34th Annual INCOSE international symposium
hybrid event
Dublin, Ireland
July 2 - 6, 2024

What works and what does not work in teaching non-Systems Engineers about systems thinking

Our Why and The Panelists

Introduction

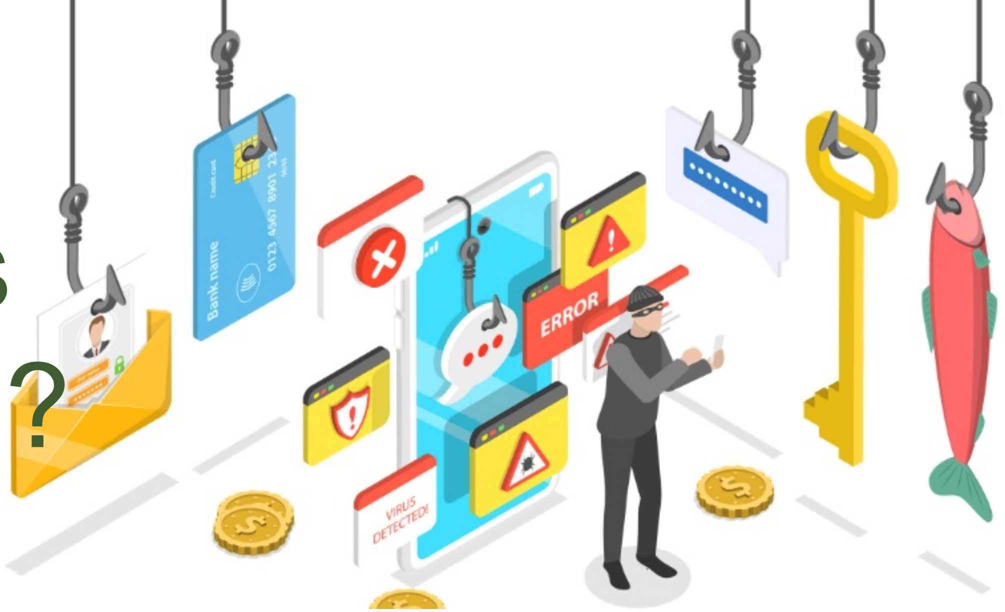
Our Why

- Real-world problems extend beyond technical fields, making systems thinking an essential skill across disciplines for better success.
- Systems engineers, technically considered the experts in systems thinking, struggle to teach it effectively to non-engineers due to its complexity.
- Not all systems engineers excel at systems thinking themselves
- Relying solely on Systems Engineering tools to spread systems thinking within an organization is misguided.

The goal of this panel is to discuss and debate these assumptions, as well as share best practices and lessons learned.


Jill
Kamran
Quentin
Sarwat
Graeme
Trae
Kirk

What is Systems Thinking?



Systems thinking is **an intentional mental practice** that looks at multiple perspectives to **solve complex problems**.

Key Questions

- Are systems engineers consistently practicing systems thinking?
- Will adoption of SE Processes and Tools naturally lead to greater adoption of systems thinking in non-technical roles?
- How do you differentiate between systems thinking and systems engineering?
- What elements or tools of systems thinking have the highest leverage in different industries or professions?
- Who should teach systems thinking?
- What teaching approaches have worked effectively, and what have been less successful in teaching systems thinking?

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Panelists Position Statements

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Experience with Teaching Systems Thinking to Industry and Technical/Non-Technical Graduates

Kamran Eftekhari Shahroudi

Systems Fellow (Woodward, Inc.) and Professor of SE (CSU)

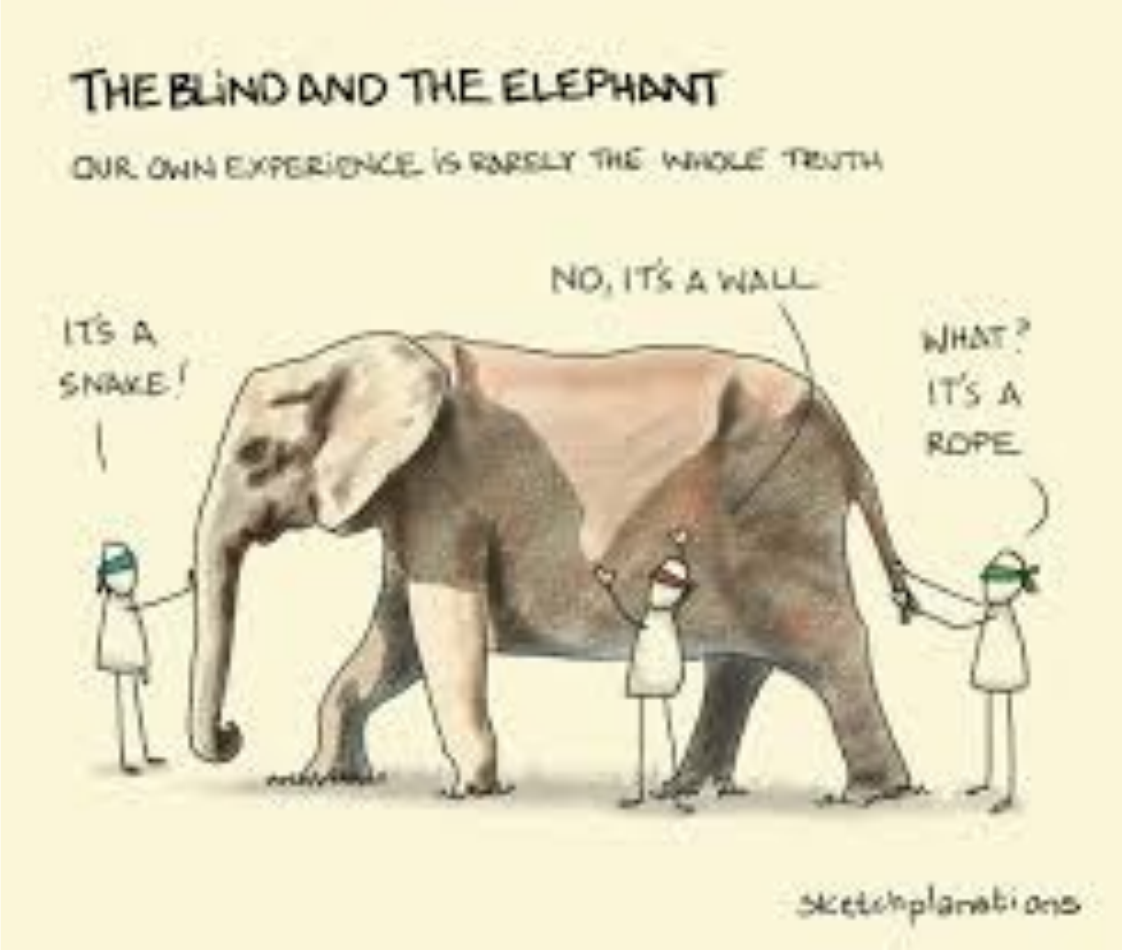
Why do we Need to Teach Systems Thinking Skills to both STEM and Non-STEM Disciplines?

Real-World Challenges are increasingly Complex & Complicated

Major Decisions are often based on Static and Old Mental Models

Problems do not fall neatly inside individual Disciplines *Including Systems Engineering*!

Education and Org. Culture tend to reinforce *Counter-productive Mental Models*



Unhelpful Mental Models/Behaviors

- ***Divide*** and ***Conquer*** always works!
- ***Cause*** is ***Close*** to the visible part of the problem!
- Pure ***Focus*** on (Tools, Processes &) ***Solution*** versus the ***Problem*** or ***Purpose***!
- ***Confusing*** (or preferring) ***Simulation*** with the ***Real-World***!
- Limit the ***Scope*** of ***Thinking*** and ***Working*** to the ***Deliverable***!
- ***Real-World*** problems are always ***Well Defined***!

Observations apply to *Both* STEM and Non-STEM including Systems Engineers!

This Formula Appears to Work Well!

- Teaching domain agnostic SP's and SW's
  - Versus system theory, system science, system laws, SEBoK principles and SE Handbook.
- Teaching rigorous ST tools Vs. just buzz words
  - SD, DSM/N2, Architectural Modeling, AI/ML etc.
- Reflection on Success & Failure Real-World Cases
  - e.g. Use SP's to explain the 737 MAX, Borneo Malaria, problem
- Guest Lecturers dealing with Complexity
- Learn by Doing/Teaching: Biz Unit Challenge (Industry) or Final Project on a Real-World Problem (CSU SYSE505/ SYSE 532)

Answers based on Coaching and Mentoring Professionals/Students

Panel Questions

1. Are systems engineers consistently practicing systems thinking?
2. Will adoption of SE Processes and Tools naturally lead to greater adoption of systems thinking in non-technical roles?
3. How do you differentiate between systems thinking and systems engineering?
4. What elements or tools of systems thinking have the highest leverage in different industries or professions?
5. Who should teach systems thinking?
6. What teaching approaches have worked effectively, and what have been less successful in teaching systems thinking?

Kamran's Answers

1. It depends! SE's may focus purely on the process and tools and lose sight of the why
2. It depends! Systematic does not replace Systemic but can encourage it! The SE machinery is specialist and not directly transferrable to other disciplines
3. ST != SE. ST is a philosophy, approach and method for solving complex/complicated challenges. ST is a required competency for SE but much broader and transdisciplinary than today's SE discipline.
4. Practice derived SP's and SW's are the most leverageable across disciplines and domains. Rigorous methods(e.g. MBST) has proven to be applicable and useful to a broad range of complex problem domains
5. Every undergrad program across all discipline. Many think start with high school.
6. Moving from ST Fundamentals to MBST methods has been easier for roughly 2/3 of the students than the other way around. See

Martin “Trae” Span

What teaching approaches have worked effectively, and what have been less successful in teaching systems thinking?

- Teaching Systems Thinking:
  - Case Studies
    - Relevant to Student Area of Interest
  - Guest Lectures
    - Respected Professionals
  - Exercises
    - Egg Conveyer
    - Lifecycle of a System in 2 hours

Graeme Troxell

Perspective: a former non-engineer who learned ST

- What works:
  - Background & historical/theoretical positioning
  - Relevant examples and case studies
  - Practice and application
  - Time
- What does not:
  - Relying exclusively on SE
    - Tools
    - Domains
    - Terms
  - Ex: Policy and management students

Graeme Troxell

	Position Statement
Q1: Are SEs consistently practicing ST?	Systems engineers are likely to consistently practice ST in their work, but I'm not confident that ST is frequently practiced beyond the workplace.
Q3: Differentiating between ST and SE	Systems thinking is about developing, improving, and refining mental models of complex phenomena, and thus is broader than systems engineering. SE leverages this to change/control complex phenomena.
Q5: Who should teach SE?	People with sufficient expertise in developing, improving, and refining mental models—and putting them to use in particular domains—can teach systems thinking effectively.

Graeme Troxell

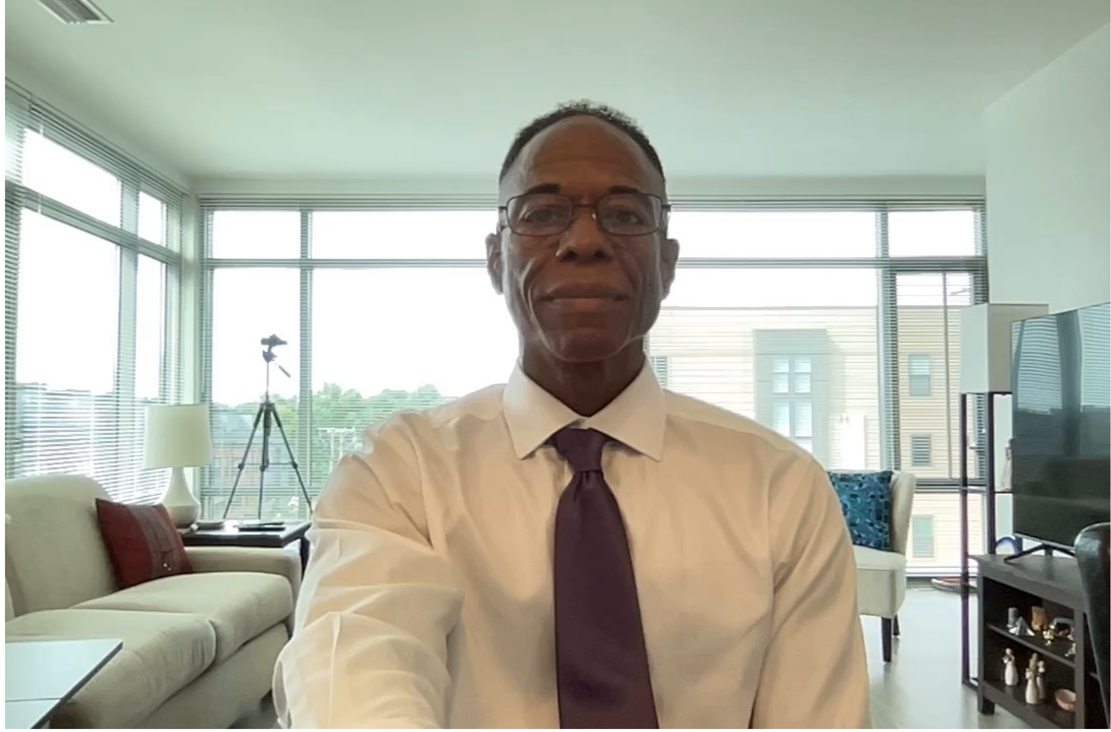
Observations from teaching ST

- Highlight the non-intuitive
  - The importance of structure and relationships
  - Causation may not be linear, immediate, or singular
  - Boundaries are vague/fuzzy
  - No mental model is correct—models are better or worse, not right or wrong

Quentin Saulter

Question: How do you differentiate between systems thinking and systems engineering?

Answer: Cognitive thinking: You have to think Why instead of HOW before you engineer a system.



- Observation: The process begins with making observations about the behavior of a system.
- Question Formulation: These observations lead to the formulation of a question about what has been observed, WHY?.
- Hypothesis Formation: A hypothesis, or a conjecture based on knowledge obtained while seeking answers to the question, WHY.
- Validation: Test hypotheses by using system dynamics tools.
- Conclusion: Based on the results, hypothesis may be adjusted or discarded.

Background
Difference Between SE and ST

- A Systems Engineer is a professional who specializes in **HOW** to design, integrate, and optimize complex systems or processes.
- Systems Thinking is a **Cognitive** thought process for problem-solving on scales ranging from personal to global.
- Thinking in systems explains **WHY** something behaves or gives an outcome.

Think Causation before Correlation

How to Differentiate Correlation and Causation Using Systems Thinking

DATA:

A COLLECTION OF FACTS, STATISTICS, OR INFORMATION THAT IS COMPRISED OF NUMBERS, TEXTS, IMAGES, AUDIO, OR VIDEOS.

INFORMATION:

PROCESSED DATA THAT GIVES MEANING AND CONTEXT. I
T IS DATA THAT HAS BEEN INTERPRETED AND ORGANIZED IN A WAY THAT IT CAN BE UNDERSTOOD AND USED EFFECTIVELY.

KNOWLEDGE:
UNDERSTANDING AND AWAR
ENESS GAINED FROM INFORMATION AND EXPERIENCES. IT IS THE ACCUMULATION OF FACTS AND DATA THAT HAVE BEEN INTERPRETED AND UNDERSTOOD IN CONTEXT.

WISDOM: WISDOM IS MORE THAN JUST KNOWING FACTS AND INFORMATION; IT’S ABOUT UNDERSTANDING AND DISCERNING THEIR DEEPER MEANINGS AND IMPLICATIONS.

Systems Thinking a Cognitive Thought Process

- Cognitive thinking refers to the mental processes that allow us to perceive, understand, and analyze information.
- These processes are essential for problem-solving, decision-making, and critical thinking.
- Cognitive thinking skills can be taught, learned, and developed with practice and training for any field or discipline.

Position Statement - Kirk

- Our brains can only penetrate so much complexity – And improvements will be on an evolutionary scale
- But the complexities we face and the risks thereof are growing exponentially, on time scales of months, not millennia. It will get worse as resources are ever more squeezed and bad outcomes cause worse outcomes
- Solving these complex problems while avoiding the risks is the domain of Systems Engineering. Of MBST
- We must learn to use tools routinely and intensely to see as far as we can, so that we can engineer the best outcomes available
  - Why? Because profit, power, and survival are at stake. You'll need inexorable and irrefutable logic in your slide deck to argue for the necessary solutions.

Sketch of Curriculum of ST for SE - Kirk

Broad instruction in ST has been tried with limited success since the 70’s. Make sure we know that history before trying again.

- Foundational MBST – Mastery of why ST is important and what it is. Familiarity with major tools. Mastery of recognizing when it should be applied.
- Critical Thinking – Systems Thinking gone wrong is Conspiracy Theory – Know the Differences
- Foundational system context – Politics and human nature
- MBST tools and theory – Augmentation of standard engineering curricula. System Dynamics, CLD, agent-based simulation, optimization, constraint satisfaction, Control Theory, Intro to nonlinear dynamics and chaos, domain-specific math and tools, statistics, ML(!), AI(!). All to level of competent user.

A.I via Big Data reaches well beyond any other tools known to date. All engineers should have substantial exposure to AI and ML combined with gigantic data volumes available today. A trillion-parameter curve fit?? Sure!

Quentins model approximated by a trillion-parameter curve fit

Using a tool I built based on Gemini Pro and my own code for importing models from Vensim along with prompts to set up focus on human nature. I analyzed Quentins model for missing loops. This is what it came up with. Total wall clock time, about 2 minutes from receipt of model to generation of this output. The point is this wasn't difficult and got pretty good results much more quickly than a human could have. We all need to know how to use AI.

Purpose of SDM: To simulate the adoption of an innovation considering the influence of relevant communities of researchers and user feedback

Potential New Variables and Units

•**Perceived Profit Potential** (unitless index or monetary units/time)

•**Perceived Power Gain** (unitless index)

•**Marketing/Lobbying Efforts** (monetary units/time or unitless effort index)

Revised Causal Relationships and Polarities

Here are some additional relationships to consider:

```
Perceived Profit Potential (+) -> Adoption Probability (+)
Perceived Power Gain (+) -> Adoption Probability (+)
Researchers That Adopted Innovation (+) -> Perceived Profit Potential (+)
Researchers That Adopted Innovation (+) -> Perceived Power Gain (+)
Perceived Profit Potential (+) -> Marketing/Lobbying Efforts (+)
Perceived Power Gain (+) -> Marketing/Lobbying Efforts (+)
Marketing/Lobbying Efforts (+) -> Researchers Exposed (+)
```

Explanation of New Relationships

•**Positive Relationships (+):**

- Higher perceived profit and power potential directly increase adoption probability.
- More adoptions signal greater potential for profit and power to others.
- Higher profit/power potential incentivizes more marketing and lobbying to influence decision-makers and promote adoption.
- Increased marketing/lobbying efforts lead to more researchers being exposed to the innovation.

Additional Causal Loops

These new relationships introduce a few more feedback loops:

1. **Reinforcing Loop (R2):** Researchers That Adopted Innovation -> Perceived Profit Potential -> Adoption Probability -> Researchers Adopting -> Researchers That Adopted Innovation
   - This loop suggests a self-reinforcing cycle where early adopters increase perceived profit, driving further adoption.
2. **Reinforcing Loop (R3):** Researchers That Adopted Innovation -> Perceived Power Gain -> Adoption Probability -> Researchers Adopting -> Researchers That Adopted Innovation
   - Similar to R2, but focusing on power dynamics: early adopters can consolidate their position, making adoption more attractive to others seeking power.
3. **Reinforcing Loop (R4):** Perceived Profit Potential -> Marketing/Lobbying Efforts -> Researchers Exposed -> Researchers Adopting -> Researchers That Adopted Innovation -> Perceived Profit Potential
   - This loop highlights how profit motives can fuel marketing/lobbying campaigns, which in turn drive adoption and further reinforce the perception of profit potential.

Integrated CLD with Profit and Power Motives

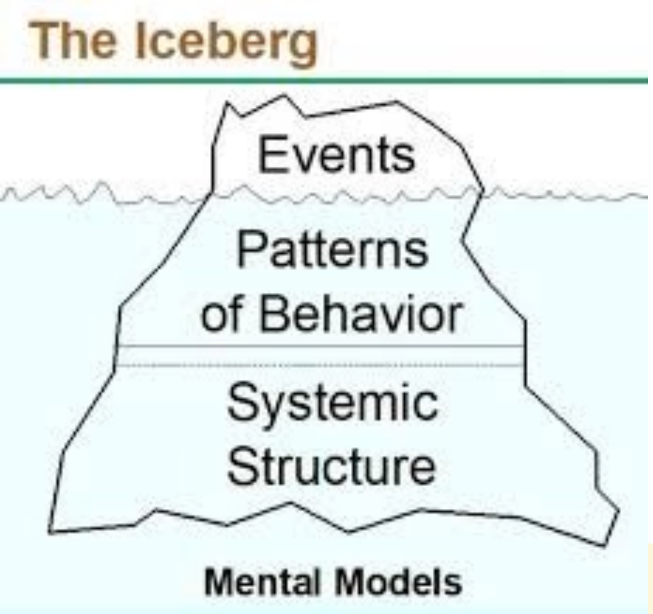
The revised CLD now incorporates the original loops (R1, B1) along with the new loops (R2, R3, R4) that consider profit and power dynamics. This creates a more comprehensive and realistic model of innovation adoption.

Important Considerations

•The relative strengths of these loops will vary depending on the specific innovation, the actors involved, and the socio-economic context.

•The model still simplifies the complex interactions of profit, power, and innovation adoption, but it provides a more nuanced view than the initial version.

Background



- Mental models are the perspectives and frameworks that humans use to interpret the world
- Mental models directly affect Systems Thinking(ST) Culture
- Mismatch between ST culture and intended purpose of system can lead to unintended patterns of behavior

Sarwat Chappell

What elements or tools of systems thinking have the highest leverage in different industries or professions?

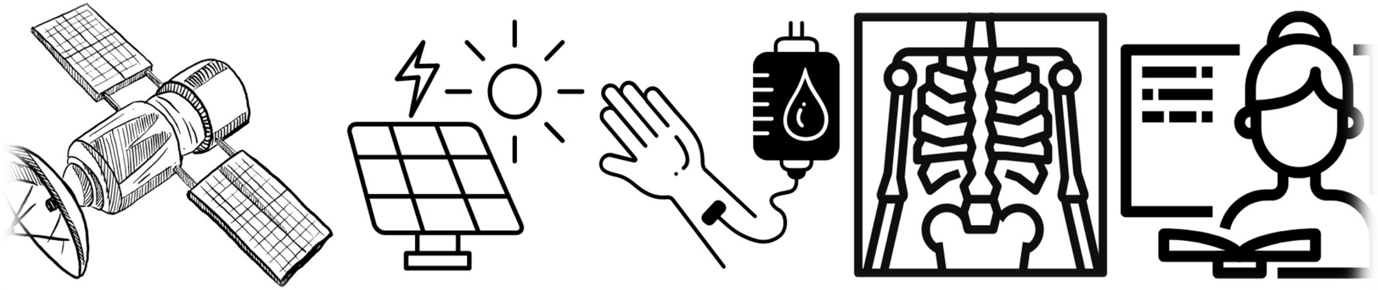
- Systems Thinking is applicable to all industries and professions
- Systems Thinking is an intentional mental practice that looks at multiple perspectives to solve complex problems
- Mental models are the highest leverage point for Systems Thinking
- Tools related to Systems Thinking enable adoption of this mindset
- Systems Principles, Systems Dynamics Modeling, MBSE, N2DSM, etc. are all parts of the toolkit

Sarwat Chappell

Will adoption of SE Processes and Tools naturally lead to greater adoption of systems thinking in non-technical roles?

- The adoption and continued use of Systems Thinking(ST) requires:
  - Change in mindset
  - Intentional practice of Systems Thinking
  - Adoption of a ST culture to sustain its use
- Linear Thinking training can resist Systems Thinking
- Tools and SE Processes alone will not lead to greater adoption of systems thinking in non-technical roles
- Certain ST tools such as ST principles and Ways/habits of a Systems thinker will enable adoption and continued use.

Jill Speece



Group picture from Cal Poly's 2024 Change the World Challenge finale

The interdisciplinary competition is a transformative student design challenge created to address the world's most pressing contemporary problems.

Systems thinking requires effort and discipline, similar to building any new habit, and is essential across all fields, not just Systems Engineering.

Systems Engineers are the most qualified to teach systems thinking due to their expertise in the discipline.

In healthcare, the easiest way to teach systems thinking is by integrating the tools in with existing continuous improvement programs and/or methodologies already being used.

For undergraduate students, a great way to help them learn systems thinking is to intentionally form cross-discipline teams and have them use systems thinking tools to come up with a solution to a "wicked problem."

Audience Discussion and Q&A

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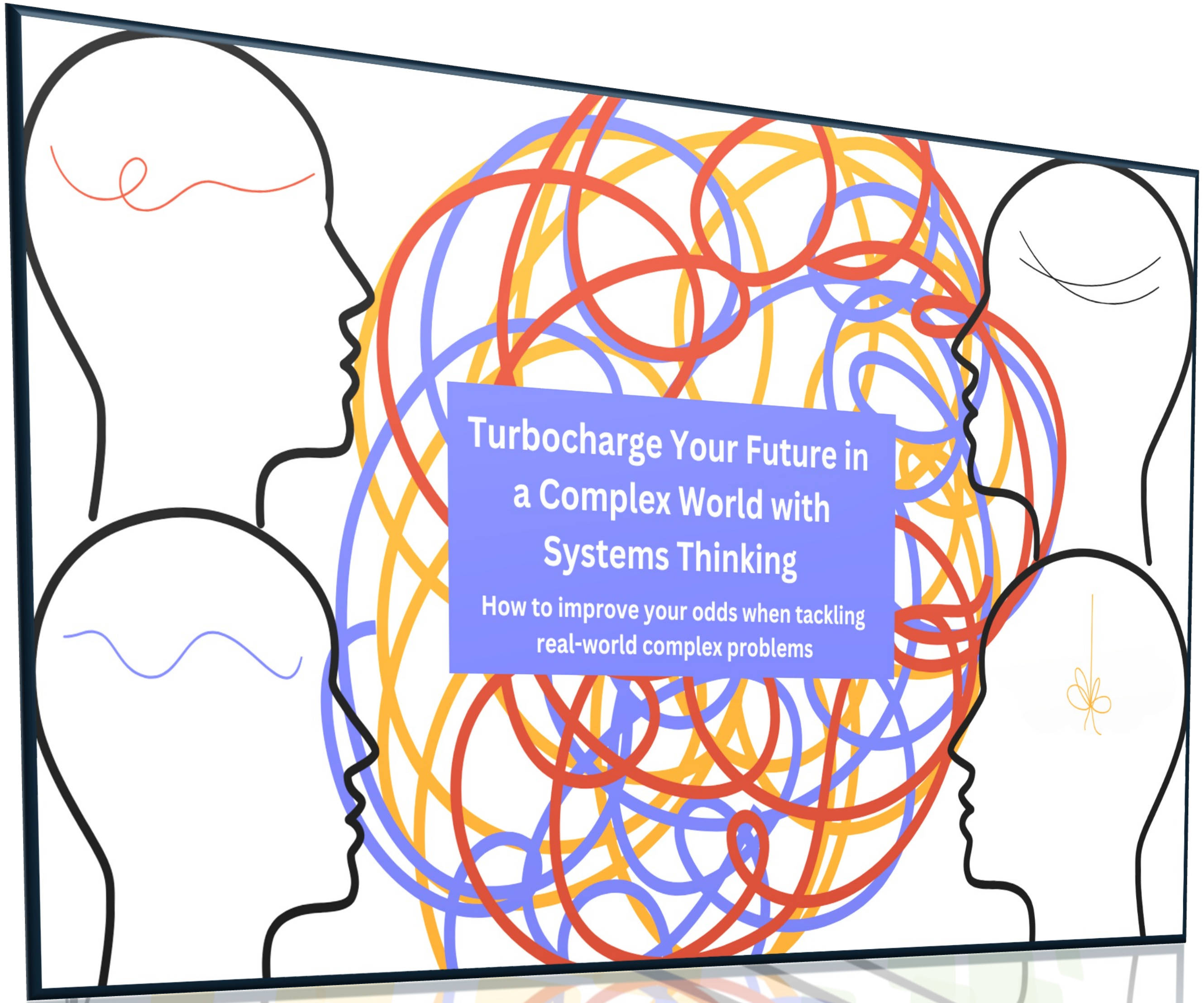

Be an early reviewer!

Turbocharge Your Future in a Complex World with Systems Thinking

How to improve your odds when tackling real-world complex problems

Backup

Topic proposal

Systems Thinking is an essential concept: structures lead to behaviors, and actions have consequences, which in turn have their own repercussions. Everything is interconnected.

However, the very need for Systems Thinking highlights a critical point: if it were easy and intuitive, we wouldn't be writing books about it or discussing it in panels like this one. The crux of the matter is that complexity, when truly complex, is irreducible. It's not merely a matter of perspective; some behaviors are unpredictable regardless of how we view them.

Fortunately, we can glean insights through simulations, approximations, heuristics, regressions, and various other technical methods. This leads to my stance: the efficacy of Systems Thinking would be significantly bolstered if it were taught and implemented alongside key technical tools and practices.

The 21st century is ushering us into a realm of tighter constraints, with previously externalized factors re-entering our System-of-Interest (SOIs). Let's learn and teach Model-Based Systems Thinking (MBST) as a core practice of Systems Engineering to better understand and optimize the outcomes of our engineering decisions.

An AI experiment

Just for fun, I asked Google Gemini Advanced to rif on this topic:
Systems engineers employ a multi-faceted [LLM giveaway! – Kirk] approach to understand and document the intricacies of system behavior:

Tools:

•**Modeling and Simulation Software:** They utilize specialized software to construct dynamic models that mirror the real-world system. These models enable them to visualize and analyze complex interactions between components, simulate different scenarios, and predict system responses under varying conditions.

•**Causal Loop Diagrams (CLDs):** These visual representations depict cause-and-effect relationships within a system. They help identify feedback loops, where changes in one variable can lead to a chain reaction affecting other variables, ultimately influencing the original variable.

•**Stock and Flow Diagrams (SFDs):** These diagrams complement CLDs by visualizing the accumulation and flow of resources within a system. By analyzing stocks (accumulations) and flows (rates of change), engineers can uncover patterns of growth, decline, or oscillation.

•**Network Analysis:** This technique involves mapping the relationships between different components of a system. By analyzing the resulting network, engineers can identify key influencers, bottlenecks, or vulnerabilities that impact overall system behavior.

•**Data Mining and Machine Learning Algorithms:** These tools help uncover hidden patterns and correlations in large datasets collected from the system. By analyzing this data, engineers can gain insights into system behavior that might not be apparent through traditional analysis methods.

Knowledge:

•**Systems Thinking Principles:** Systems engineers apply a holistic perspective, recognizing that systems are more than the sum of their parts. They understand the importance of feedback loops, delays, non-linearity, and emergence in shaping system behavior.

•**Complex Systems Theory:** This interdisciplinary field provides a framework for understanding systems with many interacting components and unpredictable behavior. Systems engineers use this knowledge to identify emergent properties and anticipate unexpected consequences.

•**Control Theory:** This field focuses on understanding how systems maintain stability and respond to disturbances. Systems engineers apply this knowledge to design control mechanisms that ensure optimal system performance.

•**Information Theory:** This provides a foundation for quantifying and analyzing the flow of information within a system. Systems engineers use this knowledge to understand how information exchange affects system dynamics.

•**Domain-Specific Knowledge:** Expertise in the specific domain of the system, such as biology, economics, or engineering, is crucial for interpreting the meaning of observed patterns and structures. This knowledge allows engineers to make informed decisions based on a deep understanding of the system's context.

By integrating these tools and knowledge, systems engineers gain a comprehensive understanding of the complex interactions and dynamics that govern system behavior. This understanding is then translated into clear documentation, including reports, diagrams, simulations, and other formats that effectively communicate these insights to stakeholders. This ensures that the knowledge is preserved and can be used to inform future decisions, optimize system