A Maturity Model for the Competency of Systems Engineers

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Topics

- Need for certification
- Definitions of systems engineering
- Types of systems engineers
- Requirements for competencies
- Current ways of assessing competencies
- The Maturity Model
- Future research
- Questions and comments

Need for effective systems engineers

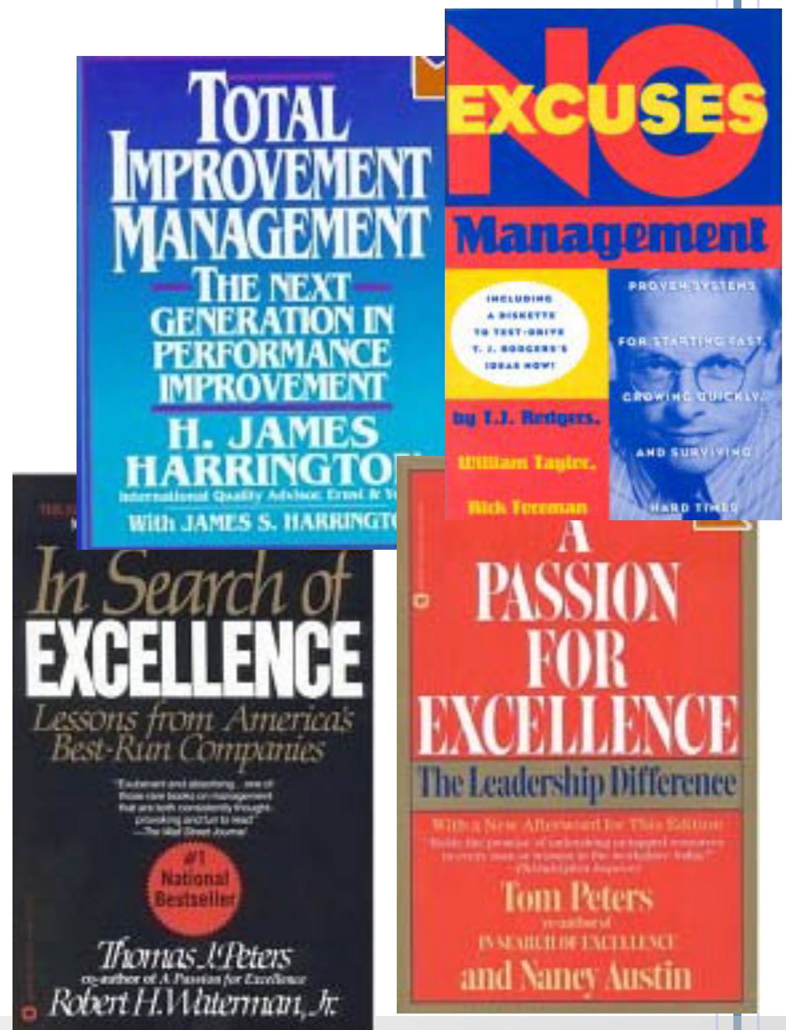
- *"**Systems**, even very large systems, **are** not **developed by** the tools of **Systems** Engineering, but only by the **engineers** using the tools."**

•Dr. Robert A. Frosch, 1969

- •Assistant Secretary of the Navy for Research and Development
- •Later becoming NASA Administrator during the Carter Administration (1977-1981)

The focus is on people not process

- Literature
  - Is full of advice as to how to make projects succeed
  - Has little if anything to say about the proliferating process standards
- Garbage-in-garbage-out



Kasser, J. E., "*The Certified Systems Engineer - It's About Time!*" proceedings of The 10th Annual Symposium of the INCOSE, Minneapolis, MN, 2000.

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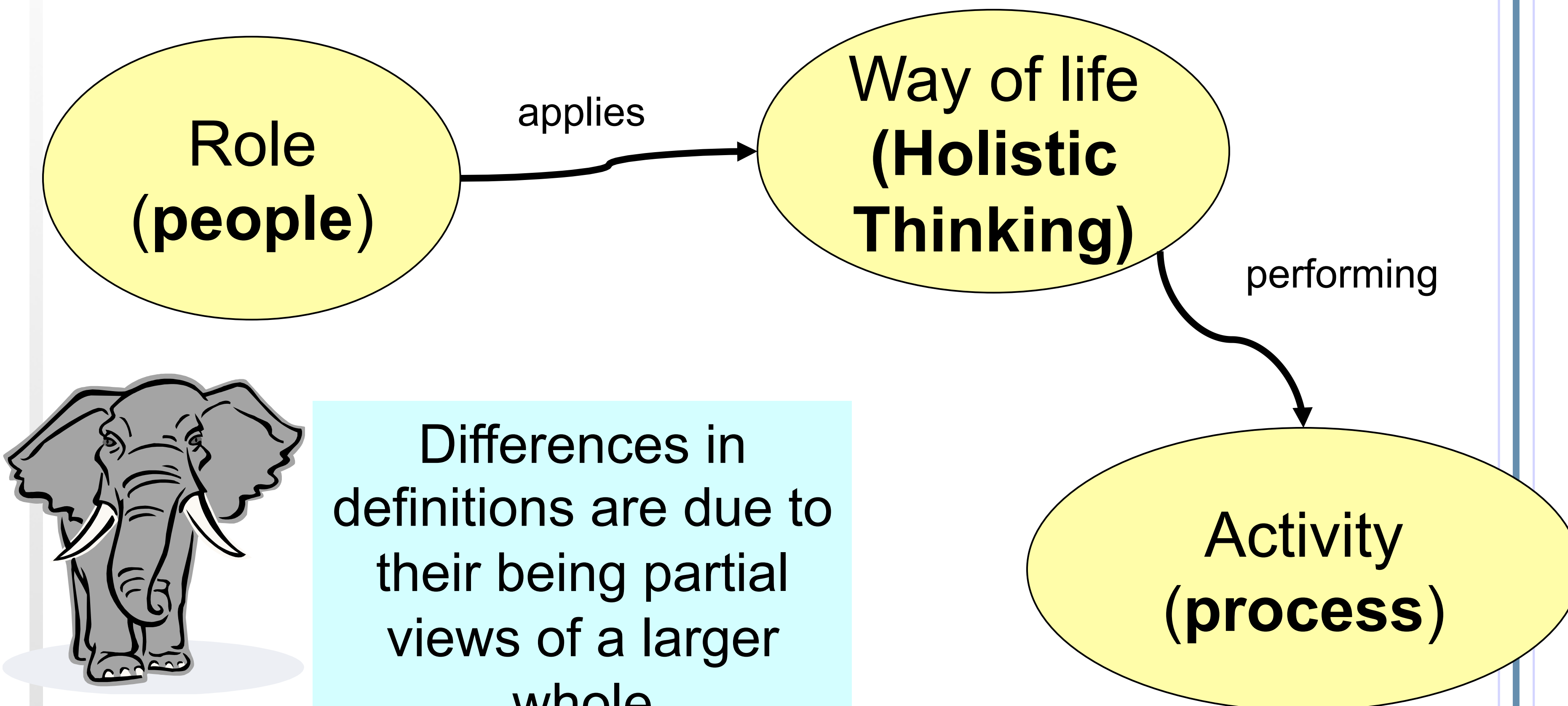
Definitions of systems engineering
Three dimensions of systems engineering

INCOSE International Symposium

- **Activity**
  - Systems engineer**ing**
  - Objective criterion (INCOSE Fellows, 2009)
  - Other activities in the workplace
    - project managem**ent**, etc.
- **Role** - People
  - Systems engine**er**, project manag**er**, design**er**, etc.
  - Subjective
    - Systems engineers perform mix of systems engineering and non-system engineering activities
  - Different mix in each organization
- **Way of life** (Hitchins)
  - [interpreted as] application of cognitive skills or Holistic Thinking
    - Analysis, system thinking and critical thinking (Kasser 2010)

Definitions of systems engineering: Linking the dimensions



Differences in definitions are due to their being partial views of a larger whole

Five types (maturity levels) of systems engineers and project managers* (engineer-leaders)

- **Type V** - who can "define the problem" and then determine "what" needs to be done to implement an optimal solution
- **Type IV** - who can "define the problem"
  - (Wymore, Model Based Systems Engineering, 1993 p 2)
- **Type III** - who can be given the problem and can then determine "what" needs to be done to implement an optimal solution
  - design the process
- **Type II** – who can be told "what" needs to be done to implement a solution and can work out "how" to do it
  - follow the process
- **Type I** – (apprentices) who can be told " " to implement a solution and can then do it

* Kasser, J. E., Hitchins, D. and Huynh, T. V., "*Reengineering Systems Engineering*", proceedings of the 3rd Annual Asia-Pacific Conference on Systems Engineering (APCOSE), Singapore, 2009.

Sample of requirements for competencies based on literature review

- List of specifications or traits for an "Ideal Systems Engineer" (Hall, 1962), pages 16-18)
- Being able to define the problem (Wymore, 1993), page 2)
- Competent, skilled and knowledgeable systems engineers capable of effectively working on various types of complex integrated multi-disciplinary systems in different application domains, in different portions of the system lifecycle, in teams, alone, and with cognizant personnel in application and tool domains
- Important skills and knowledge to include in corporate systems engineering training programs (Watts and Mar, 1997)
- The ability to communicate systems engineering principles to others
- In the acquisition portion of the system lifecycle, facilitate the effective acquisition of solution systems that meet the customer's needs at the time the system is specified, at the time the solution system is actually acquired and during the full length of its operational life
- Engineers who are effective at solving open-ended problems (Durward K. Sobek II and Jain, 2004)

Characteristics of systems engineers

- **Knowledge – (activity)**
  - Systems engineering
    - requirement analysis, functional analysis, architecture design, etc
  - Application domain
- **Way of life**
  - **Cognitive capabilities**
  - **Problem solving**
- **Role (individual traits)**
  - Communications
  - Leadership
  - Management
  - Administration
  - Integrity
  - Earned respect
  - Ethics
  - Etc.

Definitions

- **Knowledge**
  - a body of information needed for the successful performance of a function.
- **Ability**
  - the required competence to perform the function successfully.
- **Skill**
  - the observable or measured competence in performing the function.

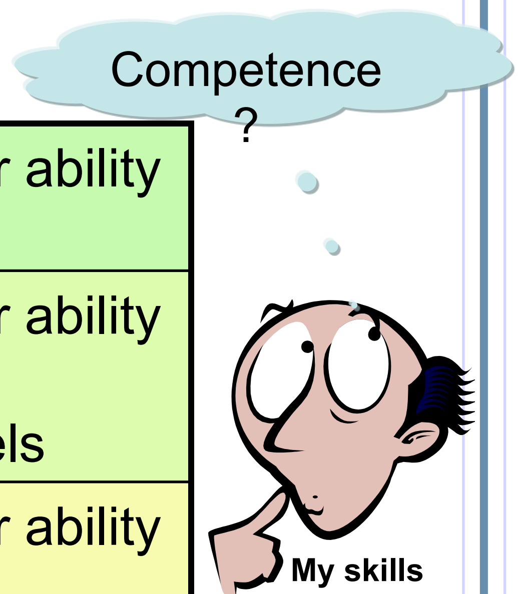
Knowledge*

- **Declarative knowledge** - knowledge that can be declared in some manner
  - It is "knowing that" something is the case
- **Procedural knowledge** - "knowing how" to do something and must be demonstrated
  - Describing a process is declarative knowledge
  - Performing the process demonstrates procedural knowledge
- **Conditional knowledge** - "knowing when and why" to apply the declarative and procedural knowledge

* A. E. Woolfolk, "Chapter 7 Cognitive views of learning," in *Educational Psychology*, 7th ed. Boston: Allyn and Bacon, 1998, pp. 244-283.

Two-dimensional assessment*

- [Knowledge of] the process, or set of processes, considered relevant to the discipline of interest*
  - needs validated exams/tests
- The level of proficiency attained*
  - typically using a progression of increasing-value cardinal points that are defined in terms of attainment or performance criteria*
    - needs validated rubrics
- Can be based on a number of items
  - e.g. CMM



Something being assessed	Highest Level of proficiency	Requirements for ability level at this level
	Intermediate levels	Requirements for ability levels at these intermediate levels
	Lowest level	Requirements for ability level at this level

* Arnold, S., "*Systems Engineering: From Process towards Profession*", proceedings of The 10th Annual Symposium of the INCOSE, Minneapolis, MN, 2000.

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Assessment approaches

- Discussed at EUSEC 2010*
  - Knowledge, Skills, and Abilities (KSA)
  - INCOSE Certified Systems Engineer Professional (CSEP) Examination
  - INCOSE UK Systems Engineering Competencies Framework
    - (Hudson, 2006)
  - Capacity for Engineering Systems Thinking (CEST)
    - (Frank, 2006)

* Kasser, J. E., Frank, M. and Zhao, Y. Y., "*Assessing the competencies of systems engineers*", proceedings of the 7th bi-annual European Systems Engineering Conference (EuSEC), Stockholm, Sweden, 2010.

Assessment discussion-3

- Each of these ways of assessing competences has been developed as a result of a different need.
- None of ways of assessing competency provides a way of differentiating between the five types of systems engineers
- Recommendation
  - A maturity model for distinguishing between the five types of systems engineers should be developed.

Assessing competencies (skills) of systems engineers in two dimensions

- **Knowledge**
  - Systems engineering
  - Application domain
- **Cognitive capabilities**
  - Quality of thinking
  - Problem solving
  - Solution generation
- **Individual traits**
  - Communications
  - Leadership
  - Management
  - Etc.

- **Ability level** (requirements)
  - Type V
  - Type IV
  - Type III
  - Type II
  - Type I

Generic to professions

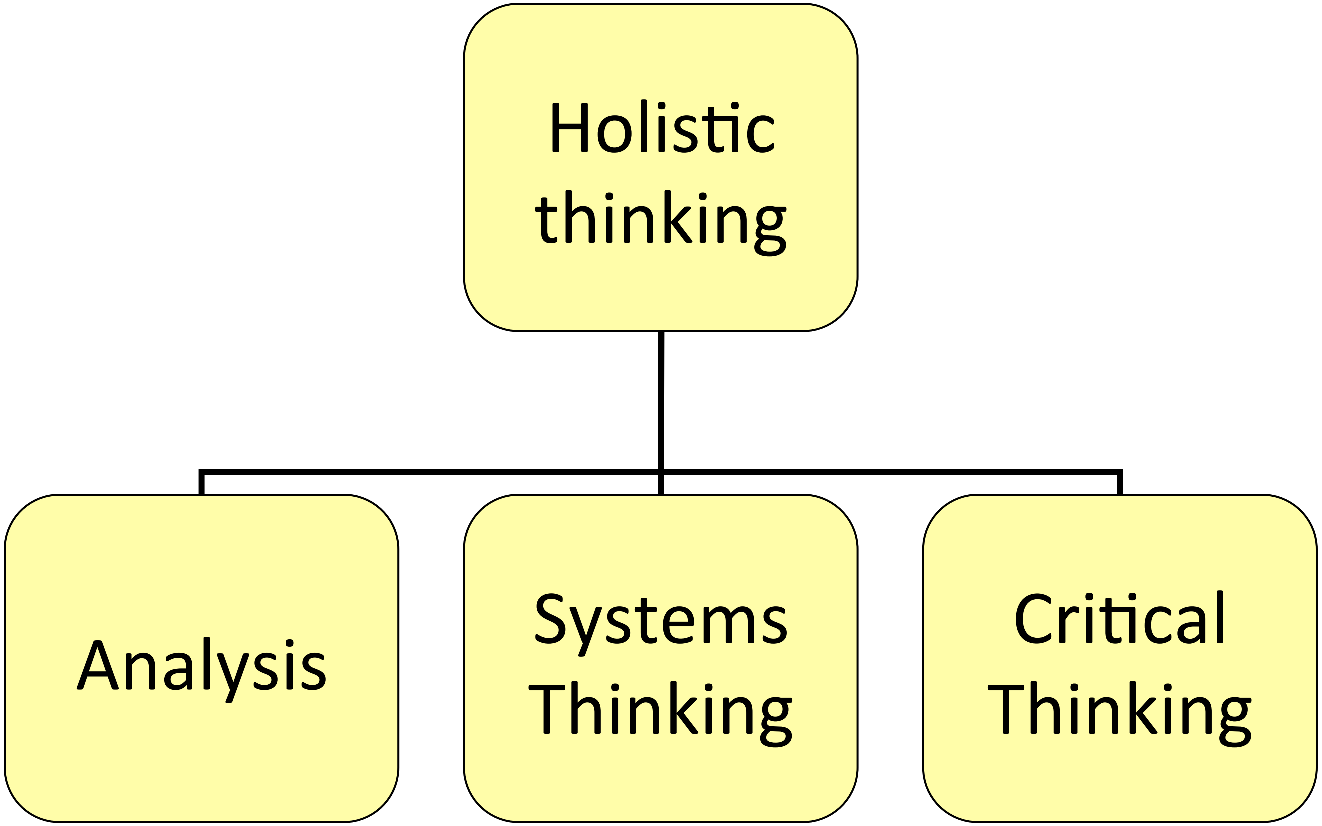
Exam and experience

What does it mean to * think systemically?"

- "Systems thinking is a way of thinking? You know it when you see it."
- "If you're considering something in its totality along with its characteristics as well as it's interaction with its environment AND considering its parts along with the interactions between the parts then you are thinking systemically"
- "Approach to a system with love, understand it holistically and heuristically"

* **LinkedIn Groups,** Systems Thinking World discussion group, June 2010

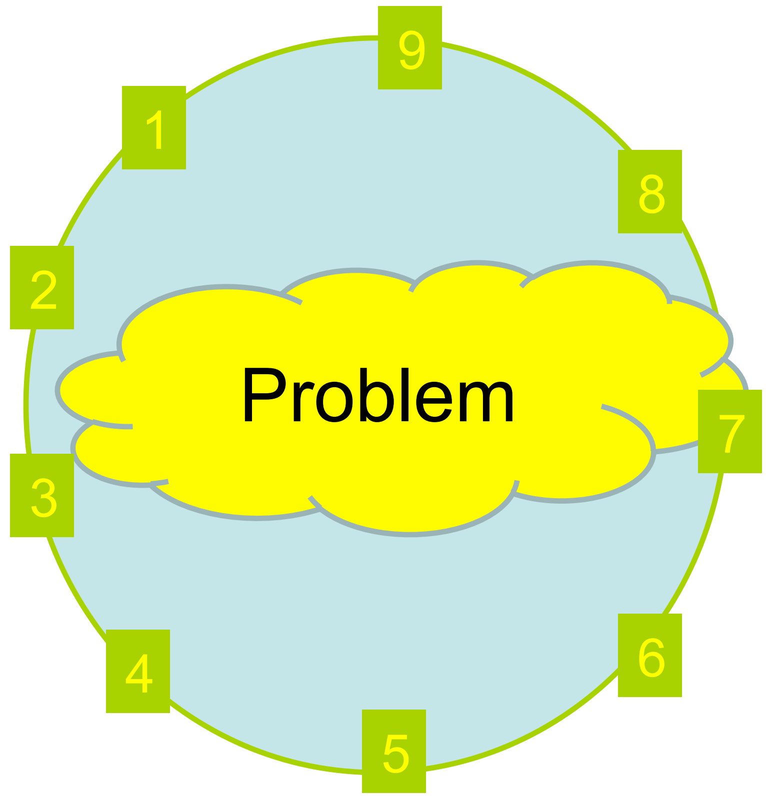
Cognitive capabilities: structural perspective



J. E. Kasser, "Holistic Thinking and How It Can Produce Innovative Solutions to Difficult Problems," the 7th bi-annual European Systems Engineering Conference (EuSEC), Stockholm, Sweden, 2010.
J. E. Kasser, "A theoretical multi-tasking executive function for the information processing model of the human brain," the 3rd International Conference on Applied Human Factors and Ergonomics (AHFE), Miami, FL, 2010.

Systems thinking perspectives* analysis and systems thinking

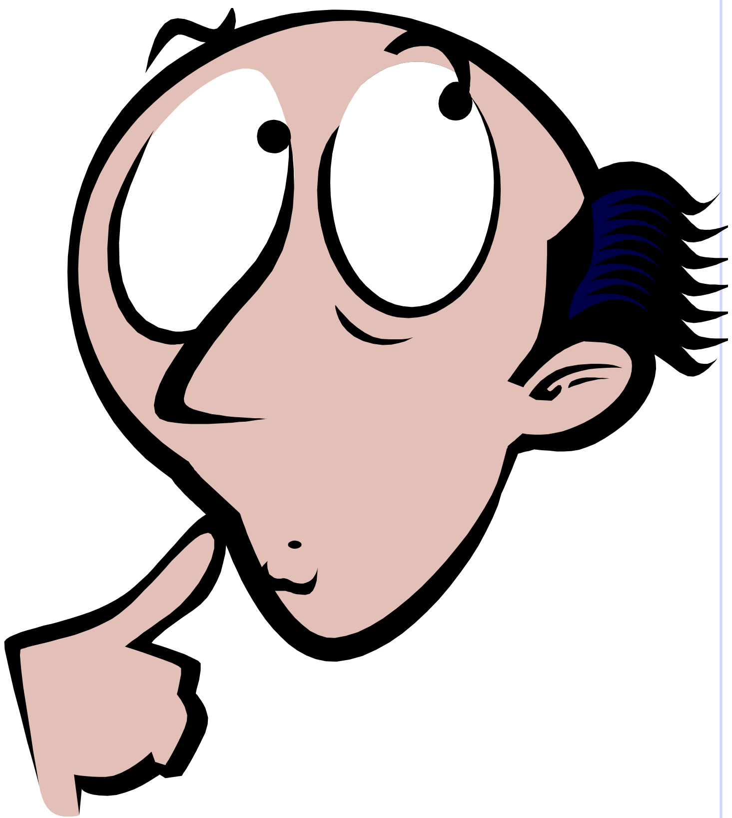
1. Big picture
2. Operational
3. Functional
4. Structural
5. Generic
6. Continuum
7. Temporal
8. Quantitative
9. Scientific



*summarized in paper, more details in Kasser, J. E. and Mackley, T., "*Applying systems thinking and aligning it to systems engineering*", proceedings of the 18th INCOSE International Symposium, Utrecht, Holland, 2008.

Critical thinking

- Five steps or levels*
  - 4 Strategic re-visioner
  - 3 Pragmatic performer
  - 2 Perpetual analyzer
  - 1 Biased jumper
  - 0 Confused fact finder



* © Susan K Wolcott 2003

Knowledge: starting point

- Declarative and procedural knowledge of systems engineering
  - in literature of systems engineering
    - e.g. Blanchard and Fabrycky, 1981; Jansma and Jones, 2006; Hitchins, 2007; Wasson, 2006 etc.
  - much of that knowledge is summarized in INCOSE Systems Engineering Handbook
- Systems engineers work in different domains (e.g. aerospace, land and marine transportation, information technology, Defence, etc.),
- Systems engineer will need the appropriate domain knowledge
  - e.g. CSEP Acquisition
  - Should be at the same ability level as for systems engineering, namely declarative, procedural and conditional.

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Proposed Maturity Model for measuring competencies of engineer-leaders

	Type I	Type II	Type III	Type IV	Type V
Knowledge					
Systems engineering	Declarative	Procedural	Conditional	Conditional	Conditional
Domain (problem solution)	Declarative	Declarative	Conditional	Conditional	Conditional
Cognitive characteristics					
System Thinking					
Descriptive	Declarative	Procedural	Conditional	Conditional	Conditional
Prescriptive	No	No	Procedural	No	Conditional
Critical Thinking	Confused fact finder	Perpetual analyser	Pragmatic performer	Pragmatic performer	Strategic re-visioner
Individual traits (sample)					
Communications	Yes	Yes	Yes	Yes	Yes
Management	No	Yes	Yes	Yes	Yes
Leadership	No	No	Yes	Yes	Yes

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Activity-based role of the systems engineer

- Systems engineer (role) is not equal to systems engineering (activity)
  - Role is different in different organizations
  - Overlap between roles is different in different organizations
- **Basing a SEBoK on a list of activities is no improvement**
  - Literature contains long lists of activities
    - E.g. Eisner 1988, Eisner 1997
  - Long lists are NOT the way to go
    - Lessons learned from Psychology
- If accepted, then debate changes to "you should be including the activities on 'my list' "

Structure: Activity Paradigm Criterion

- Projects contain streams of activities in series/ parallel
- If the activity ***deals with parts and their interactions as a whole***, then it is an activity within the set of activities to be known as **systems engineering**
- If the activity ***deals with a part in isolation***, then the activity is not an activity within the set of activities to be known as systems engineering but is part of '**something else**'
  - e.g., engineering management, software engineering, etc.

Structure: Role is more than activity

- Recognising that **systems engineers need the knowledge to perform or understand many of the activities defined as 'something else'** but that knowledge *per se* is **out of the scope** of the SEBoK and **should be identified accordingly**
  - PMBoK, Corporate handbooks,
  - Domains
  - Etc.
- Produces a BoK for "systems engineering", not a BoK for an undefined number of job descriptions

Layer of Systems Engineering \ Phase in the Life Cycle		Needs identification	Requirements	Design	Construction	Unit testing	Integration & testing	O&M, upgrading	Disposal
Socio-economic	5								
Supply Chain	4								
Business	3								
System	2								
Product	1								
		A	B	C	D	E	F	G	H

Algorithm for populating the SEBoK

- Publish structure of SEBoK database
- Invite systems engineers to provide information
- For each area in the Hitchins-Kasser-Massie Framework (HKMF) for understanding systems engineering
  - Identify the set of activities which end up producing the solution system
  - Identify the subset of activities performed by the role of the systems engineer
  - Use criterion (not opinion) to determine
    - IF activity is or is not systems engineering
      - » Yes, determine knowledge elements and place in SEBoK
        - traceable to activity
      - » No, just note need for knowledge
        - traceable to activity

Knowledge element

- **Not opinion-based**
  - Traceable to specific activity or activities and can be tagged as such
- Should be at high level [A Spec] (abstract)
  - E.g. Understand ways of communicating solution system performance to those that need to know it
- Should provide example ways of using that knowledge [B spec]
  - E.g. Requirements, models, pictures, prototypes
- Other attributes
  - See report to INCOSE Fellows, 2009

Using SEBoK to design a degree

- Some knowledge elements will be used in more than one activity in more than one area of the HKMF
- Elements with
  - high counts go into core courses/modules
  - few counts go into elective and specialty courses/modules
- Organize courses by area of HKMF
  - Example at NUS

Future expansion

- Use work flow analysis to build map to show
  - how different activities fit together
  - Where products are used and by whom
- Indentify competencies for activities
  - Based on knowledge and other criteria
- Optimize tools for areas
- Might remove overlap between professions
  - Align roles with activities
  - No, don't think so, not soon anyhow
- Must not turn into a detailed micromanaged Standard
  - Freeze status quo

Summary

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Questions and comments?

Backup and contingency

- EUSEC comments on Assessments
- Levels of critical thinking
- HKMF

Assessment discussion-1

- Each of the ways of assessing competences has been developed as a result of a different need
  - KSAs are designed to be used to assess the suitability of applicants for job positions
  - CEST focuses on the cognitive skills, individual traits, capabilities and knowledge and background characteristics of a systems engineer
  - CEST was developed based on a survey of what people thought were characteristics of successful systems engineers
  - INCOSE UK SECF is designed to be used to assess the systems engineering knowledge capability of organisations and individuals

Assessment discussion-2

- Each of the ways of assessing competences has been developed as a result of a different need.
  - INCOSE Certified Systems Engineer Professional (CSEP) Examination seems to be designed to be used to assess the applicant's knowledge of the contents of the INCOSE Systems Engineering Handbook
  - The INCOSE CSEP and UK SECF focus mainly on the [systems engineering] knowledge domain.
  - The CSEP and SECF focus on assessing declarative and procedural knowledge and tend to produce Type II systems engineers
  - SECF is multi-level but one level is orthogonal to others

Critical thinking

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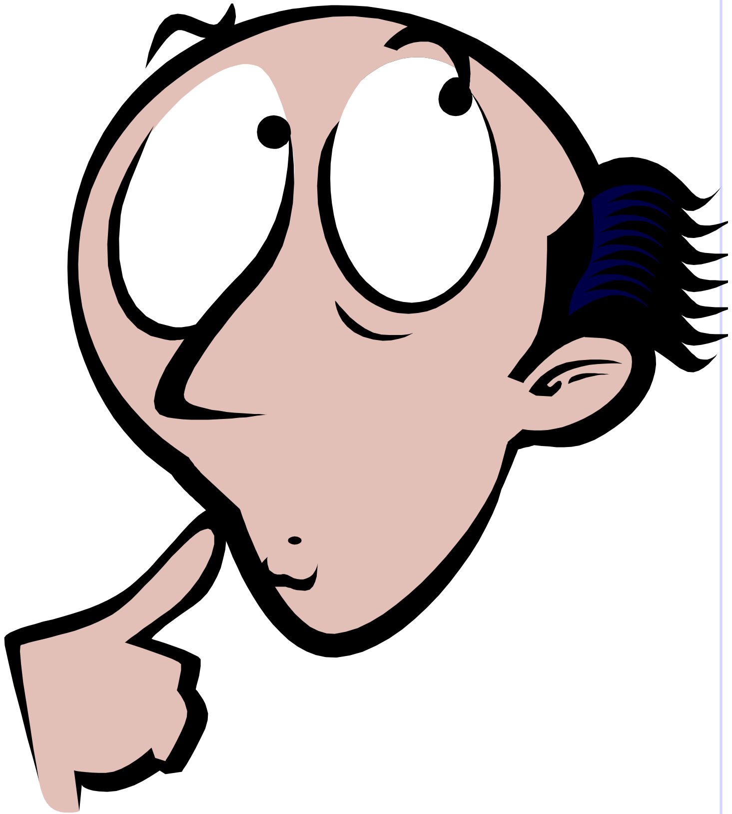


0 - Confused fact-finder

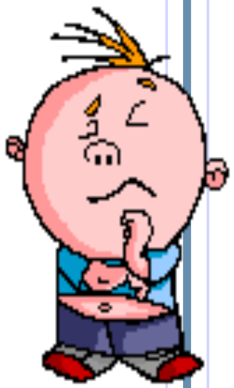
- Looks for the “only” answer
- Doesn’t seem to “get it”
- Quotes inappropriately from textbooks
- Provides illogical/contradictory arguments
- Insists professor, the textbook, or other experts provide “correct” answer even to open-ended problems

1 - Biased Jumper

- Jumps to conclusions
- Does not recognise own biases; accuses others of being biased
- Stacks up evidence for own position; ignores contradictory evidence
  - Uses arguments for own position
  - Uses arguments against others
- Equates unsupported personal opinion with other forms of evidence
- Acknowledges multiple viewpoints but cannot adequately address a problem from viewpoint other than own

2 - Perpetual analyzer

- Does not reach or adequately defend a solution
- Exhibits strong analysis skill, but appears to be "wishy-washy"
- Write papers that are too long and seem to ramble
- Doesn't want to stop analysing
  - "I can look at it this way, and I can look at it that way..."
  - Wait! What about _______?"



3 – Pragmatic performer

- Objectively considers alternatives before reaching conclusions
- Focuses on pragmatic solutions
- Incorporates others in the decision process and/or implementation
- Views task as finished when a solution/decision is reached
- Gives insufficient attention to limitations, changing conditions, and strategic issues
- Sometimes comes across as a “Biased Jumper”, but reveals more complex thinking when prompted

4 – Strategic Re-Visioner

- Seeks continuous improvement/lifelong learning
- More likely than others to think “out of the box”
- Anticipates change
- Works toward construction knowledge over time

Big picture and temporal perspectives

Phase in the Life Cycle / Layer of Systems Engineering		Needs identification	Requirements	Design	Construction	Unit testing	Integration & testing	O&M, upgrading	Disposal
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Supply Chain	4								
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The higher the layer, the longer the lifecycle (in general)

Evolution is faster in lower layers