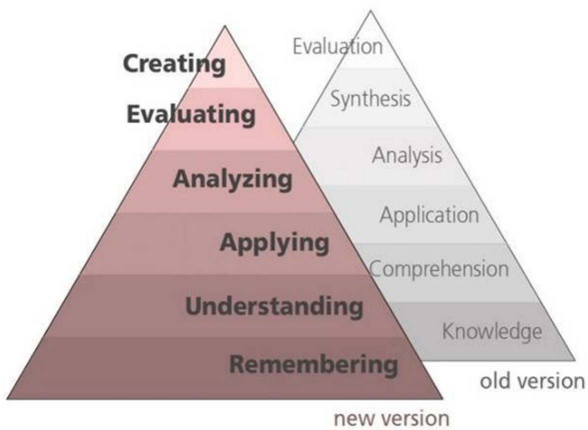

Figure 1. Bloom's Taxonomy
(Rodgers, 2011)
Note. This figure contrasts the original (old) version with an updated (new) version; note changes in top two levels.

Third, the course learning objectives (expected student outcomes) from three selected systems engineering courses developed and delivered by the Naval Postgraduate School (NPS) were categorized according to their required levels of functional thought, using Bloom's Taxonomy. The three courses were as follows:

- SE3100 Fundamentals of Systems Engineering; resident and distance learning; 5 quarter hours (3 lecture/2 lab); equivalent to DAU SYS 101, SYS 202, and SYS 203.
- SI3400 Fundamentals of Engineering Project Management; distance learning; 5 quarter hours (3 lecture/2 lab); equivalent to DAU SYS 302.
- SE4012 Management of Advanced Systems Engineering; distance learning; 4 quarter hours (4 lecture/0 lab); equivalent to DAU SYS 302.

The course learning objectives were obtained from Professor Gary Langford of the Systems Engineering Department, Graduate School of Engineering and Applied Sciences, NPS.

Finally, student learning assessments were examined in the four DAU and the three NPS systems engineering course to determine if the current assessments promoted deep or surface learning. Surface learning is promoted by assessments that emphasize recall based upon rote memorization. Deep learning is promoted by assessing the student's understanding of topics (Felder & Brent, 2005, p. 64).

Results

Time allocated to computer-based training (CBT), lectures, and problem-based instruction in each of the four systems engineering certification courses developed and delivered by DAU are found in Table 1.

Table 1. DAU Systems Engineering Course Hours Categorized by Method of Instruction
(DAU, 2011)

Course	CBT Hours	Lecture Hours	Problem-Based Hours	Total Hours
SYS 101	35			35
SYS 202	30			30
SYS 203		9	27	36
SYS 302		21	47	68
Totals	65	30	74	169
Percentage	**38.46%**	**17.75%**	**43.79%**	**100%**

Lesson learning objectives (expected student outcomes), categorized by Bloom's level, for each of the four systems engineering certification courses developed and delivered by DAU are found in Table 2.

Table 2. DAU Systems Engineering Course Objectives Categorized by Bloom's Level
(DAU, 2011)

Course	Remember	Understand	Apply	Analyze	Evaluate	Create	Total Objectives
SYS 101	14	138	1	1			154
SYS 202	1	29					30
SYS 203	3	9	5	6	12	1	36
SYS 302	2	49	14	8	24	28	125
Totals	20	225	20	15	36	29	345
Percentage	**5.80%**	**65.22%**	**5.80%**	**4.45%**	**10.43%**	**8.41%**	**100%**

Course learning objectives (expected student outcomes), categorized by Bloom's level, for three selected systems engineering courses developed and delivered by NPS are found in Table 3.

Table 3. NPS System Engineering Course Objectives Categorized by Bloom's Level
(NPS, 2011)

Course	Remember	Understand	Apply	Analyze	Evaluate	Create	Total Objectives
SE 3100	2	1	2	2	1	2	10
SI 3400	1	1	6	1		1	10
SE 4012	2	2	1	1		1	7
Totals	5	4	9	4	1	4	27
Percentage	**18.52%**	**14.81%**	**33.33%**	**14.81%**	**3.70%**	**14.81%**	**100%**

The types of assessments used in the four DAU systems engineering certification courses and the three NPS systems engineering courses are found in Table 4.

Table 4. Types of Learning Assessments Used in DAU and NPS Systems Engineering Courses
(DAU, 2011; NPS, 2011)

Assessment	SYS 101	SYS 202	SYS 203	SYS 302	SE 3100	SI 3400	SE 4012
Objective Exam/Quiz	X	X	X	X	X	X	X
Subjective Exam/Quiz					X	X	X
Homework					X	X	X
Discussion Participation			X		X	X	X
Reflective Writing						X	
Individual Briefing			X	X	X	X	X
Individual Project					X	X	X
Team Project			**X**	**X**	**X**	**X**	**X**

Discussion

The results of this research, as presented in Table 1, reveal that DAU systems engineering certification courses use a mix of computer-based training, lecture, and problem-based instruction. The SYS 101 and SYS 202 courses are designed as computer-based training for individuals and have no student-led problem-solving exercises. However, SYS 202 does use an integrated case study to help the student understand systems engineering in the context of a notional defense weapon system. The SYS 203 course was designed as the exercise extension of SYS 202, so students in SYS 203 spend about 75% of the class time in problem-solving exercises. Problem-solving exercises also account for 69% of the class hours in the SYS 302 course. Thus, two of the four DAU systems engineering certification courses do provide students with significant amounts of problem-based instruction.

With respect to student learning objectives, the DAU SYS 203 and SYS 302 courses grade out at higher Bloom's levels (*analyze, evaluate,* and *create*) in about half of their learning objectives (see Table 2). These top three Bloom's levels are usually associated with critical thinking. Bloom's *understand* level predominates in the other two DAU systems engineering courses.

Half of the student learning objectives for the NPS SE3100 course grade out at the critical thinking level (e.g., *analyze, evaluate,* and *create*; see Table 3). Bloom's *apply* level predominates in the NPS SI3400 course and the *remember* and *understand* levels are the focus of the NPS SE4012 course.

It should be noted that Tables 2 and 3 are not directly comparable. The assessment in Table 2 is based upon *lesson objectives* in the four DAU systems engineering certification courses, of which there are a great number. The assessment in Table 3 is based upon *course objectives* from the three NPS systems engineering courses, of which there are but a few. Also, the number of hours of CBT, lecture, and problem-based instruction in the NPS courses was not clearly identified on the syllabi examined. Therefore, no categorization of instructional methods for the NPS courses was possible (and methods can be expected to vary by instructor).

With respect to course assessments, further research into the types of objective and subjective questions is needed to conclusively determine if the questions really assess the depth of student learning (see Table 4). However, deep learning by the students taking the SYS 101 and SYS 201 courses might be encouraged through the use of other assessment methods besides online multiple choice exams. While this might seem difficult for computer-based training, it is certainly not impossible. For example, computer simulations, scored games, and intelligent essay assessors might be used. The other DAU certification courses and the three NPS courses appear to have a good mix of both objective and subjective assessments that encourage a deep approach to learning.

Based upon this research, deep learning, which promotes the development of critical thinking skills, can occur in the SYS 203 and SYS 302 courses when students are involved in problem-based exercises. However, both SYS 101 and SYS 201 could be improved by adding problem-solving scenarios to stimulate the mind and help students build more sophisticated mental models of the systems engineering discipline earlier in their training. Also, more of the lesson objectives within all of the DAU systems engineering courses could be written with verbs that target the *analyze, evaluate,* and *create* levels of Bloom's Taxonomy.

Some might argue that the systems engineering fundamentals course (SYS 101) and intermediate course (SYS 201) have to first target the *remember* and *understand* Bloom's levels before students are able to move on to the *analyze, evaluate,* and *create* levels that develop student critical thinking skills. I would disagree. Research has shown that that even novice adult students benefit from learning approaches that build on past experiences. From a constructivist point of view, the goal of training and education is to develop within the student increasingly sophisticated ways of reasoning and problem solving. In effect, exposure to problem solving, even in these initial courses, would help students build bridges from their current ways of thinking to more correct contextual ways of thinking about systems engineering. Rather than filling their brains with lists of terms and acronyms that they may not even be able to apply, the goal should be to correct any pre-existing mental models and mature the right mental models that students need in order to succeed in the complex world of defense systems engineering (Pratt, n.d., p. 4).

Similar observations can be made regarding the three NPS systems engineering courses. Since the three courses provide equivalent credit to the DAU systems engineering certification courses, far-transfer of learning to the job is essential. Course learning objectives requiring students to *remember, understand,* and *apply* could be rewritten to challenge students to think critically (i.e., *analyze, evaluate,* and *create*). Of course, this would also require that the context for these objectives be stepped up from lecture to problem-based instruction and that students be assessed to the higher Bloom's levels of functional thought.

In the balance of this paper, I summarize my literature search that led me to conclude that deep learning and far-transfer of learning to the job are best achieved using problem-based instruction that challenges students to think critically. I also suggest areas for further research.

Learning—What Really Works?

Since 1986, Ken Bain, Director of the Center for Teaching Excellence at New York University, has conducted ongoing research to identify and examine highly effective university and college teachers. In his book, *What the Best College Teachers Do*, one of the questions that Bain asked was the following: What do the best teachers know about how students learn? Here are the top four answers:

- Knowledge is constructed, not received, and students bring pre-existing paradigms to the class that shape how they construct meaning.
- Mental models change slowly and only by challenging students intellectually (i.e., engaging them in deep thinking).
- Questions are crucial because they help students construct knowledge.
- Caring is crucial; if students don't ask important questions and care about the answers, they will not try to reconcile or integrate new information and replace old mental models. (Bain, 1986, pp. 26–32)

The implications for how we should teach systems engineering are significant. Bain reports that the best teachers create a natural critical learning environment in which knowledge and skills are incorporated into real-world (i.e., authentic) tasks that engage the student, arouse their curiosity, and challenge their assumptions (i.e., mental models). He also saw the best teachers create safe learning environments, where students were free to fail, receive feedback, and try again before being assessed. And finally, Bain found that the students understood and retained what they had learned because they had exercised their reasoning abilities to solve problems that concerned them (Bain, 1986, pp. 46–47). In other words, deep learning rather than surface learning had occurred.

Bain (1986) concludes the following:

> The most effective teachers use class time to help their students think about information and ideas the way scholars in the discipline do. They think about their own thinking and make students explicitly aware of that process, constantly prodding them to do the same. They do not think only in terms of teaching their discipline; they think about teaching students to understand, apply, analyze, synthesize, and evaluate evidence and conclusions. (pp. 114–155)

As discussed earlier, teaching to *analyze, evaluate,* and *create* challenges students to think critically.

Learning Style Preferences

One of the potential traps with systems engineering instruction is falling back into traditional methods of engineering instruction. I experienced traditional instruction in my undergraduate years as I pursed a Bachelor of Science degree in the engineering sciences. Most of my chemical, electrical, mechanical, and materials science classes were taught as lectures. The problem is that I'm a *visual* learner. I understand concepts and information most readily when they are presented in pictures and flow charts or by demonstrations.

Richard Felder, a professor emeritus of chemical engineering at North Carolina State University has studied the learning style preferences of over 2,500 engineering undergraduate students at 12 universities. He and his colleagues have found the following:

- 82% of these students are *visual* vice verbal learners, preferring pictures, diagrams, flow charts, and demonstrations;

- 64% of these students are *active* vice reflective learners, processing information through engagement in physical activity;
- 63% of these students use their *senses* vice intuitions, perceiving sights, sounds, and physical sensations; and
- 60% of these students are *sequential* versus global learners, preferring a logical progression of incremental steps.

Yet, engineering instruction at the schools they attend is primarily verbal, reflective, and often intuitive, emphasizing theory and mathematical modeling over demonstration or the use of visual aids (Felder & Brent, 2005, p. 61). Could this mismatch of learning style preference and methods of instruction be a problem in systems engineering training and education within the Department of Defense? Perhaps future research could sample the learning style preferences of systems engineering students taking the four DAU certification courses (and equivalent courses) and compare those student preferences with the teaching styles of the instructors.

We have intuitively known that a picture is worth a thousand words. When compared with written words or verbal communications, people actually do communicate more simply and efficiently with pictures or visual images. This is due to our natural ability to process and retain visual images in our minds. Pictures are *information-rich* and can convey more precise meanings and more clearly depict ideas (Gerard & Goldstein, 2005, pp. 18, 45). Learning transfer can also be improved with images. With images, patterns emerge, revealing relationship. These patterns also help in understanding how processes work. Communicating ideas with a visual image can result in clearer understanding of complex processes (see also Mintzberg & Westley, 2001, pp. 92–93).

Kevin Forsberg, Hal Mooz, and Howard Cotterman (2005) from the Center for Systems Management have dedicated the third edition of *Visualizing Project Management* to “mastering complexity” (p. xxi). They say that logical and systematic project management and systems engineering processes are left-brain activities. To stimulate creativity, the visually oriented right-brain needs to be engaged. Therefore, their book is full of visual models that simplify these complex process and help the student understand how things really work (Forsberg, Mooz, & Cotterman, 2005, pp. xxiv–xxv). In particular, they use the “V” model to depict the systems engineering process of top down requirements decomposition and design definition and bottom-up system integration and validation. It should be noted that the DAU and NPS systems engineering courses studied in this research all make good use of visual models.

Far-Transfer of Learning to the Job

In her book, *Building Expertise: Cognitive Methods for Training and Performance Improvement*, Ruth Colvin Clark (2008) discusses the psychology of learning transfer and practical ways to teach for transfer. She posits that far-transfer of learning, the ability to solve ill-defined or ambiguous problems on the job, comes from creative and critical thinking (Clark, 2008, pp. 234, 245). Yet, far-transfer of learning does not result from a single training event. In addition to training, far-transfer requires an innovative culture, collaborative projects, diverse work experiences, and the ability to reason within unfamiliar contexts or on novel tasks (i.e., fluid intelligence; Clark, 2008, p. 249).

To promote far-transfer of learning, Clark recommends the inductive training technique. Inductive training can be described by comparing it with traditional training. During traditional training, the *instructor* presents the content, the *instructor* provides examples, and the *students* apply the content. Inductive training changes the sequence and puts more emphasis on active engagement of the students: the *instructor* provides examples, the *students* derive the content, and the *students* apply the content. Traditional training actively engages the students only one third of the time; inductive training actively engages the students two thirds of the time (Clark, 2008, p. 270).

According to Clark (2008), the reason that inductive learning enables far-transfer of learning is because the students are engaged in building a personal mental model based on their own experience and collaboration with other students. Clark also recommends the use of simulations (used in a guided discovery mode) and problem-centered instruction. Both methods promote far-transfer of thinking skills by engaging the students to build their own knowledge and skill base in long-term memory (i.e., mental models) within a real-world context (Clark, 2008, pp. 273, 283–285).

Many others agree with Clark. Nobel laureate Herbert A. Simon, a professor of psychology and computer science at Carnegie Mellon University who studies human decision making has concluded that experience (e.g., from a problem-solving exercise) enables us to "chunk" information so that we can store and retrieve it more easily (as reported by Hayashi, 2001, p. 7). Felder and Brent (2005) say that inductive teaching methods such as problem-based and project-based learning can motivate students by making subject matter relevant to prior and future experiences, emphasizing conceptualization, versus rote memorization (p. 64).

Learning for Rapid Cognition

In his book *Blink: The Power of Thinking without Thinking*, Malcolm Gladwell (2005) explains how rapid cognition that happens in a blink of an eye can be used to make fairly good decisions in otherwise complex situations. Psychologists call the critical part of rapid cognition *thin-slicing,* which refers to the ability of our subconscious mind to recognize *patterns* in everyday life situations based upon narrow slices or samples of experience (Gladwell, 2005, p. 23). For example, I can tell by my wife's voice, within the blink of an eye, if she is happy, sad, or mad. Even on the telephone, the patterns of her voice—just her first few words—give me all the clues I need to correctly determine her mood. This is based upon my experience in listening to her and the fact that I love her dearly. I have created in my mind an array of mental models of her different voice patterns. Can rapid cognition be useful in training systems engineers to recognize and act on problems even in the complex environment of defense systems engineering? Perhaps it can.

Gladwell (2005) tells the story of Cook County Hospital (Chicago, IL) that has a trauma center that inspired the television series *ER.* Faced with overwhelming costs and a shoe-sting budget Brendan Reilly, chairman of the hospital's Department of Medicine, turned to cardiologist Lee Goldman who, based upon his years of experience with heart attacks, came up with an equation for predicting if chest pains really meant that a heart attack was about to happen. In the past, doctors would ask lots of questions of the patient, ask for expensive tests, and as a precaution, admit the patient. When Goldman's decision tree (i.e., pattern analysis) was implemented in the hospital emergency room over a two-year period, diagnoses were 70% better than the old method. The point, according to Gladwell, is that too much information confuses the issue and makes it harder to pick up the basic signature of the problem (i.e., the pattern; Gladwell, 2005, pp. 125–136, 142).

Nobel laureate Herbert Simon has concluded that "experts see patterns that elicit from memory the things they know about such situations [and]…what distinguishes experts is that they have very good encyclopedias that are indexed and pattern recognition that is that index" (as quoted in Hayashi, 2001, p. 63). So, what patterns should we be teaching our systems engineering students? For example, are there patterns in technical reviews, earned value analysis, or risk assessments that could instantaneously (in the blink of an eye) let them know whether a problem exists? Moreover, if every systems engineer working for or with the Department of Defense used decision trees prepared by systems engineering experts, would our system acquisition programs have better outcomes? Twenty years ago when I attended the Defense Systems Management College Program Management Course, I recall the recommendation to use the Willoughby templates to identify risk areas when transferring systems from development into production. Today these templates have been incorporated into the Best Manufacturing Practices Center of Excellence (BMPCOE) Technology Risk Identification and Management Systems (TRIMS). Would more emphasis on the use of such expert templates simplify issue and risk identification for earlier responses and ultimately help our acquisition programs succeed?

Learning Patterns of Response

According to UCLA Professor Moshe Rubinstein, an internationally renowned authority on problem solving and creativity in organizations, "We must learn to live harmoniously with change, chaos, and uncertainty. It is now the age of the brain. It is the age of finding ways to tap more of the human potential for creativity and innovation, to learn to adapt to chaos and uncertainty, and to use our minds to establish a sense of purpose and meaning in our personal and professional lives" (Rubinstein & Firstenberg, 1999, p. 20). In an age of growing connectivity and complexity, to include more complex defense systems, we must be able to embrace uncertainty, change, and chaos. According to Rubinstein, the human brain has the capacity to do just that.

During a recent weekend getaway to Marin County, CA, my bride and I took some time to visit the national office and kennels of Guide Dogs for the Blind in San Rafael. While touring the kennels, we were told that the young Labrador Retrievers are actually trained to respond in patterns of behavior. Clearly, the training course can never simulate all of the possible obstacles (to include change, chaos and uncertainty) in a city, home, work, or recreational environment that these young Labs will encounter. So, the Labs are taught "patterns of response" in order to lead the blind person around obstacles in their path. Can systems engineering training and education take a lesson from how guide dogs are trained?

Robert C. Collins, MD, a professor and the chair of the Department of Neurology at the UCLA School of Medicine, has discovered that brain wave patterns for hand movements are unique, but there is about a 50% overlap across various patterns. This means that hand movements start out planned, but end up as unplanned responses to the environment (Rubinstein & Firstenberg, 1999, p. 49). For example, I play the slide trombone. Let's assume that I'm going to try to play a solo and have never seen the music before (I'm sight reading). Based on past experience, my brain knows how far to extend my arm and wrist to reach the slide to the 4^{th} position G to start my solo (i.e., the planned brain waves). But, the next note is B-flat. Do I play that note in the first position or the fifth position? Either position will work. And, if I encounter eighth or sixteenth notes, the next series of notes up or down the slide could happen in a blink of the eye. How then does my brain know what to do next (i.e., handle the unplanned)? Answer: spontaneous improvisation from previous experience (patterns of response). Even though I've never seen the music before, I've stored patterns of *rules* in my brain for getting to the next note(s) quickly and efficiently. In the case of the G to B-flat, I'll look to the note(s) after the B-flat to decide if it is easier to use the first or fifth position, thereby being better prepared to play the subsequent notes.

Rubinstein says, “We can safely conclude that human experience almost always involves both the earlier stored part, which is reproduced, and the newly created part, which is produced” (Rubinstein & Firstenberg, 1999, p. 49). How might this knowledge of our how the brain works and stored rule/response patterns change the way in we teach systems engineering? Might we teach patterns of response that could ultimately be applied to solve complex systems engineering issues and mitigate risks?

Rubinstein also has an interesting perspective on creative thinking. “Creative thinking requires a process that is quite different from that of rational thinking. Whereas rational thinking depends on categories and labels that have been set up in advance, creative thinking demands that we form new categories and labels. Rational thought leads us to find the similarities between a new experience and previous experiences so that we can treat them the same way. Creative thought looks for the differences among experiences, seeking unique ways of both interpreting situations and acting upon them. Rational thinking seeks to confirm; creative thinking seeks to invent.” (Rubinstein & Firstenberg, 1999, p. 22). Perhaps this definition of creative thinking should also be used to guide and assess the success of our systems engineering problem-based exercises.

Conclusions

Knowledge, skills, and abilities within the discipline of systems engineering are best learned experientially through problem-based instruction. Opportunities to role play, simulate, or actually perform system engineering tasks really help the students transfer learning from the classroom to their work. Over the years, the most successful training and education programs I’ve participated in as a member of the defense acquisition workforce have been case studies and simulations that combine the technical aspects of the systems engineering discipline with activities that require the application of interpersonal skills and leadership. Having been an instructor in both systems engineering training and education environments, I know that students do their best when challenged with authentic problems that have meaning to them in the real-world. As adult students, they appreciate a learning environment in which they can “do it until they get it right.” Knowingly or unknowingly, they can learn much from their peers. Also, they excel when invited to display their knowledge in front of their peers. All of the experience I’ve had in learning and teaching within this discipline point to the absolute necessity for active learning activities that are relevant to the real-world of the systems engineer.

The purpose of instruction in the defense systems engineering discipline is to equip adult students to succeed in what can be a very complex and often ambiguous public policy environment. These students want to understand the “why” behind the concepts and principles of their profession. Only with that knowledge can they know what is important and what to ignore when overloaded with information. Also, they need to have had opportunities in a nonthreatening academic environment to experience what happens when they ignore that which is important (i.e., learn from their mistakes). Moreover, they need to think deeply within the discipline to understand what to accept and what to challenge. In other words they need to be humble critics of their profession who can rationally argue for change when change is needed. As an instructor, I need to come alongside my students (current and future systems engineers) to awaken and develop their intellects in the following key areas:

- Intellectual Humility—the systems engineering discipline is so big and dynamic that no one person can ever know everything.

- Intellectual Empathy—the systems engineer must be able to understand the perspectives and objectives of all acquisition stakeholders (e.g., warfighters/users, Congress, Executive branch, and defense industry).
- Intellectual Autonomy—in defending the program's systems engineering approach, the systems engineer has to be able to justify why he/she tailored a systems engineering process model, technical reviews, audits, verifications, etc.
- Intellectual Integrity—responsibility and accountability for program goals, to include credible cost, schedule, and performance reporting, are required from the systems engineer.
- Confidence in Reason—the systems engineer must develop sound rationale for the development approach, testing strategies, and logistical support for the system.
- Fair-mindedness—the systems engineer is a public servant, expected to give due consideration to all viewpoints and avoid even the appearance of any conflict with his/her personal interests or ambitions.

These intellectual traits ("Foundation for Critical Thinking," 1996) can only be awakened and developed through a *deep approach* to learning. My students need to be challenged to think beyond the course and look to the expert application of the knowledge they are learning as it affects their real-world jobs. To do this, I need to provide learning activities that target Bloom's *evaluate* level and frequently go above that to the *create* level. I have to prepare learning objectives and assessments that go beyond simply remembering facts and applying procedures. I need to create a *critical natural learning environment* that invites students to test the boundaries of the discipline (Bain, 2004, p. 99). A learning environment that invites my students to argue, compare, rate and ultimately judge for themselves what works and what doesn't work is what I'm seeking. After learning activities, I need to give the students time to *reflect deeply* on what they have experienced. In so doing, I want them to see the patterns of thought that led them to their conclusions. By recognizing these patterns, they can begin to experience the power of *thinking without thinking* -- like the experts do (i.e., *rapid cognition* based on *thin-slicing*, per Gladwell, 2005).

Critical natural learning environments can be cultivated and observed through classroom and online discussions of real-world case studies. Such environments can also be achieved through an integrated course exercise where student-led teams develop and brief a technical systems engineering strategy pertaining to a real-world need. Role playing during classroom discussions of dilemmas faced in real-world case studies would also work nicely. However, the one intangible in all of these learning activities is my passion and motivation for learning the systems engineering discipline. It is the creativity and drive that I bring to the course and into the classroom that truly motivates my students. To keep the energy and motivation flowing, I must constantly improve the learning activities and keep them relevant, gain a better understanding of where my students are coming from experientially and professionally, and be responsive to the constructive feedback my students give me.

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