Learning SE by Teaching It

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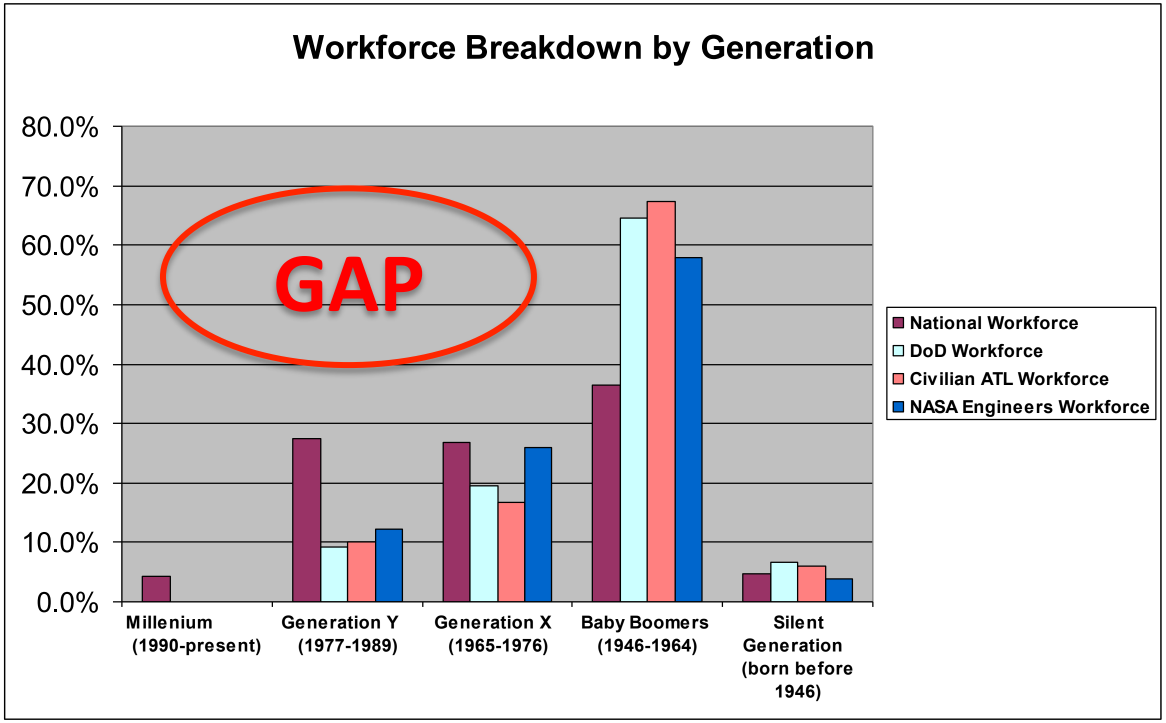
Introduction

- Study Motivation
  - Increasing system complexity has provided a need for developing systems engineering expertise faster.
  - Current estimate 15-20 years.
  - Primary development mode – work experience
    - Slow and unpredictable
  - Efforts to speed up - Experience Accelerator
  - Missing element is definition of how SEs learn
    - Other fields have more defined knowledge.
- Problem Statement
  - How do systems engineers develop their expertise?
  - What needs to be included in accelerated development?

Why Important

- Systems are becoming more complex
  - E.g., FAA NEXTGEN
- Need to accelerate development of expertise
  - NASA Workforce Trend

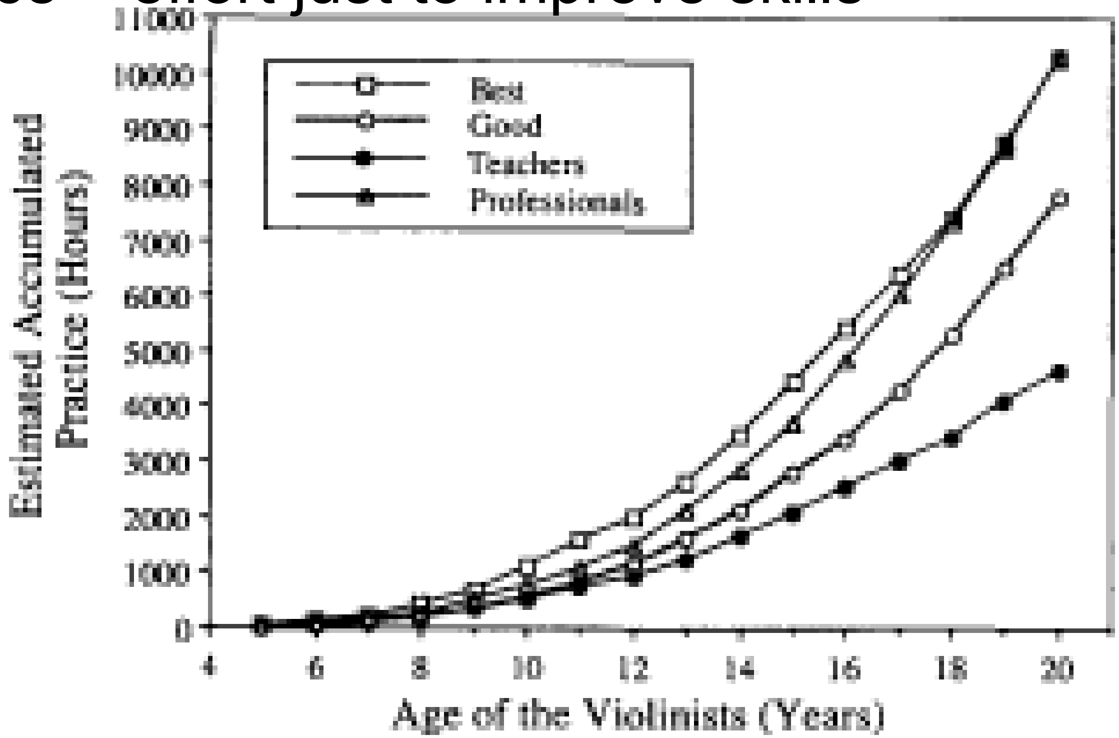


Prior Research

- Bloom
  - 3 fields, 2 representatives each
    - Psychomotor/athletic – swimmers and tennis players
    - Aesthetic – pianists and sculptors
    - Cognitive/intellectual – research mathematicians and research neurologists
    - Interpersonal relations – could not define who would be the expert
  - Studied childhood through early adulthood
  - Key finding – time to develop in decades
    - Research Mathematicians "devoted at least 10 years to intensive – nearly obsessive - effort in mathematics. This period typically begins with graduate school (although for a few it began in college)."

Practice Makes Perfect

- Gladwell – 10k rule
  - Bill Gates and Beatles – not overnight successes
- Ericsson, Krampe, and Tesch-Romer – deliberate practice – effort just to improve skills



Ericsson, Krampe, and Tesch-Romer, 1993

How Do SEs Develop

- An opinion survey: Work Experience #1

Key Steps to the Development of Systems Thinking										
Category	All Participants (202)		Expert Panelists (37)		Senior Systems Engineers (61)		Senior Technical Specialists (52)		Junior Systems Engineers (52)	
	Rank	Number	Rank	Number	Rank	Number	Rank	Number	Rank	Number
Work experiences	1	139	1	35	1	36	1	38	1	30
Education	2	80	3	13	3	22	3	17	2	28
Individual characteristics	4	64	2	16	4	16	4	11	3	21
Life experiences outside work	3	72	4	5	2	27	2	19	3	21
Interpersonal skills	5	37	4	5	5	13	4	11	5	8
Training	6	16	6	4	6	7	6	2	6	3

Davidz, 2007

Study Method

- Grounded Theory
  - Starts with a research question instead of a hypothesis
    - How do systems engineers develop expertise?
    - Is deliberate practice part of the process?
- The target population is selected
  - Expert systems engineers – ESEPs, INCOSE Fellows, senior SEs from industry
  - Less experienced SEs for comparison
- Interviews use broad questions
- Hypothesis generated from responses
- Iterative process

Interviews

- Structure is similar to Bloom's approach
  - Early years – pre-college influences
  - College education
  - Development since undergraduate degree
    - Additional education and training
    - Experience – what learned and how
    - Other sources
    - Focus on deliberate practice.
  - Top systems engineering areas
    - INCOSE set of SE areas plus soft skills
  - Deliberate Practice

Data Coding

Q: request bio. Your current position is?

A: Oh, uh, President [redacted] and semi-retired.

Q; So the things you do that are professional at this point...

A: Professional activities at this time are primarily teaching courses in systems engineering. Just completed teaching a masters course for [redacted], masters in systems engineering. And, I am the [redacted] which oversees the policy and strategies for [redacted].

Q: Background and education particularly related to systems engineering?

A: One of the things it talks about is when did you, in development, when in the early years what experiences did you have development. And as a kid, my dad was in construction and we were always looking at ways, you know of making the construction better. Back in the old days, back in the late 60s early 50s, and one of the things I used to do was pick up the leaves. and picking up the leaves was a real time-consuming job but I realized that I could take two rakes and make a … could pick up a lot more leaves and a lot quicker. That was probably my first a… first engineering design, probably 10 years old.

Then I worked in a grocery store and just better ways of process doing processes within the grocery store. Trying to make things smoother, save time, reduce repetitive efforts. Nothing that I could, you know, say this specific thing.

Worked with my dad in construction and learned to read blueprints which then led to the methodologies and processes of better ways of distributing, you know, 15 tons of steel that just came off a truck and getting it placed throughout the jobsite so that didn't have to carry all the way around. Then in college, I started out in aerospace engineering and one of the unique things about our school is you started into engineering immediately, freshman year. And, by the end of the sophomore year, we could calibrate and run subsonic and supersonic wind tunnels, hydrofoil test basin, and static test stand. And our sophomore project required us to basically design an aircraft which means, a class, did and presented proposed design for representatives from [redacted] who responded to us and evaluated how well we responded to their requirements for this aircraft.

So there was... we had to look at the propulsion capabilities for lift, runway criteria, passenger load, etc. So, that was probably the first major and real systems engineering, by definition, activity. But the other thing that interested me was the fact that as aero engineer, and even mechanical engineers for which there was a similarity, that other engineers took, didn't take, did not take courses in aerospace but we took courses in electronic engineering and structural engineering, but they never took courses in

		Interview Number								
	ific	1	2	3	4	5	6	7	8	9
	ems Engineering	XX	XX	XX	XX	XX	XX	XX	XX	XX
	/proj manager	XX	XX	XX		XX		XX	XX	
	hing (level)	X	X	XX	X	X	XX	XX		XX
	and evaluation	XX	-	XX	X	XX	XX		XX	XX
	sulting/advise	XX	X	-	XX					X
	rations	XX		-					XX	
						X				XX
	er	X								
	ary/Gov	XX	XX	X		X	XX	XX	XX	
	erospace (Def)	X	XX	XX	XX	XX	XX	XX	XX	XX
				XX		XX				X
	e consulting		XX							
	ll consulting	X			XX					
	ll						X			X
	uirements	X	XX	XXX	X	X	XX		XX	
		XXX	X	XX	X	XX	XX		XX	XX
	ess Definition	XX	X	XX	XX	XX	XX			
	ning	XX	X	X		XX	XX			
	ems Integration	XX	X	XX	X	X	X			
	leling & Sim	X	XX	XX				XX		XX
	skills		XXX	XXX	X	XXX	XX		XX	XXX
	OSE leadership	XX	XX	XX	XX	XX	XX	XX	XX	XX
	erience - work	XXX	XXX	XXX	XXX	XXX	XX	XX	XX	XXX
	Education	X			XX			XX	XX	XX
	Training	XX	X	XX	XXX	XX		XX		XX
	Mentors	XX	XX		XX	XX	X	XX	XX	XX
	Reading	X	X	X		-				
	Life experiences	X								
	Networking	XX			X			XX		XX
Deliberate practice		<100	<100	<100	INCOSE	<100	<100	<100	<100	<100

Validation

- Validation partly inherent in method as results converge
  - Additional data doesn't change theories
- More structured approaches:
  - Personal validation: concurrence of participants
    - Validation of input
    - Validation of resulting theories
  - Triangulation: multiple sources of data – interviews, records, public data…
  - Multiple coding: Second look at coding

Results: Sources of Learning

- Learned SE by:
  - Experience – Learning through work
  - Training – Provided by employers or on own
  - Mentors – direct input from more experienced SEs
  - Observation – observing of their behaviors
  - Formal education – Degree or certificate programs
  - Books, CDs, etc. – Reference sources of various forms
  - Networking – Meeting with knowledgeable practitioners
  - INCOSE/talks – Local meetings, symposia, tutorials
  - **Teaching – learning by teaching SE**

Learning SE By Teaching

Three modes of learning

- As the instructor
  - Teaching systems engineering
- Protégé effect
  - SE student as teacher
- Instructional System Design
  - Applying SE in course development

"Homines, dum docent discount (Men learn while they teach)" – Seneca the Younger

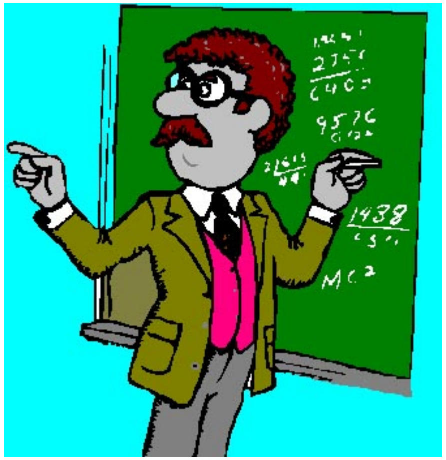
Study of Managers

Mode of Learning	%
Teaching	100
Experience (attempts/successes/failures)	85
Experience of Others	85
Classroom training	75
Help/advice of colleagues	60
Coaching by superiors	45
Reading of books/manuals	35
Participation in reflection/discussion groups	20

Cortese, 2005

The Teacher…

- Observes new ideas in the student's performance.
- Observes mistakes in the student's performance.
- Observes their own performance.
- Receives student feedback on observations of either good or bad things the teacher did
- Listened to the student and finds new ideas or criticism
- Is able to experiment with new approaches or concepts,



Cortese, 2005

Need For Better Knowledge

Level	Definition
Remembering	Retrieving, recognizing, and recalling relevant knowledge from long-term memory.
Understanding	Constructing meaning from oral, written, and graphic messages through interpreting, exemplifying, classifying, summarizing, inferring, comparing, and explaining.
Applying	Carrying out or using a procedure through executing, or implementing.
Analyzing	Breaking material into constituent parts, determining how the parts relate to one another and to an overall structure or purpose through differentiating, organizing, and attributing.
Evaluating	Making judgements based on criteria and standards through checking and critiquing.
Creating	Putting elements together to form a coherent a=or functional whole; reorganizing elements into a new pattern or structure through generating, planning, or producing.

Bloom's Taxonomy

Knowing the Root Cause

- The best teachers know why the student makes the mistake, not just that it's wrong
  - Ball, Thames, and Phelps

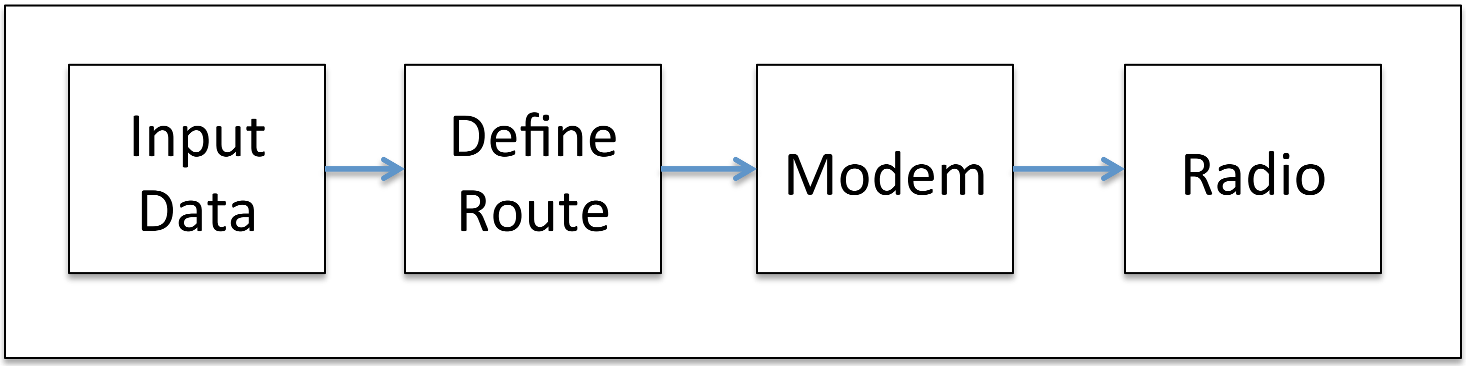
- For instance:

$$\begin{array}{r} 307 \\ -168 \\ \hline 261 \end{array}$$

  - Subtracting smaller digit in each column

SE Example

- Mixing functions and components



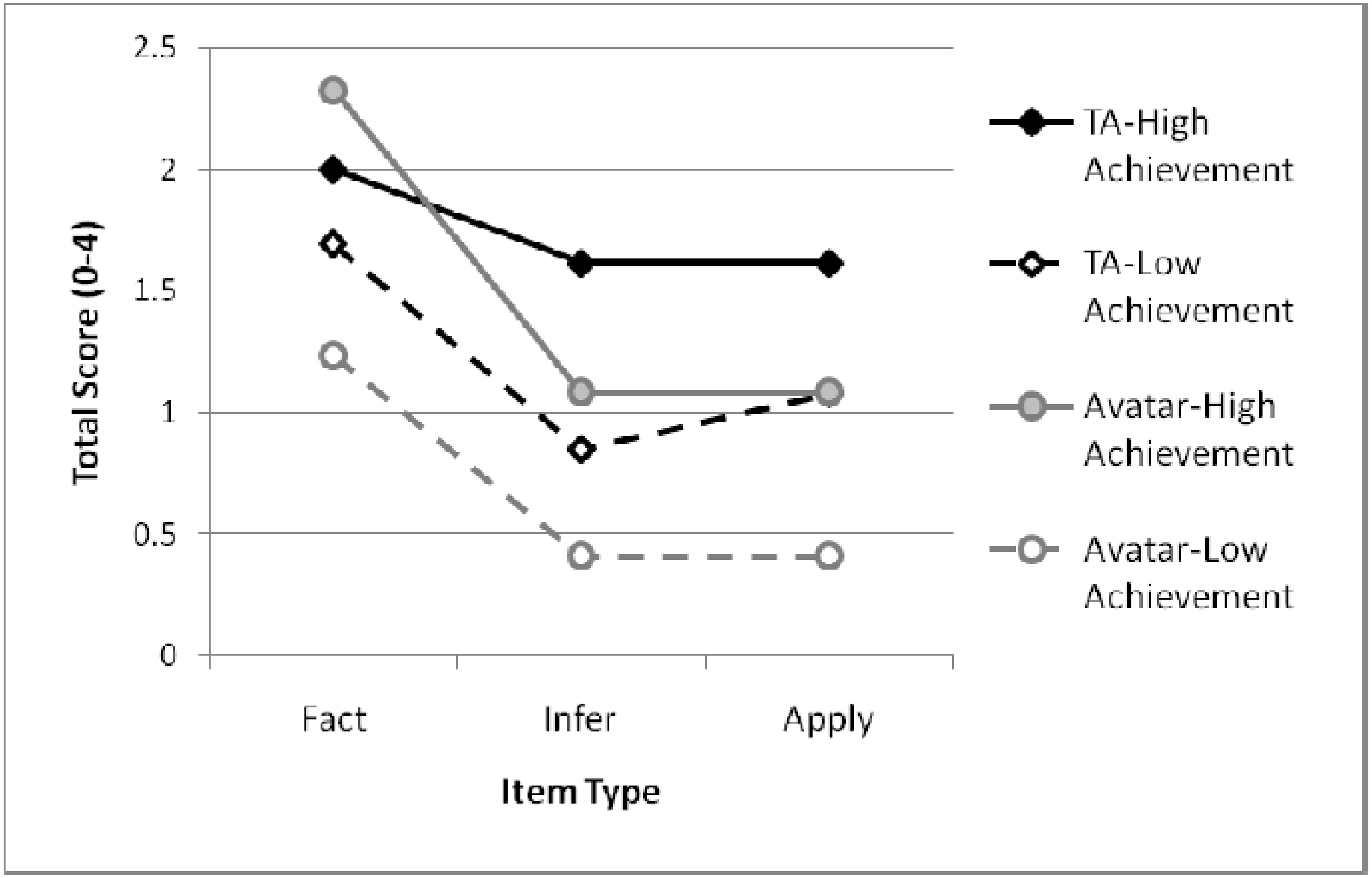
- Response – Instruction in basic elements

Functions	Requirements	Components
What it does Verb/Noun	How well Measurable	What it is Noun

Protégé Effect

- Tiered mentoring program
  - Univ of Pennsylvania
  - College students teach
  - High school students who teach
  - Middle school students
- Teaching mode in computerized class
  - Betty"s Brain
  - Two modes
    - Avatar (You in the computer)
    - Teachable Agent (student)
  - Quiz show game

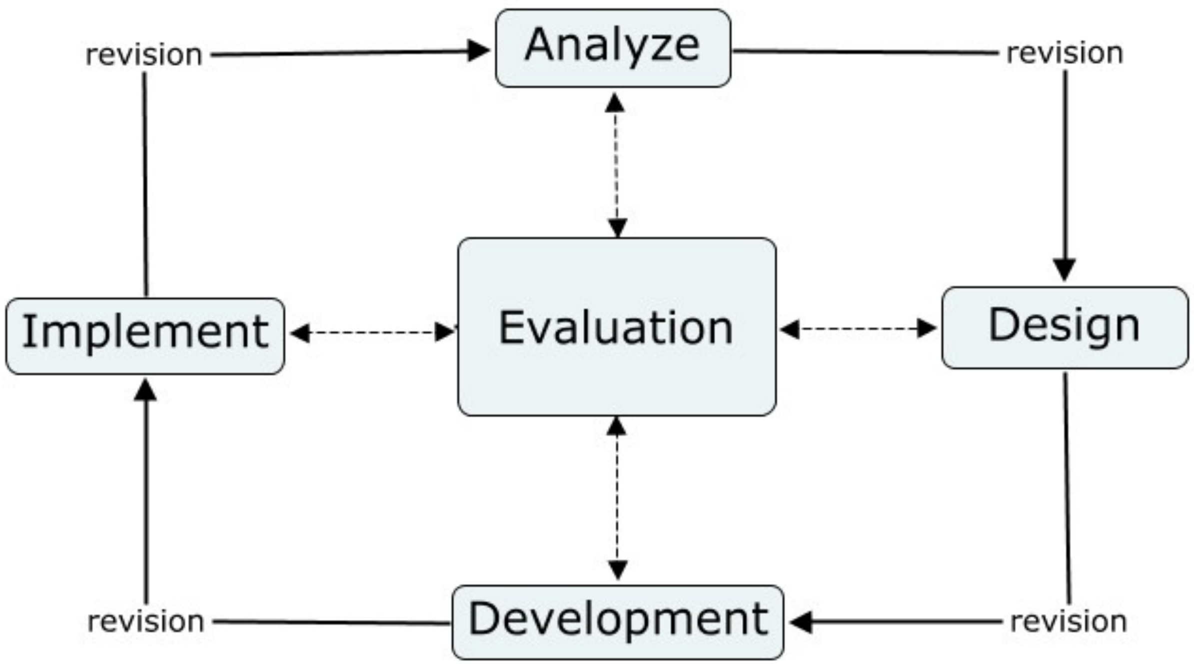
Teaching an Avatar or TA



Instructional System Design

- Process steps similar to SE
  - Requirements, design, test, deployment, etc.
- Addresses whole system
  - Course material, facilities, tools, instructors…

ADDIE Model



http://commons.wikimedia.org/wiki/File:ADDIE_Model_of_Design.jpg#mediaviewer/File:ADDIE_Model_of_Design.jpg

Now What?

- Recognize teaching as SE experience and a learning method
- Consider learning need as well as teaching skills in assigning instructors
- Develop root causes of SE errors
- Have tiered mentor programs
- Develop training with student doing teaching
  - Betty's Brain approach to computerize courses
- Apply ISD more consistently

Backup

Sources of Learning

- Experience is principle source – however, it is not done in isolation
  - Experience forces learning
  - Experience uses learning
  - Future anticipated tasks stimulate learning
  - Self learning is critical to this relationship

Experience for Breadth

- Experience adds breadth in:
  - Levels of system – Component to System of Systems
  - Disciplines – Different engineering and other areas
  - Life cycle – Concept to disposal
  - Technologies – Different designs and applications
  - Customers – Variety in customer base
  - Government/Commercial – Customer type
  - Management – Leadership and supervisory roles

Interpersonal (Soft) Skills

- Important for higher level responsibilities
- Includes leadership, communications, interpersonal relations, teamwork,
- Technical and soft skill education and training not well connected.
- Primary sources were military service and management training

Deliberate Practice

- Several very strong positive responses
  - Seen as encompassing the varied learning methods described above
  - Not the same drills as sports or music

- Concept not always fully understood by interviewee

Conclusions

Experience is the primary method of learning SE skills

- However, not in isolation
  - Forces learning of required skills
  - Stimulates learning of skills anticipated to be needed
  - Provides application of previous learning
- Self study skills are beneficial to learning SE skills

Teaching is a method of learning not addressed as such in prior research.

Conclusions

Experience develops breadth of knowledge in multiple dimensions

- Levels of system
- Disciplines
- Life cycle
- Technologies
- Customers
- Government/Commercial
- Management

Conclusions

- Interpersonal (soft) skills are critical to expert level systems engineering
- The connection between soft and technical skill training needs to be improved for systems engineering