IS2010 Paper Track 2 – Session 1

System Engineering Competency: The Missing Element in Engineering Education

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Presentation Outline

- Introduction
- Abstract - The Industrial System Development Challenge
- State of System Engineering Practice in Many Organizations
- Causal Analysis - Tracing the SE Root of Poor Project Performance
- Solving the Problem
- Recommendations
- Summary
- Q & A

Abstract

The Industrial System Development Challenge

Abstract (1 of 2)

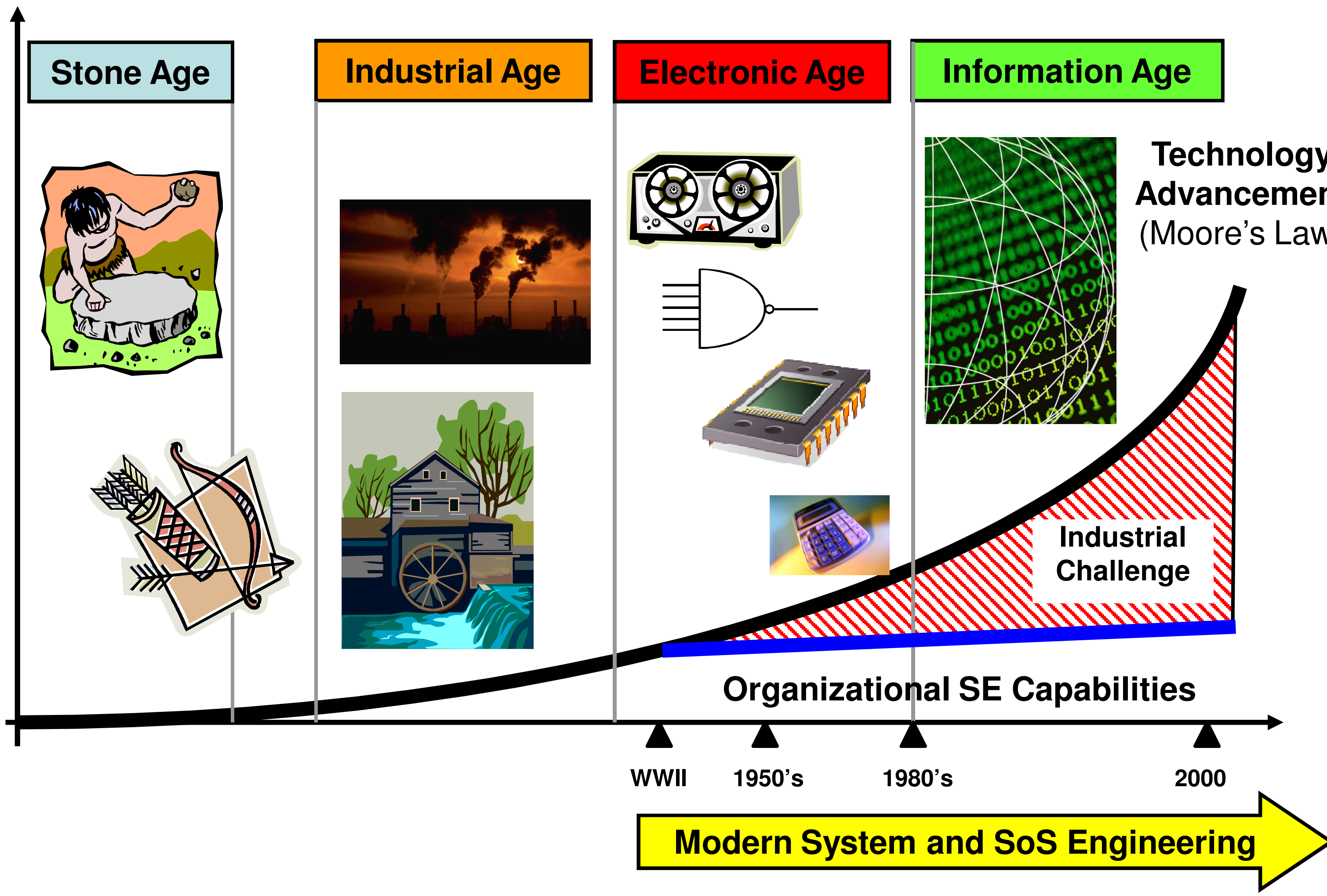
- ***The "engineering of systems" performed in many organizations is often characterized as chaotic, ineffective, and inefficient.***
  - *Objective evidence of these characteristics is reflected in program performance metrics such as non-compliance to requirements, overrun budgets, and late schedule deliveries.*
  - *Causal analysis reveals a number of factors contribute to this condition:*
    - *A lack of technical leadership*
    - *A lack of understanding the user's problem / solution spaces*
    - *Quantum leaps to point design architectural solution*
    - *A lack of integrated decision making, et al.*
  - *Further analysis indicates these factors are symptomatic of a much larger competency issue traceable to undergraduate engineering education - the lack of a course in Systems Engineering fundamentals taught by seasoned instructors with robust, industrial experience acquired from a diversity of small to large, complex systems.*

Abstract (2 of 2)

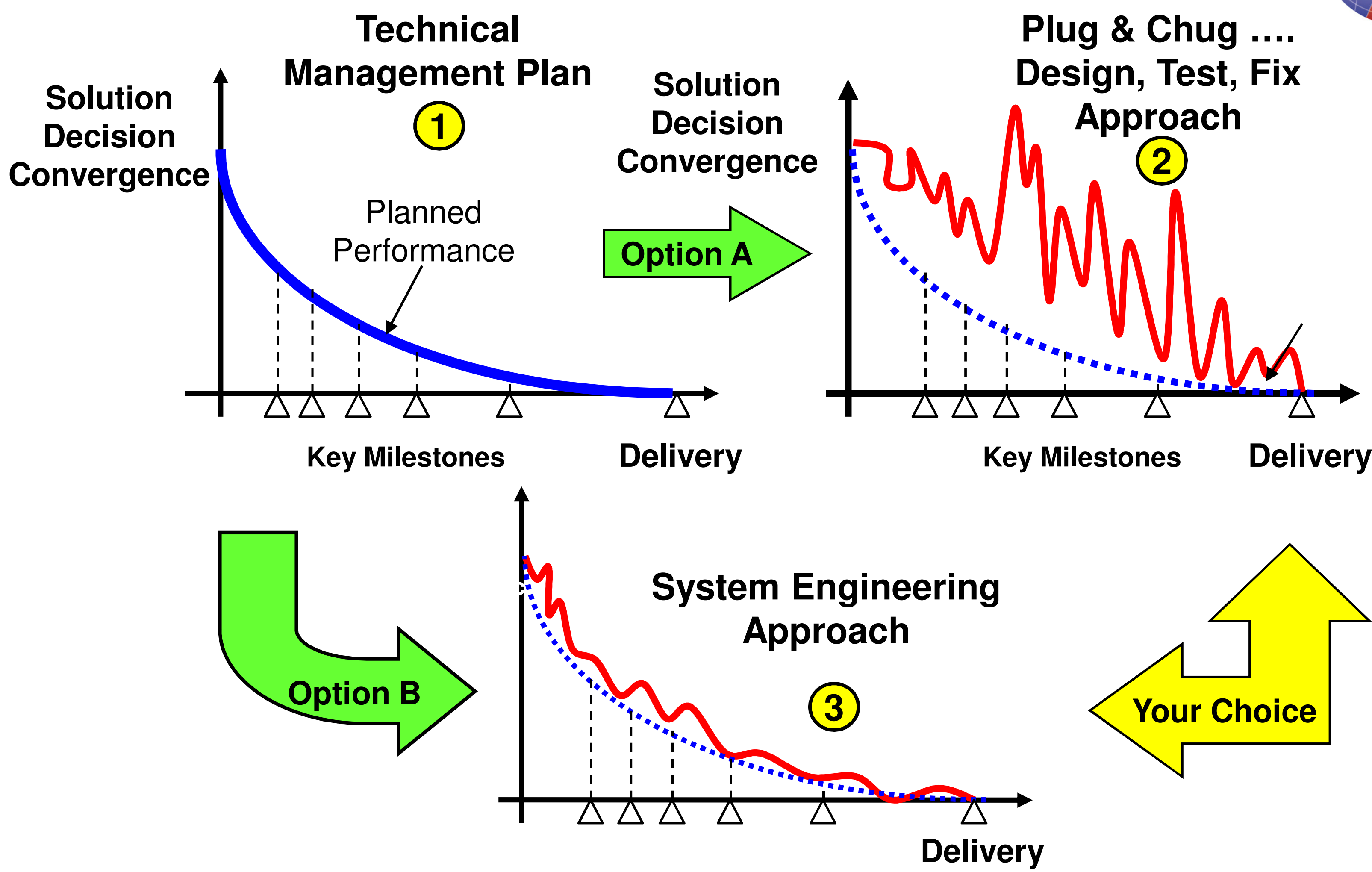
- ***This paper explores the ad hoc, chaotic, and dysfunctional nature of technical planning and execution.***
  - We trace its origins to the industrial Plug and Chug … Specify-Design-Build-Test-Fix Paradigm and its predecessor Plug and Chug … Design-Build-Test-Fix Paradigm acquired informally in engineering school.
  - Whereas these paradigms may be effective for academic application, they are not suitable or scalable to larger, complex system, product, or service development efforts.
- ***The solution is to bolster the competency of the engineering workforce at two stages:***
  - Stage 1 - Upgrade undergraduate engineering education to include a System Engineering fundamentals course
  - Stage 2 - Shift the industrial System Engineering paradigm through education and training to employ scalable SE problem solving / solution development methodologies for projects ranging in size from small to large, complex systems.

State of System Engineering Practice for Many Organizations

The System Development - Technology Challenge



Comparison of Organizational SE Capabilities

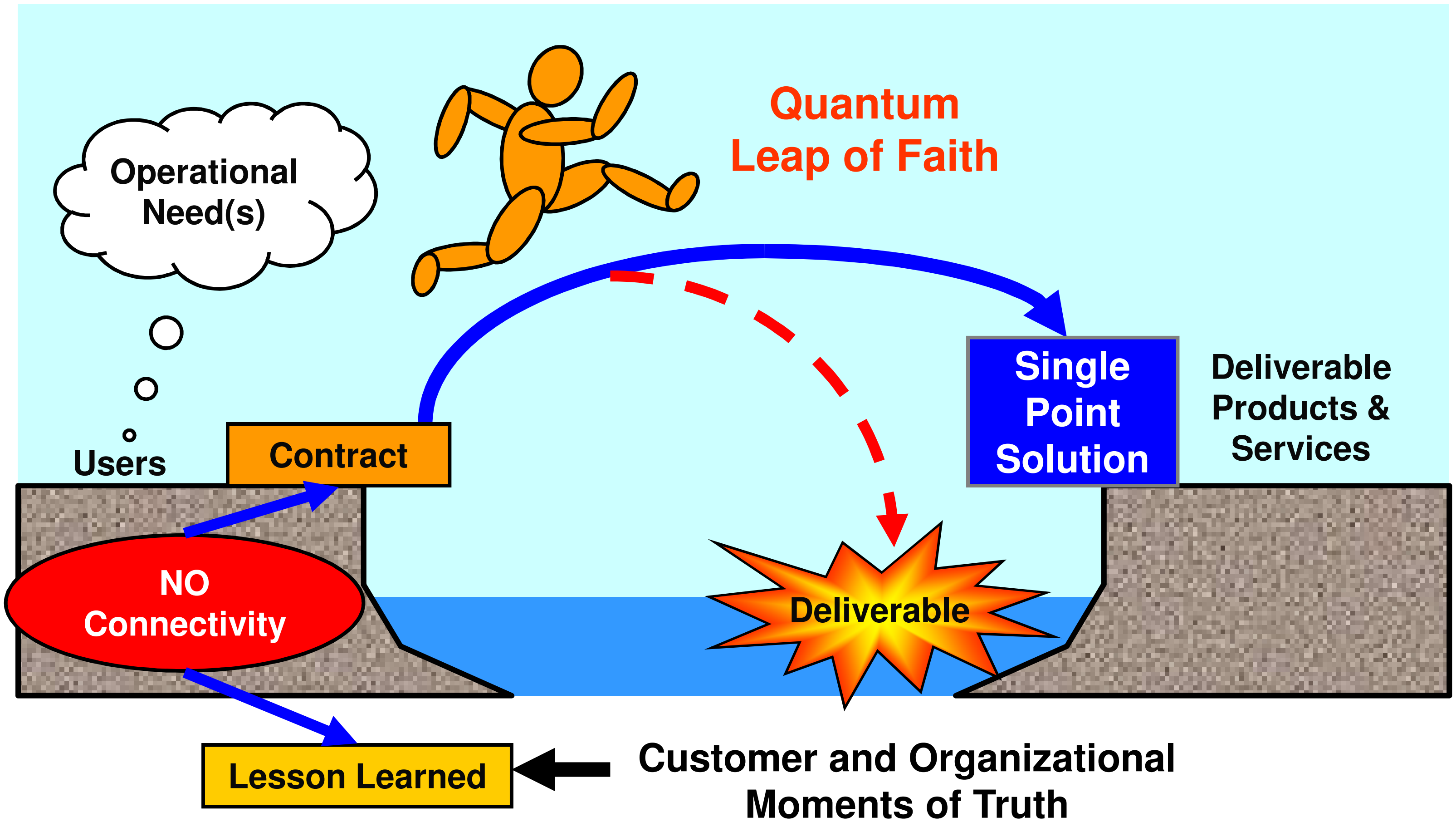


Some organizations perform and apply SE well as shown in Panel 3. Others employing a Plug & Chug … Design, Test, and Fix approach produce results as shown in Panel 2.

Two Brands of System Engineering

- **System Engineering courses generally occur in two forms:**
  - **Type 1 Courses that teach System Engineering theory**
    - E.g. awareness of WHAT should be accomplished, not HOW.
    - Students emerge with a vocabulary of semantics but lack the skills to apply what they have learned.
  - **Type 2 Courses that equip engineers with the requisite knowledge and skills to transform the "SE theory" into real-world application**
    - E.g., WHAT is to be accomplished and HOW TO do it.
- **Both types of instruction may cover the same topics. However, the differences reside in two areas:**
  - The seasoned knowledge, skills, and experience of the instructor in SE practices.
  - The knowledge, efficiency and effectiveness of the students to apply and scale WHAT they have learned into HOW TO apply SE methods to solve real-world problems.
- **The degree of success of these two points, coupled with insightful SE leadership, may provide insights as to WHY some organizations taut their SE training metrics and publicize standard assessment ratings. Yet, exhibit project performance that fails to correlate with the rating.**

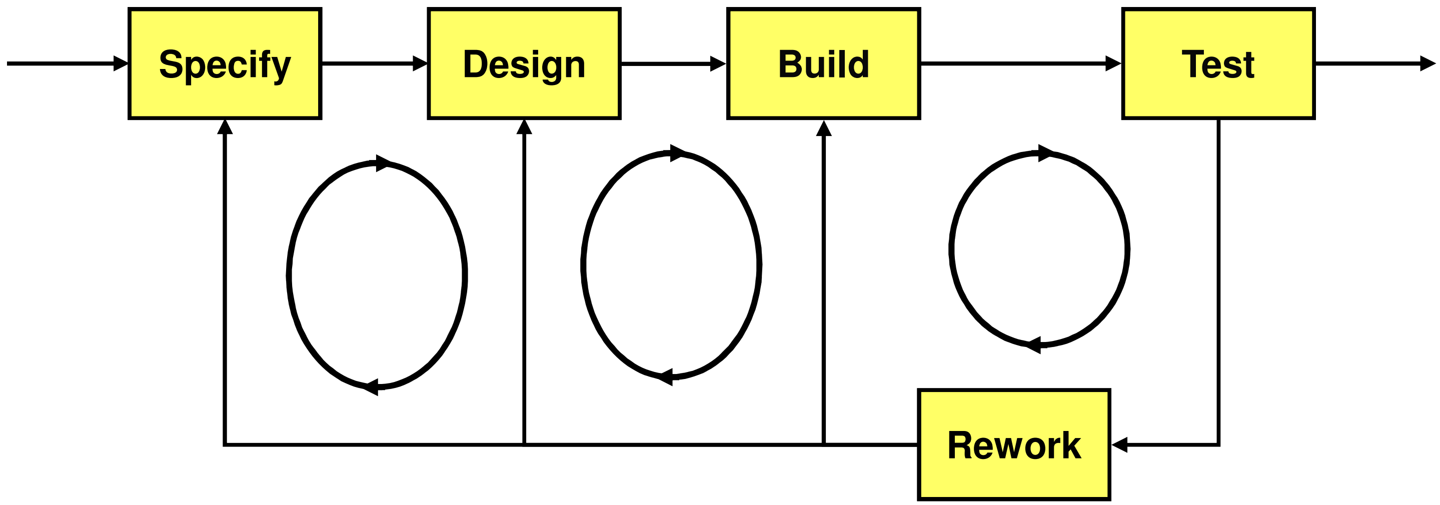
Quantum Leap to A Point Solution



Every system is PERFECTLY designed to produce the results you are observing.

The Industrial System Development Paradigm

Our iterative process evolves the system design …. …
(until we finally get it RIGHT!! … sometime in the future)

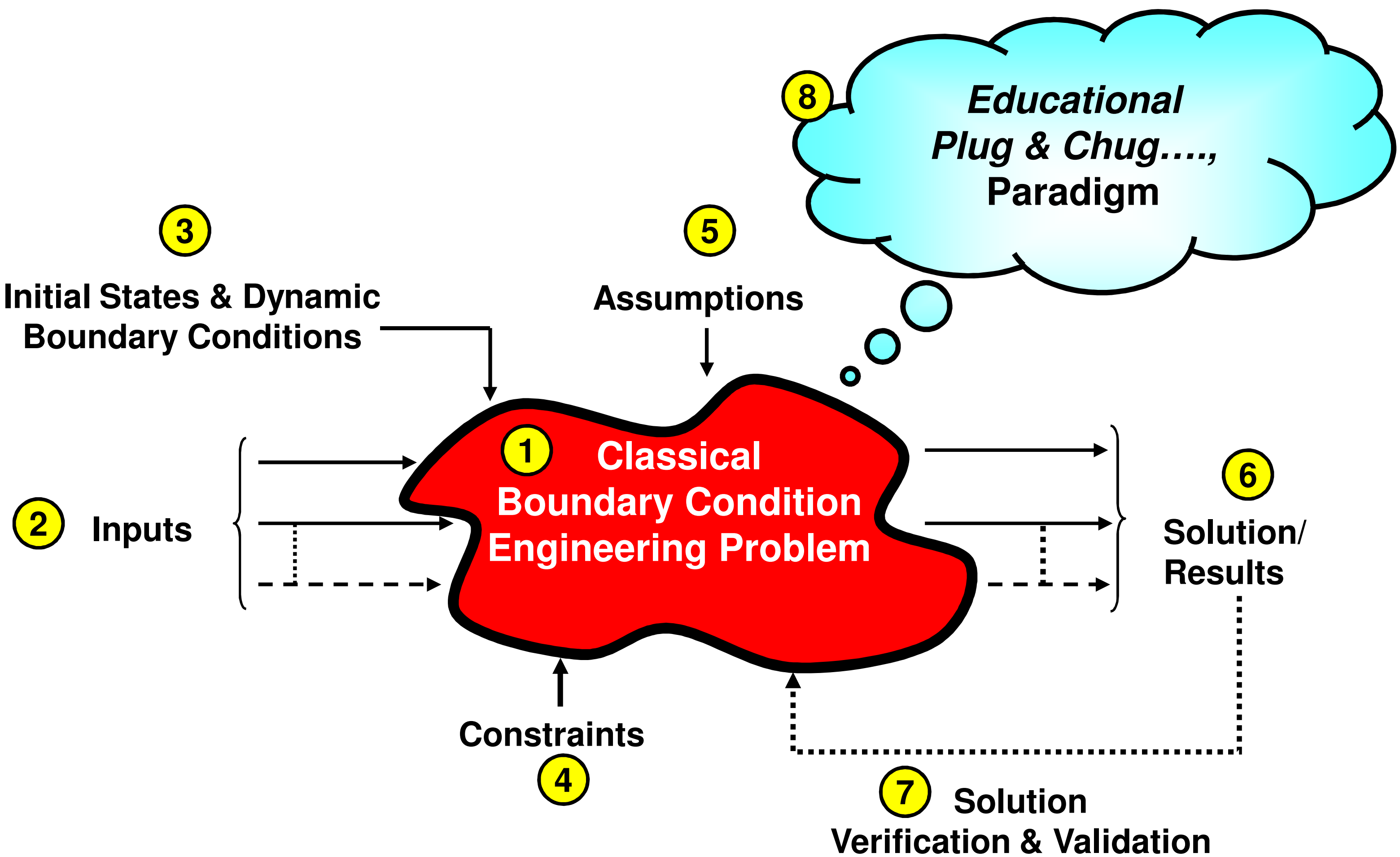


This graphic characterizes how many organizations perceive and perform "System Engineering"

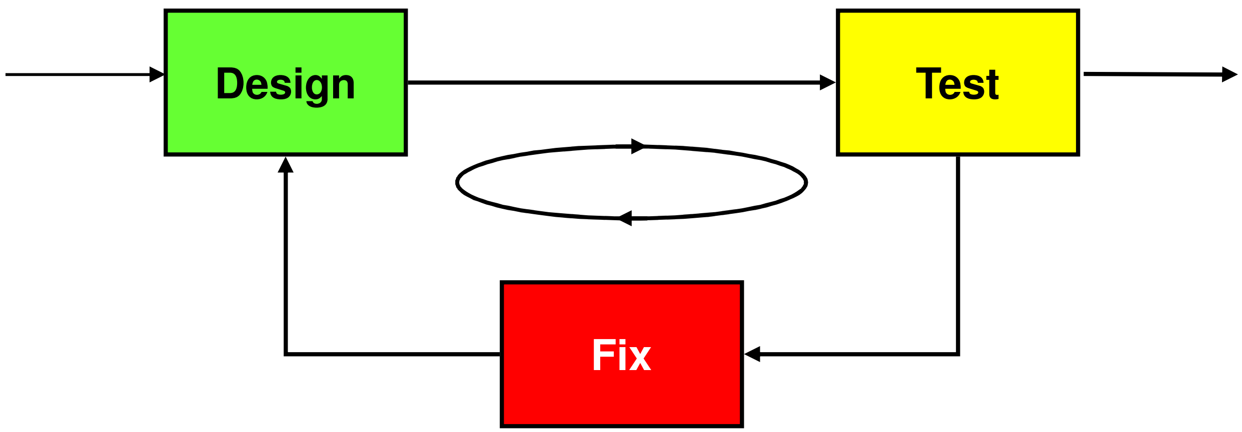
Causal Analysis

Tracing the SE Roots of Poor Project Performance

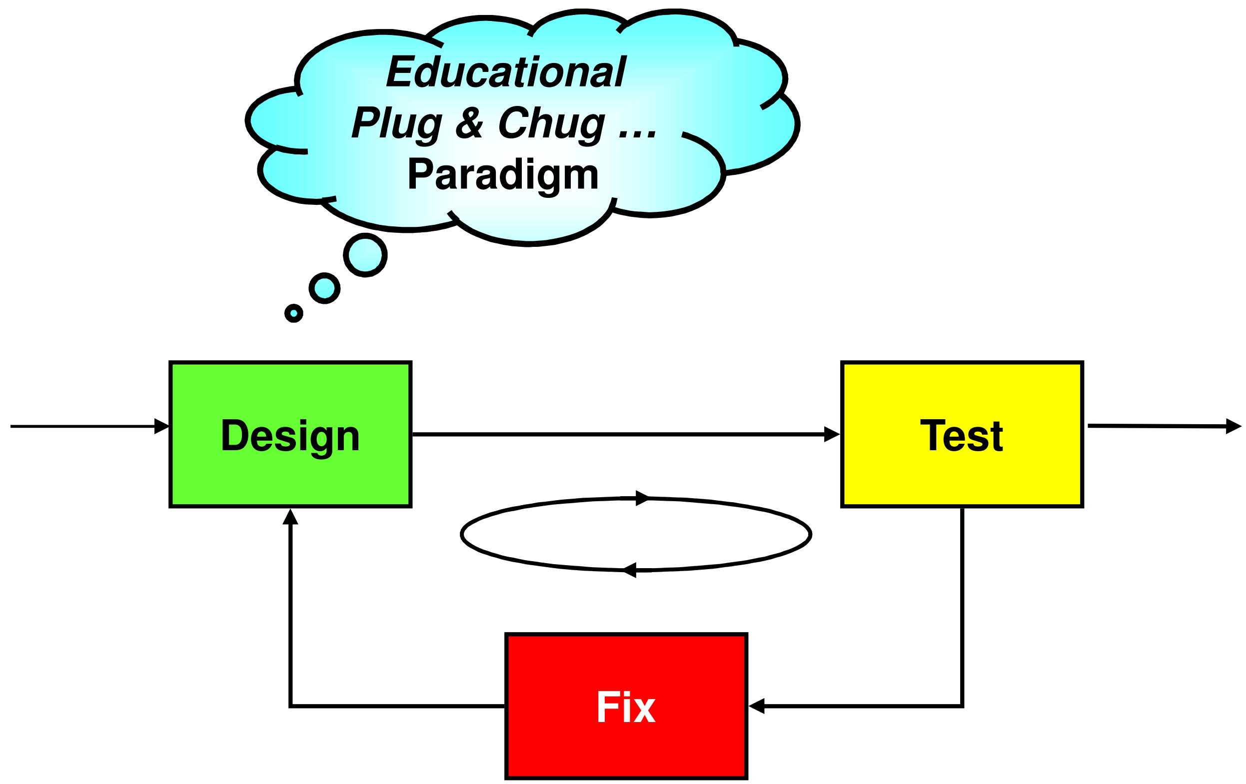
Educational Plug & Chug – Design-Build-Test-Fix Paradigm



Laboratory Experiment Design-Test-Fix Paradigm

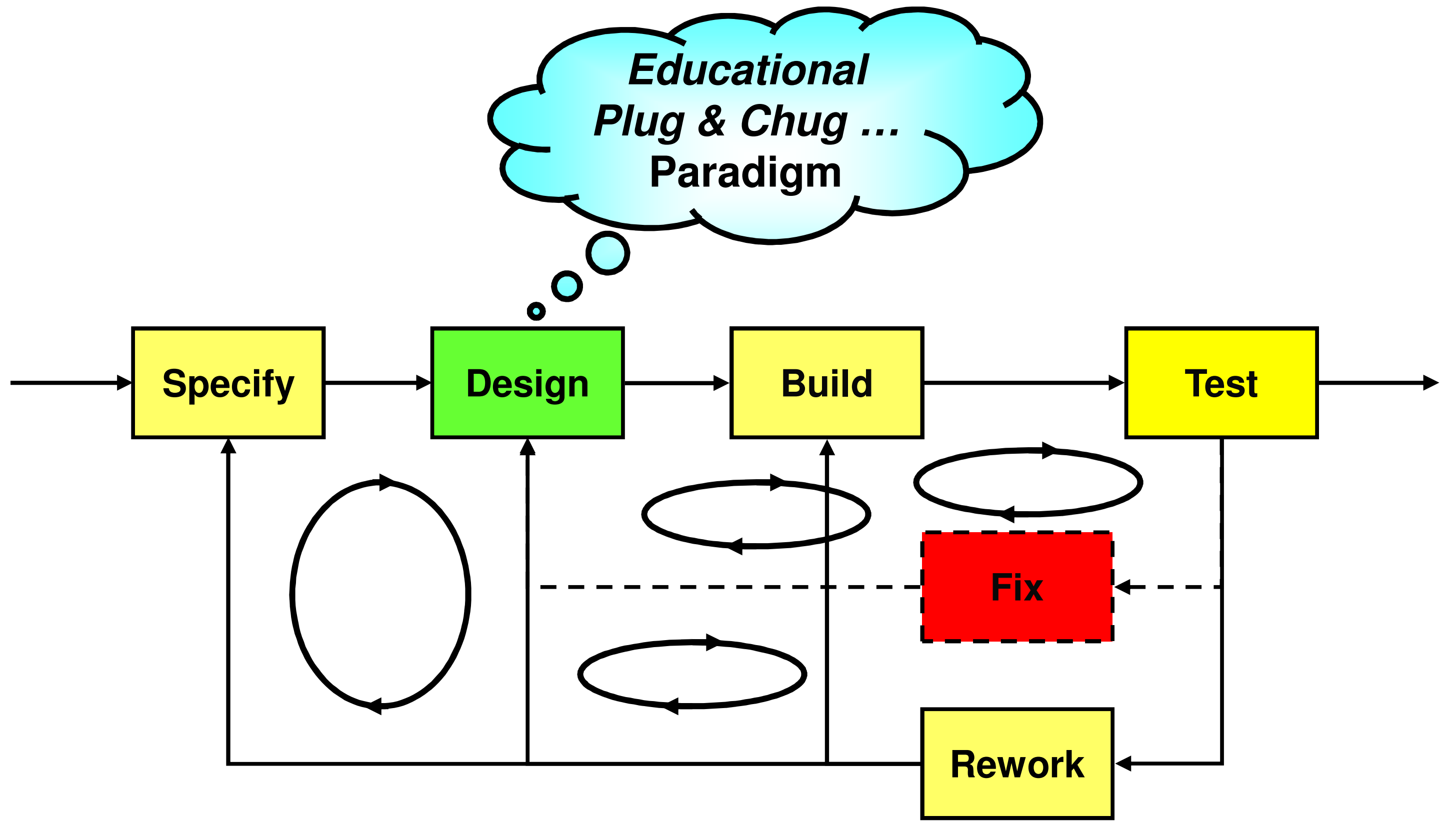


Merging the two paradigms …



… which forms the basis for the
Industrial Specify-Design-Build-Test-Fix Paradigm

Instantiatiion of the Educational Paradigm in Industry



Net Result:
"Plug & Chug … Design-Test-Fix" Paradigm migration into industry

Solving the Problem

An Instructional System Development (ISD) Perspective

Addressing the Need for an SE Course (1 of 2)

- **Caldwell [8] in addressing engineering curricula reform**
  - Describes the traditional engineering course presentation order as bottom-up - COMPONENTS - INTERACTIONS - SYSTEMS.

- **Caldwell [15] offers the following suggestions:**
  - Students seldom see SE methods presented as an integrated concept.
  - He proposes engineering course presentation that follows a SYSTEMS - COMPONENTS - INTERACTIONS approach.
  - He notes that the goal of this sequence is to provide students with an "overall sense" of SE as a problem-solving method.
  - This is accomplished by providing a general structure – e.g., "scaffolding" – that enables students to see how components and interactions "fit within a general SE context."

[8] Caldwell, Barrett S. *Teaching Systems Engineering by Examining Educational Systems*, Proceedings of the Spring 2007 American Society for Engineering Education (ASEE) Illinois-Indiana Section Conference, p. 91-92.

[15] Ibid, p.91-92.

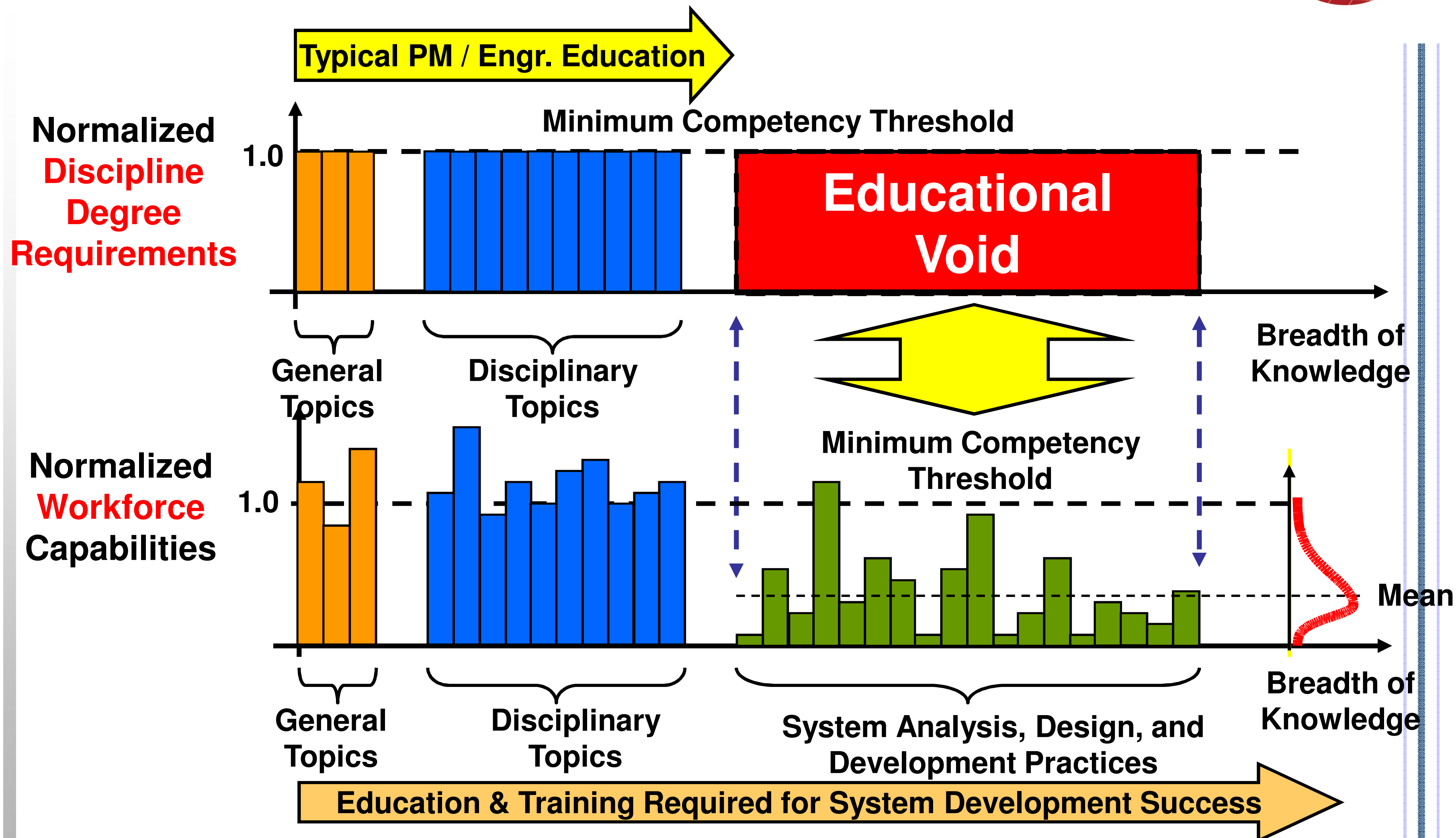
Addressing the Need for an SE Course (2 of 2)

- Erwin [9] observes that:
  - Projects in engineering schools tend to focus on the "building" aspects of systems.
  - Then, when the projects are submitted for grading, most of the assessment is based on completion of the exhibit with design having lesser importance.
  - He notes this is often rationalized on the basis of allowing the students to be "creative."
  - As a result, the student receives little or no guidance or direction.

Reference

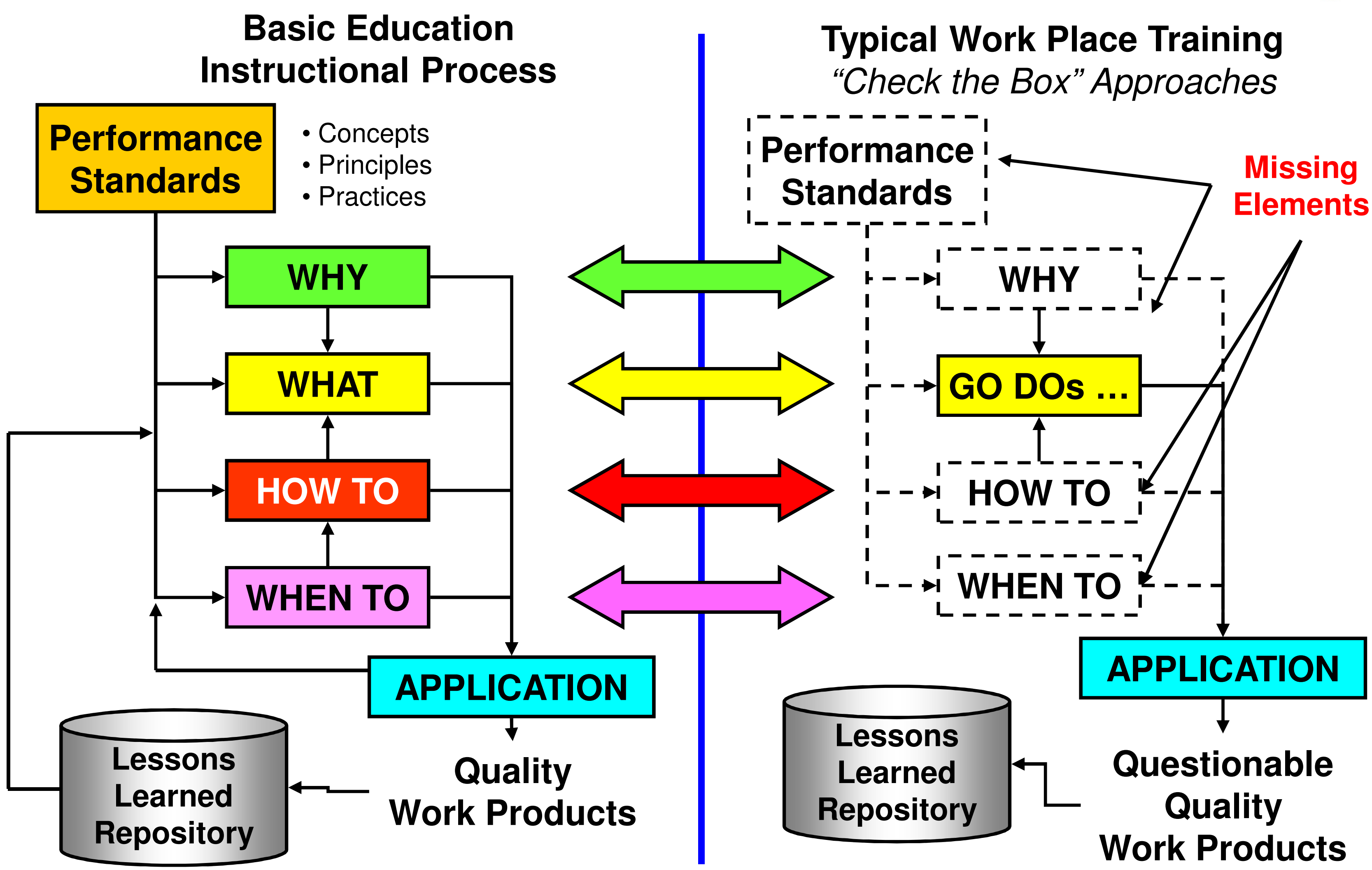
Erwin, Ben *K-12 Education and Systems Engineering: A New Perspective*, Proceedings of the American Society of Engineering Education National Conference, Session 1280, Seattle, WA July 1998, p. 6.

The Engineering Education Void



Formal Education Versus Experiential Learning

INCOSE International Symposium



System Engineering - The Missing Course Requirement

BS | 5 Years | 10 Years | **Career Evolution and Progression** | 40 Years

Career Life Cycle

System Engineering Concepts, Principles, and Practices

Typical Undergraduate Engineering Curriculum

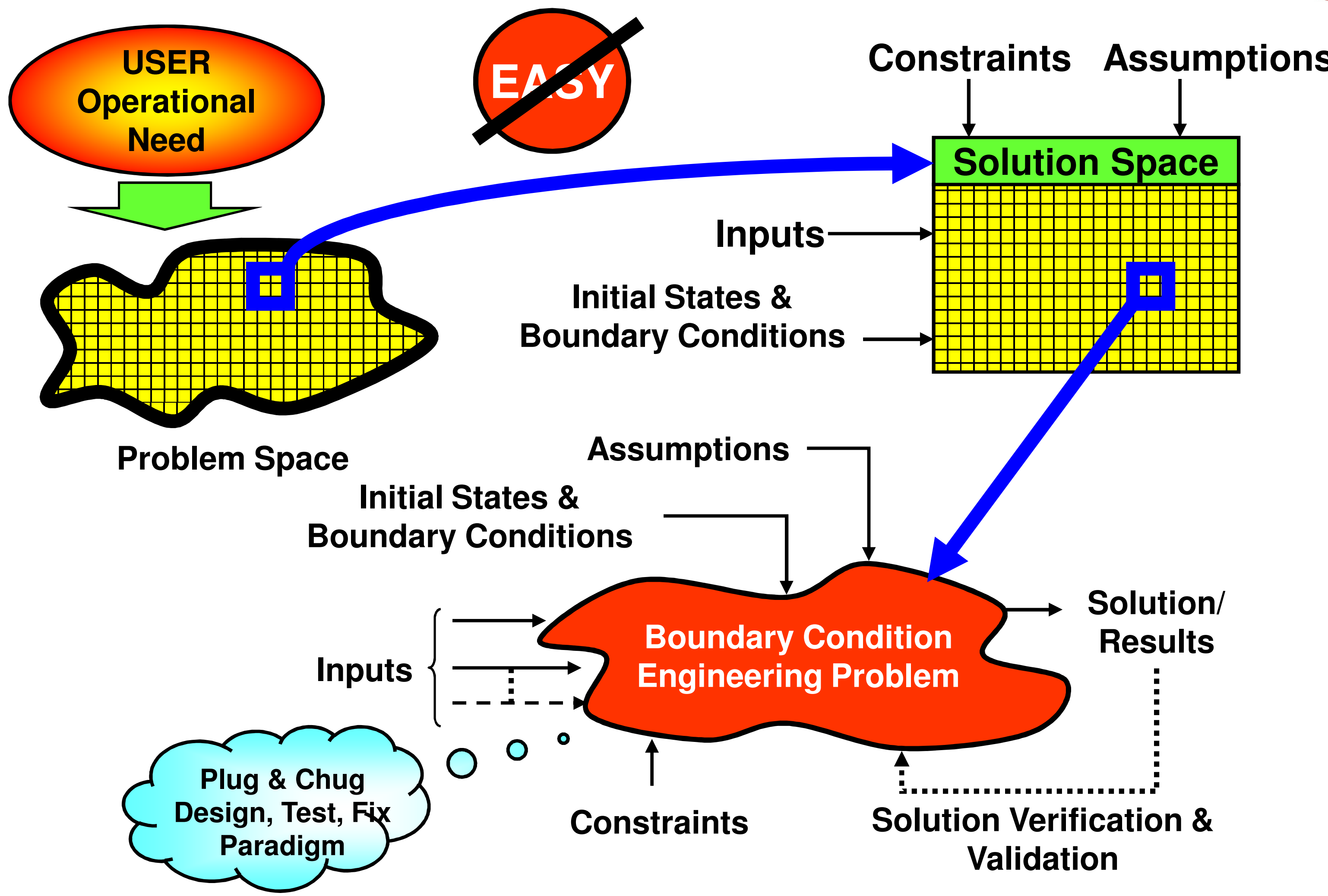
- **Core Discipline Courses**
- **Common Courses Required**
  - Engineering Statics
  - Engineering Dynamics
  - Strength of Materials
  - Thermodynamics
  - Engineering Materials
  - Engineering Economy

MISSING COURSE

System Engineering Course
- Analysis
- Design
- Development

Engineers spend 4 years obtaining an engineering degree that has a direct use shelf-life of 4 – 5 years. Yet, spend 70 – 80% of their careers performing System Engineering tasks for which they receive no formal SE education as an undergraduate degree requirement

Who Decomposes the Abstract Problem Space(s) into Multi-Layer Solution Spaces?



Recommendations

Recommendations

1. Establish minimum SE competency requirements
   – Concepts
   – Principles
   – Practices

2. Institute an SE Fundamentals Course as one of the minimum requirements for an Undergraduate Engineering Degree

3. Employ Instructors with "True SE" Industrial Strength Experience

4. Transform the Industrial "Specify-Design-Test-Fix Paradigm" to an SE-Based Paradigm

5. Industry managers need to inform new hires "up front" of organizational requirements to perform SE competently.

Example SE Competency Areas

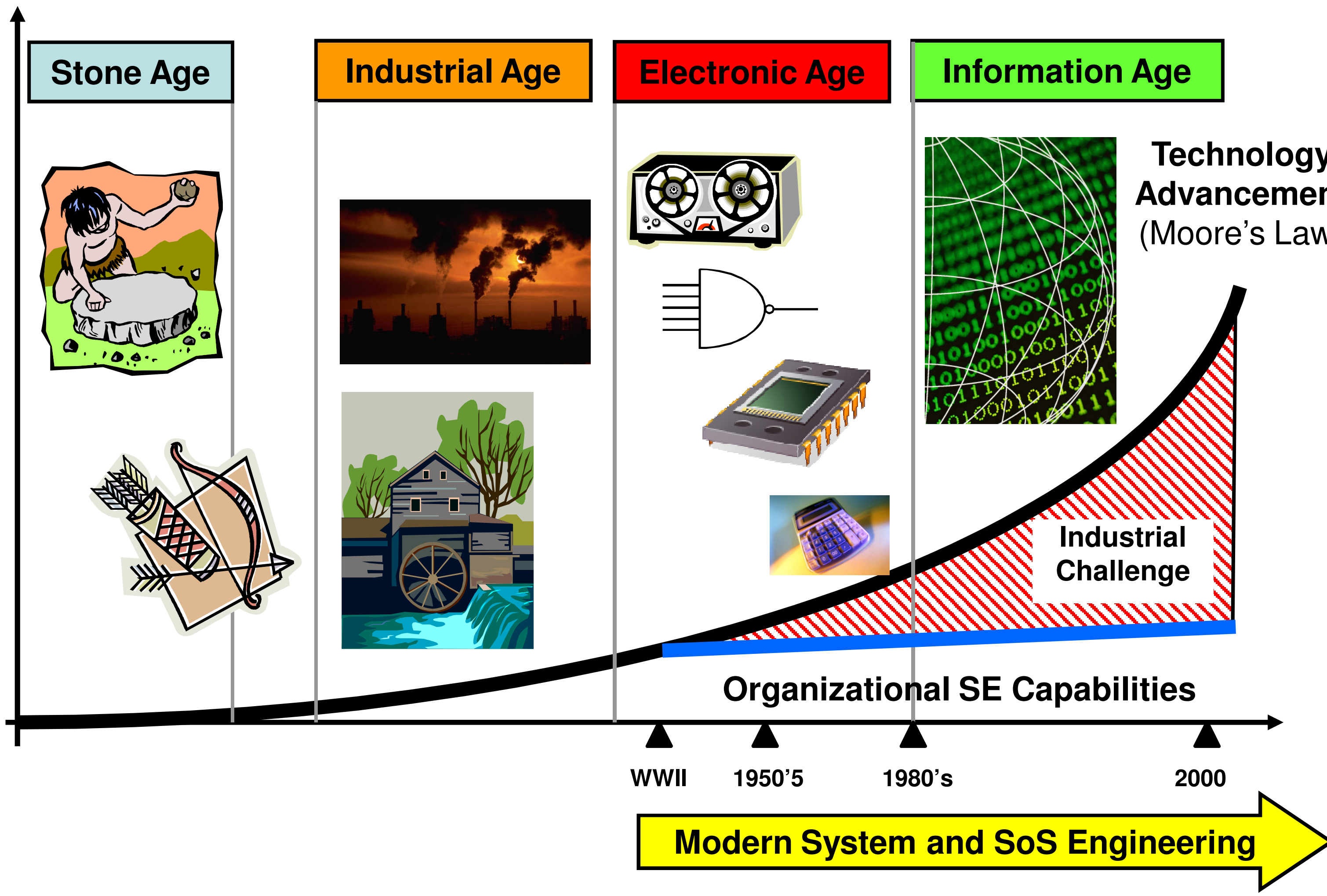
1. Technical Planning
2. Stakeholder Identification
3. Stakeholder Needs Assessment
4. Use Case Identification & Definition
5. System Engineering Process
6. Specification Development
7. Requirements Development
8. System Architecture Development
9. System Stimulus-Behavioral Responses
10. System I/F Definition and Control
11. Requirements Allocation & Flow Down
12. Requirements Traceability and Mgt.
13. System Phases, Modes, and States
14. System Decomposition
15. Analysis of Alternatives (AoA)
16. System Design & Development
17. System Test Cases
18. System Integration & Test
19. Model-Based System Engineering
20. System Performance Modeling
21. System Optimization
22. Reliability, Availability, and Maintainability
23. Specialty Engineering Integration
24. System Safety
25. System Verification and Validation
26. System Development Metrics
27. Engineering Standards
28. Configuration and Data Management
29. System Life-Cycle Cost Estimating
30. Total Ownership Costs (TOC)
31. Event Based Schedule Development
32. Integrated Master Plans (IMPs)
33. Integrated Master Schedules (IMSs)
34. System Lifecycle Cost Estimating
35. Best Value Concepts
36. Technical Reviews and Audits
37. Earned Value Management (EVM)
38. Fundamentals of Project Management

SE Context and Organizational Capabilities

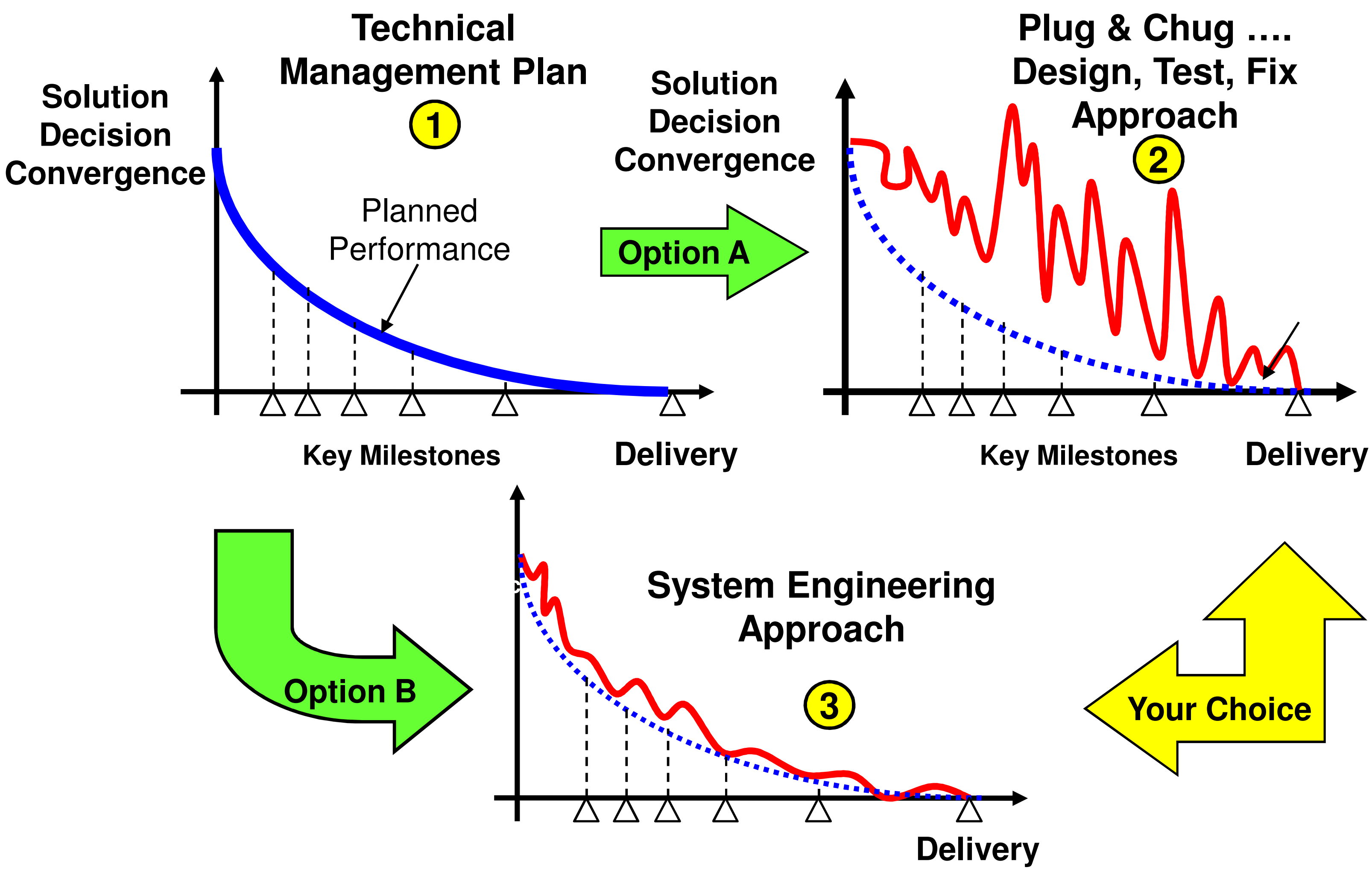
- **When organizations qualify for various levels of SE capability assessment ratings:**
  - Closely examine the “context” of their SE paradigm
  - LISTEN to the words … in most cases they truly believe they are performing SE … “DOING ALL THE RIGHT THINGS”
    - Developing specifications
    - Linking requirements
    - Selecting an architecture
    - Developing designs
    - Iterating the SE Process
  - OBSERVE what SE process is being implemented – e.g., Specify-Design-Build-Test-Fix at each level
- **This may provide partial insights as to WHY they achieve SE capability maturity high ratings but yet exhibit program performance that does not correlate.**

Summary

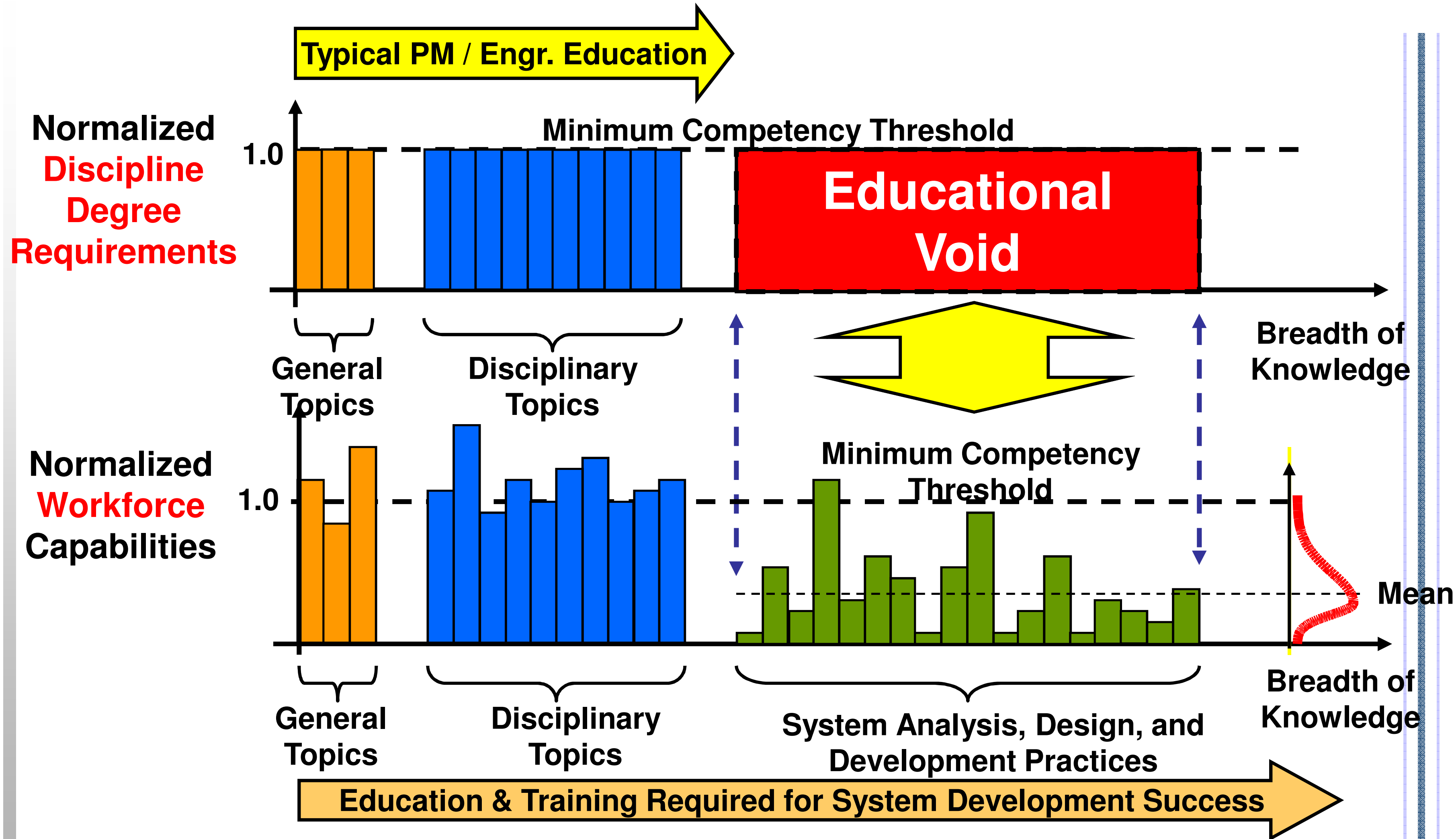
The System Development - Technology Challenge



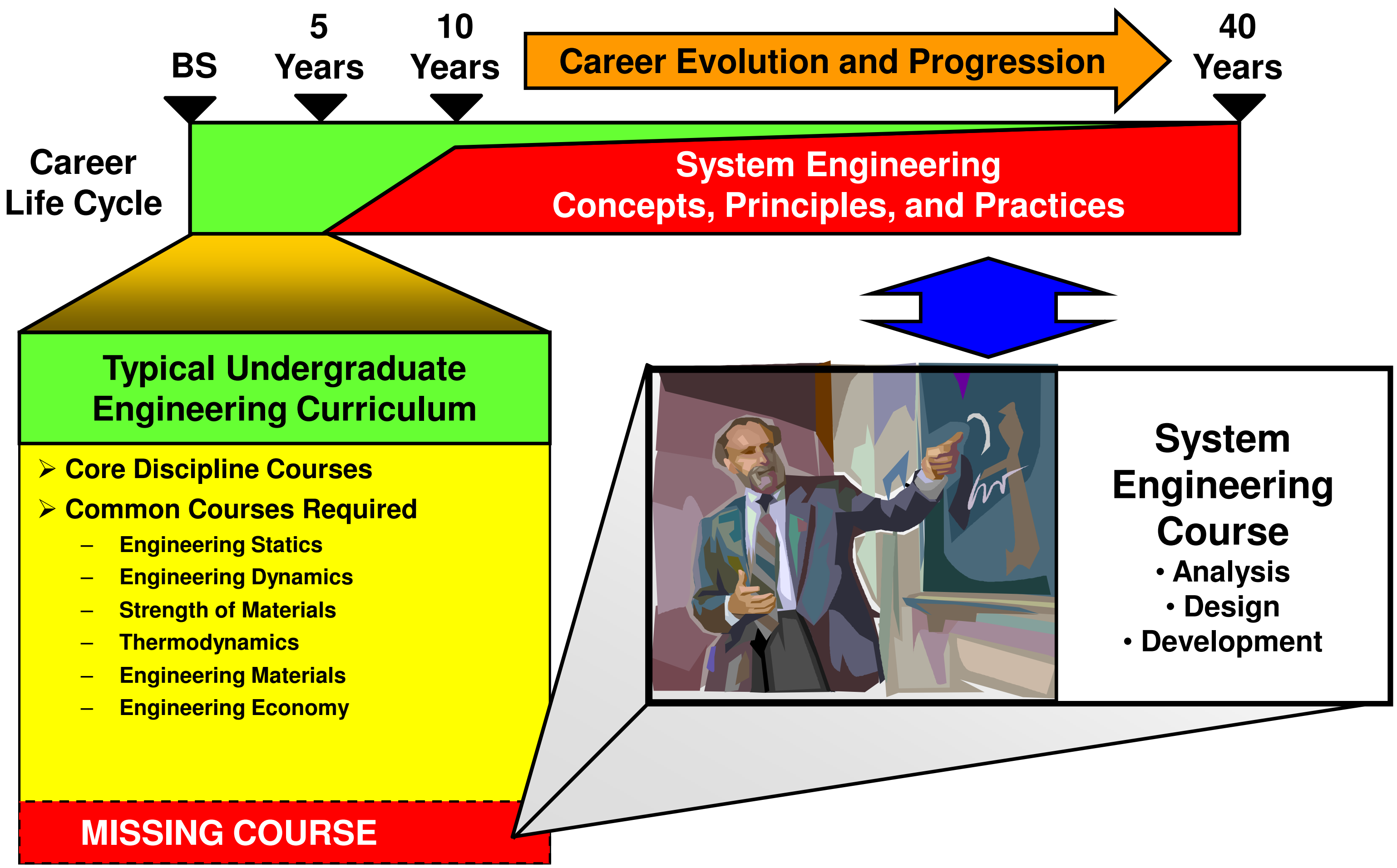
Comparison of Organizational SE Capabilities



The Engineering Education Void



System Engineering - The Missing Course Requirement



Quotes to Ponder

THE lesson learned was we didn't learn our lessons [Anonymous]

Every system is PERFECTLY designed to produce the results your are observing. [Anonymous]

Insanity is doing the same thing over and over, and expecting a different result [Dr. Albert Einstein]

Questions & Answers

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System Analysis, Design, and Development

John Wiley & Sons, Inc. (New York)

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- [2] NDIA (2006) Task Group Report: *Top Five System Engineering Issues within Department of Defense and Defense Industry*, National Defense Industrial Association, System Engineering Division, July 2006.
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- [4] Bahill, A. Terry and Henderson, Steven J. *Requirements Development, Verification, and Validation Exhibited in Famous Failures*, Systems Engineering, Vol. 8, No. 1, 2005.
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- [6] Wasson, Charles S. *System Analysis, Design, and Development*, John Wiley & Sons, Inc. (New York), p. 24.
- [7] Ibid, p. 275.

Paper References (2 of 3)

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Paper References (3 of 3)

- [14] Guskey, T. *What Makes Professional Development Effective*? Phi Delta Kappan 84, pp. 748-750.
- [15] Ibid, Caldwell, p. 91 – 92.
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- [19] Felder, Richard M. and Brent, Rebecca *The ABC's of Engineering Education: ABET, Bloom's Taxonomy, Cooperative Learning, and So On*, Proceedings of the 2004 American Society for Engineering Education Annual Conference & Exposition, p. 1.