INCOSE-LA Speaker Meeting

Systems Engineering at the Hello – Systems Engineering in Early Stage R&D Working Group Update

Michael DiMario, PhD
Ann Hodges

Agenda

- Why we're here - Mike
- What we've done - Mike
- Mind map - Mike
- Priorities
  – Value proposition - Ann
  – Principles - Ann
  – Existing frameworks and literature search - Ann
  – Case studies - Mike
- Wrap up - Mike

Why we're here: Charter overview

- **Purpose:** To provide an open forum for the development, application, and dissemination of systems engineering principles, best practices, and solutions to scaling systems engineering applications to Early Stage R&D (ESR&D) projects allowing the systems engineering effort to be tailored and commensurate with the anticipated risk to ensure the ESR&D outcomes are achieved
- **Primary Goal:** To provide knowledge, guidelines, and frameworks for the application of systems engineering in ESR&D

Why we're here: Charter Overview Cont'd

- **Scope:** Focus on activities at Technology Readiness Levels (TRLs) 1 – 5
- **Outcomes:**
  - An ESR&D SE framework that contains guidelines and processes for the "right" and "right-sized" tailored SE practices and products based on a TRL of 1-5 and other characteristics e.g., organizational culture and philosophies
  - Papers, articles, briefings, and tutorials
  - Support the development of additions to the INCOSE SE Handbook and standards related to ESR&D

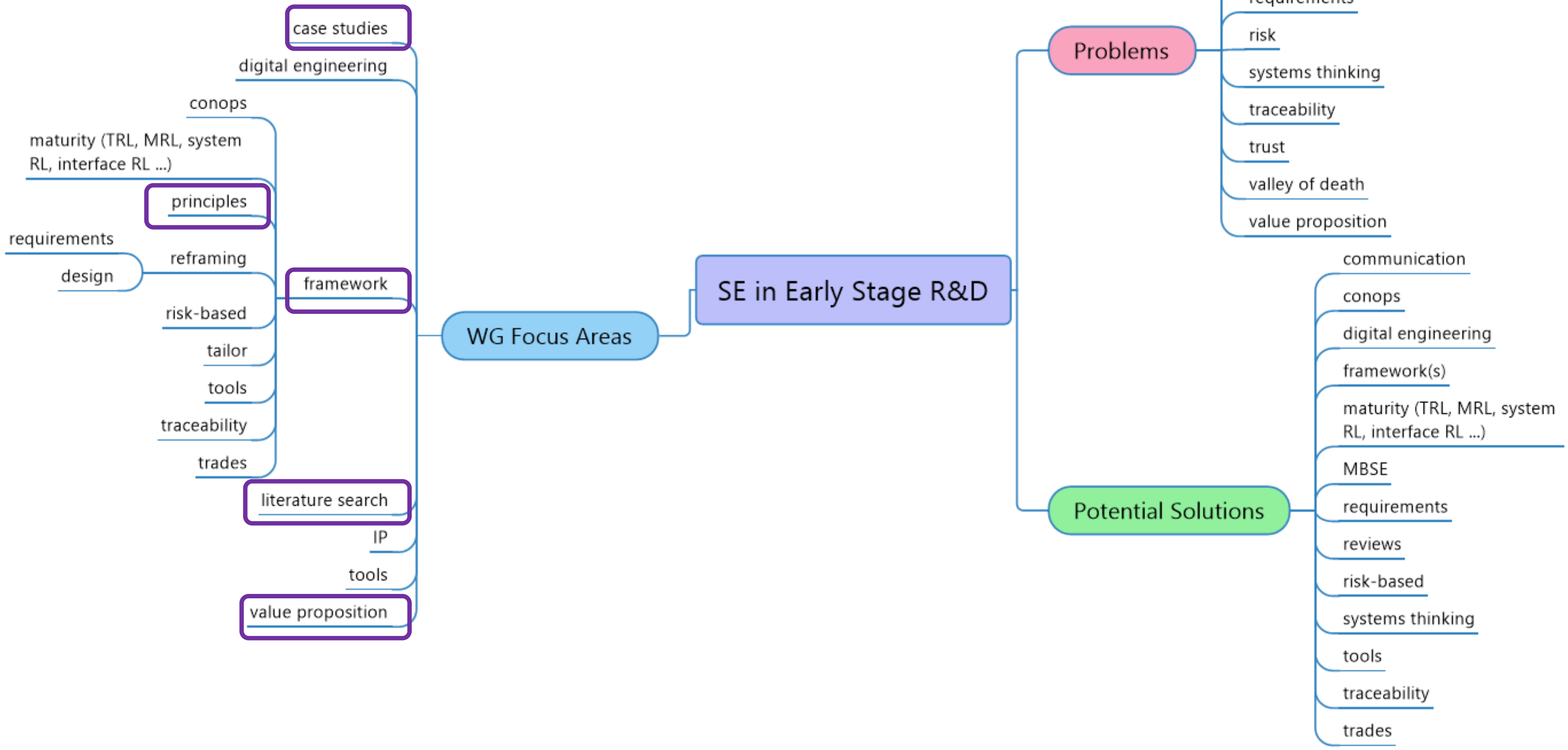
Why we're here: Charter Overview Cont'd – Background

- Early Stage Research and Development (ESR&D) is one of the most crucial phases in the product development process
  - ESR&D is defined in terms of Technology Readiness Levels (TRLs) 1 – 5
  - Is a critical phase in the product development process
- Many organizations/positions/key stakeholders are unwilling to apply SE in ESR&D due to due to perceptions of SE being process/cost heavy
  - Results in technical issues with solutions, difficulty in transitioning to higher TRLs, higher R&D costs, and extended development timelines
- ESR&D differs from traditional SE in a number of important ways:
  - ESR&D addresses higher risk technologies with multiple opportunities for failure
  - ESR&D accounts for the fact that there is much about the underlying technology *and* its associated concept of operations that is poorly understood
  - ESR&D is a way to practice SE for organizations without a strong SE culture
  - ESR&D of focused on areas of high "system development risk"
- Lack of a commonly understood and accepted framework inhibits multi-disciplinary collaboration
  - A common framework that can be tailored and sustained for ESR&D, while enabling transition to TRL 5 and higher, is needed

What we’ve done

- CORE Team officially formed February 2020
- Charter affirmed March 2020
- INCOSE recognized WG April 2020
- INCOSE Connect Site IT Logistics
- Publications
  - “Implementing Systems Engineering in Early Stage Research and Development (ESR&D) Engineering Projects” IS20 30Th Annual INCOSE International Symposium July 18-23, 2020
  - “Perceived Conflicts of Systems Engineering in Early Stage Research and Development” INCOSE InSight August 2021
- INCOSE LA Chapter presentation May 11, 2021
- IW21 working group meetings
- IS21 July 17-22, 2021 Panel
- September and November 2021 general working group meetings
- First Case Study planning underway 1st QTR 2022

Mind Map


SE in Early Stage R&D
WG Focus Areas
case studies
digital engineering
conops
maturity (TRL, MRL, system RL, interface RL ...)
principles
requirements
design
reframing
framework
risk-based
tailor
tools
traceability
trades
literature search
IP
tools
value proposition
Problems
communication
continuity
cultury
IP
requirements
risk
systems thinking
traceability
trust
valley of death
value proposition
Potential Solutions
communication
conops
digital engineering
framework(s)
maturity (TRL, MRL, system RL, interface RL ...)
MBSE
requirements
reviews
risk-based
systems thinking
tools
traceability
trades

Focus areas

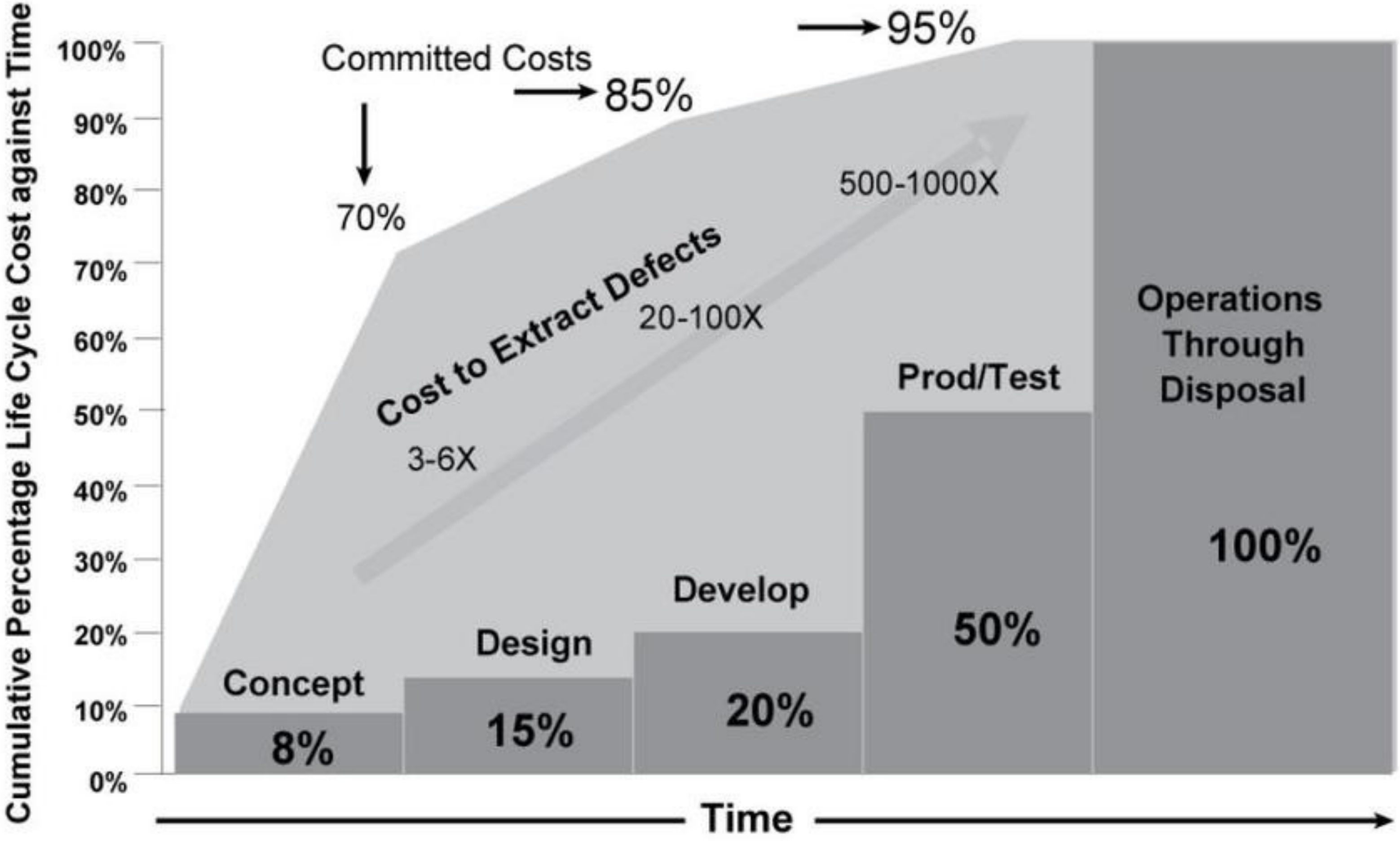
1. Value proposition
2. Principles
3. Existing frameworks and literature search
4. Case studies

SE in Early Stage R&D

1. Value Proposition Focus Area*

*Adapted from SE in ESR&D General Meeting, Dr. Heidi Hahn, 9/23/2021

INCOSE's Value Proposition for Applying SE Early



Lifecycle Costs and Cost to Extract Defects Through-out a Project (Walden et. al., 2015)

The Problem

- Value proposition is not compelling to researchers or funding organizations
  - Do not understand the value of SE and think of it as heavily process oriented, applicable only for mature technologies, and costly

The Result

- SE is often not applied to early stages of R&D
  - Resulting in the research, problem, or early prototype being solved or developed incorrectly or insufficiently incurring greater risk and not able to transition to higher TRLs

A Possible Solution

- Express the value proposition in terms of assuring quality of the research products throughout the project lifecycle
  - Result is a product that meets the stakeholder's needs and requirements, increases the credibility of the research, and makes it more likely that the research will survive peer review, cross the Valley-of-Death while still achieving the goal of avoiding the time-consuming and costly rework implied in the INCOSE value proposition

Value Proposition

- Applying systems engineering to research activities early assures quality of the research products throughout the project lifecycle and provides a foundation for tech maturation

Focus Area Tasking

- Systematically test the value proposition with researchers
- Refine the value proposition based on researchers' feedback
- Establish an assessment method for tracking quality throughout a project's lifecycle

When is ESR&D needed?

- When system development risk is ignored or minimized
- For organizations without a strong SE capability/culture
- For organizations with a wide spectrum or project types, sponsors, and/or TRL levels
- When there is a high risk of technical failure
- When system requirements/ConOps are poorly defined
- Where there is a desire to institutionalize SE processes and procedures (e.g., CMMI level 3)
- ESR&D is a mechanism to transition engineering early out of research and prototype development and to iterate between research and engineering

SE in Early Stage R&D

2. Principles Focus Area

Ann Hodges

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First things first - definition

What is a *principle*?

- Merriam-Webster: “a comprehensive and fundamental law, doctrine, or assumption; a rule or code of conduct”
  - A rule/belief that influences actions, explains the nature or workings of something

The Problem

- Identify principles that provide foundation for a framework
  - guidelines, processes and tools for the “right” and “right-sized” tailored systems engineering (SE) activities and deliverables to support early-stage research and development (R&D) projects
- Principles should be general enough to apply to a wide variety of research organizations, even if the missions differ
  - Industry
  - Academia
  - Government

Goals

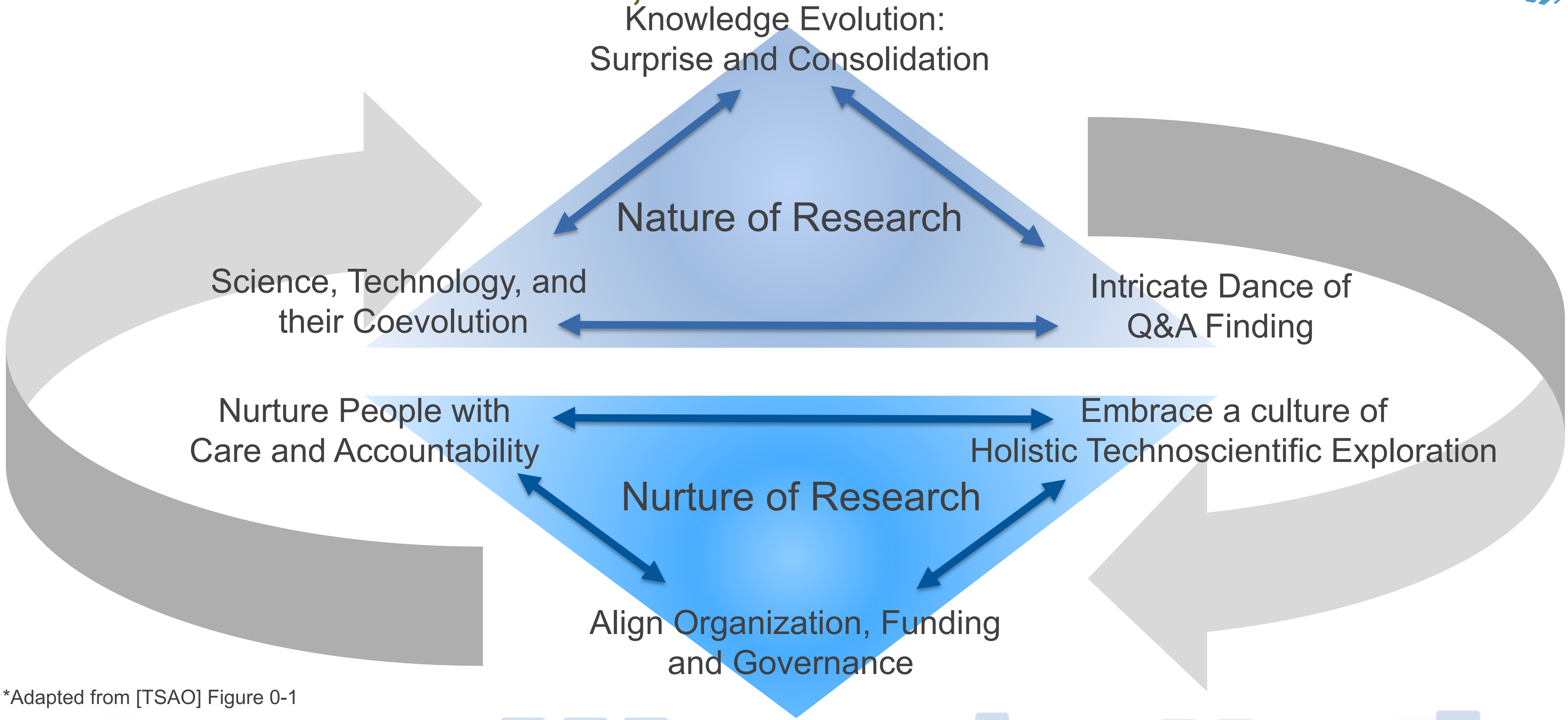
Define a set of framework principles that

- is sensitive to the nature of R&D – the culture and goals
- reframes SE verbiage for the R&D culture
- enhances the integrity and repeatability of the R&D products
- is peer reviewed by R&D practitioners
  - Industry
  - Academia
  - National Laboratories

Focus Area Tasking

- Develop a draft set of principles – be sensitive to the “nature” of research
- Leverage the value proposition focus area
- Peer review the principles with researchers and SE for later in the life cycle
  - Industry
  - Academia
  - National Laboratories
  - Systems Engineers
- Refine the set of principles based on researchers’ feedback

The Nature and Nurture of R&D*
Understand the *Nature*, Seek to *Nurture*



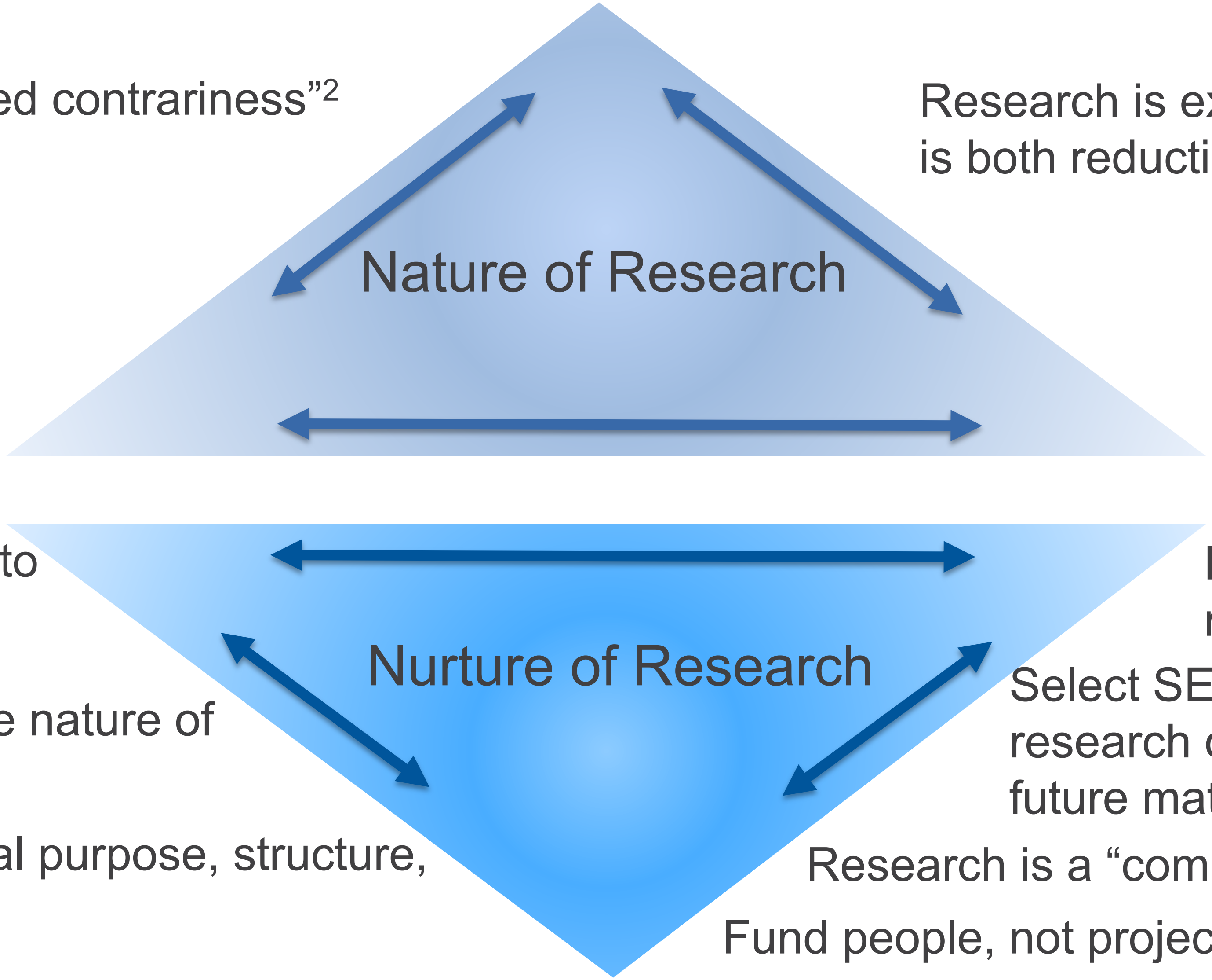
*Adapted from [TSAO] Figure 0-1

Principles – Nature of and Nurture R&D*

Zoom in, zoom out: embrace both Q&A finding[1]

"Support informed contrariness"[2]

Research is expansionist, SE is both reductionist + integrative"[3]



Use a graded approach to applying SE processes[4]

Reframe terms using researchers vocabulary[4]

Support collaborative nature of research[6]

Select SE processes that preserve research quality, defensibility, future maturation[5]

Align organizational purpose, structure, resources[8]

Research is a "competitive sport"[9]

Fund people, not projects[10]

Insulate, not isolate, research from development[7]

*Adapted from [TSAO] Figure 0-1
[1] Adapted from [COMP] pg 12, [TSAO] pg 178
[2] Adapted from [TSAO] pg 182
[3] [CONFL]

[4] [HODGES2019]
[5] Ibid
[6] [COMP], [TSAO]
[7] [TSAO] pg 156
[8] [TSAO] pg 162
[9] [TSAO] pg 192
[10] [TSAO] pg 159

Your thoughts – feedback?

- Thing 1

3. Existing Frameworks and Initial Concepts

ESR&D Framework for Research and Engineering Transition

- Innovation and research is noted with high failure
  - High risk and low return of investment
  - Projects fail at TRL 5-6 Valley of Death
  - Engineering transition is difficult and high risk
    - Research not appropriate for engineering transition
    - Basic research vs applied research
    - Solving the right problems for engineering transition
- Research and ESR&D is based in principles of expansionism vs reductionism
  - Continuous flow of ideas and experiment
  - Transition requires reductionism
- Framework must accommodate expansionism and reductionism
  - Example: Tailored process, tools and organization structure; Gated research artifacts transition to early engineered artifacts in a continual spiral of expansionism-reductionism-expansionism-reductionism using prescribed and tailored tools and processes; Research oriented engineer responsible for research whereby basic or applied research only performed to solve engineering problems

Example from Sandia National Laboratories – Ann Hodges, CSEP

Initial Framework Concepts

SAND2020-12414C

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NNSA National Nuclear Security Administration

Framework Based on Risk, Industry Standards and Project Type

- Risk-informed graded approach to the application of systems engineering (SE), project/program management (PM), and quality management (QM)
- Identified core set of practices that every project is required to follow – from the small best-effort research efforts to large pathfinder operational systems
- Implement differing level of rigor (timing, scope, formality) based on intrinsic project risk
  - Provide research-oriented projects an efficient and solid foundation for growth – either for future research efforts or further development of the research results – without stifling creativity and exploration
  - Start early in the project creation phase using a rigor-level determination template, followed by the tailoring of a project and product plan template for the determined level of rigor
- Developing project type category and subcategory templates for the risk-informed graded approach to increase efficiency and effectiveness.

Example from Los Alamos National Laboratory – Heidi Hahn (retired), PhD, ESEP, PMP

Initial Framework Concepts

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NNSA National Nuclear Security Administration

Another Framework Based on Risk, Standards and Project Type

- Risk-informed graded approach to the integrated application of systems engineering (SE), project management (PM), and quality management (QM)
  - Called this Mission Assurance
  - Quality standard for basic research is the ANSI standard, transitions to industry standard as TRL increases
- Identified core set of practices that every project is required to follow – from basic scientific research to advanced technology development
  - Provided the Mission Assurance Support Tool (MAST) as an implementation aid
- Implemented differing level of rigor (reviews, approvals, required documentation) based on project risk
  - Start early in the project initiation phase using a rigor-level determination template
  - Review risk-level determination throughout the project and adjust as needed

Pacific Northwest National Laboratory – Nick Lombardo, ESEP

Initial Framework Concepts

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Framework Based on Risk, Industry Standards and Project Type

- Extend risk-informed graded approaches for project/program management (PM) and quality management (QM) to SE
- Define SE "triggers" which drive implementation of SE (informal, semi-formal, formal)
- Define SE risks
  - Across project life cycle (e.g., concept, development, utilization phase)
  - Across project types (e.g., assessments, product development, test and evaluation)
  - By TRL (TRL 3: defines KPPs; TRL 4+: define specification)

Systems Engineering in Early-Stage Research & Development

4. Case Studies Focus Area

Michael DiMario, PhD

Objective

- Identify and Create Case Studies of Benefits and/or Problems of Systems Engineering in Early Stage R&D
  - Perform and examine empirical inquiry based on in-depth investigation of organizations and processes executing early systems engineering

The Result

- Analyze and Identify Frameworks for Early Stage R&D that are Enhanced via Systems Engineering
  - Document the qualitative and quantitative elements that provide successful R&D outcomes to a higher TRL and mitigate “Valleys of Death”

Focus Area Tasking

- Establish Case Study Strategic Approach
- Engage Associated INCOSE WGs and INCOSE Stakeholders
- Identify Existing or Create new Case Studies
- Solicit and Engage with R&D Organizations to Create or Test Case Studies

Future steps

- Flesh out the focus areas
  - Active participation – volunteer opportunities at various levels of engagement
  - Initiate case studies
- Additional publications
  - InSight editor offered the September 2023 issue for a *SE in ESR&D* theme

Wrap up

- Contact Michael DiMario mjdimario@outlook.com to volunteer or ask questions
  - Range of involvement = reviewer ←→ primary contributor
  - To volunteer, send email to Michael: provide name, email, organization, focus area(s) you're interested in, level of involvement; optionally share any other background
- Focus area leads
  - ➢ Value proposition: Ann Hodges
  - ➢ Principles: Ann Hodges
  - ➢ Frameworks, literature search: Ann Hodges
  - ➢ Case studies: Michael DiMario

Bibliography

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