Engineering Technology, Design, Production, And Management
Systems Engineering and Multidisciplinary Design Research Chair

UNIVERSITY OF TWENTE.

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Minisymposium Methodes voor het leren systeemdenken en werken| Hogeschool Windesheim Zwolle – 5th of February 2026

ABOUT ME

M.Eng. degree in Electrical and Computer Engineering at the Democritus University of Thrace, Greece, in 2012

MSc. Degree in Biomedical Engineering, at the University of Twente, The Netherlands, in 2015.

Ph.D. at the Department of Biomechanical Engineering at the University of Twente (2014-2018)

Since 2019, Assistant Professor at Systems Engineering and Multidisciplinary Design research chair, in the department of Design, Production and Management, at the University of Twente.

Since 2023 member of the SIG-CEE of the European Society for Engineering Education (Systems Thinking sub-group)

SYSTEMS

A system is "a set of **interrelated components** functioning **together** toward some **common objective**(s) or **purpose**(s)"

Blanchard, B.S. and W.J. Fabrycky, Systems Engineering and Analysis. Fifth ed, Upper Saddle River, New Jersey: Prentice Hall, 2011.

SYSTEMS THINKING

Arnold, R. D., & Wade, J. P. (2015). A Definition of Systems Thinking: A Systems Approach. Procedia Computer Science, 44, 669–678. https://doi.org/https://doi.org/10.1016/j.procs.2015.03.050

FORMAL DEFINITIONS

Barry Richmond, the originator of the systems thinking term, defines systems thinking as the **art** and **science** of making reliable inferences about **behavior** by developing an increasingly **deep understanding** of underlying structure. He emphasizes that people embracing Systems Thinking position themselves such that **they can see both the forest and the trees; one eye on each** (Richmond, 1994)

Systems thinking is an approach to **problem solving** which takes into account the overall system as well as its individual parts. According to Peter Senge, it's "a framework for seeing **interrelationships** rather than things, for seeing **patterns** rather than **static snapshots**. [***Peter Senge, The Fifth Discipline, 2nd Ed 2006***].

Sweeney and Sterman, argue that much of the art of systems thinking involves the ability to represent and assess dynamic complexity, both textually and graphically (Sweeney & Sterman, 2000). They list specific systems thinking skills as including the ability to:

1. Understand how the behavior of a system arises from the **interaction** of its agents over time (i.e., **dynamic complexity**);
2. Discover and represent **feedback** processes (both positive and negative) hypothesized to underlie observed patterns of system behavior;
3. Identify **stock** and **flow** relationships;
4. Recognize **delays** and understand their impact;
5. Identify **nonlinearities**;
6. Recognize and challenge the **boundaries** of **mental (and formal) models.**

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FORMAL DEFINITIONS

Stave and Hopper drew up a list of characteristics (Stave & Hopper, 2007):

1. Recognizing **Interconnections**
2. Identifying **Feedback**
3. Understanding **Dynamic** Behavior
4. Differentiating types of **flows** and **variables**
5. Using **Conceptual** Models
6. Creating **Simulation** Models
7. Testing **Policies**

Building on Hopper and Stave's work, Kopainsky et al. state that the definition of systems thinking should include appreciation for **long term planning**, **feedback** loops, **non-linear relationships between variables**, and **collaborative planning across areas of an organization** (Kopainsky, Alessi, & Davidsen, 2011).

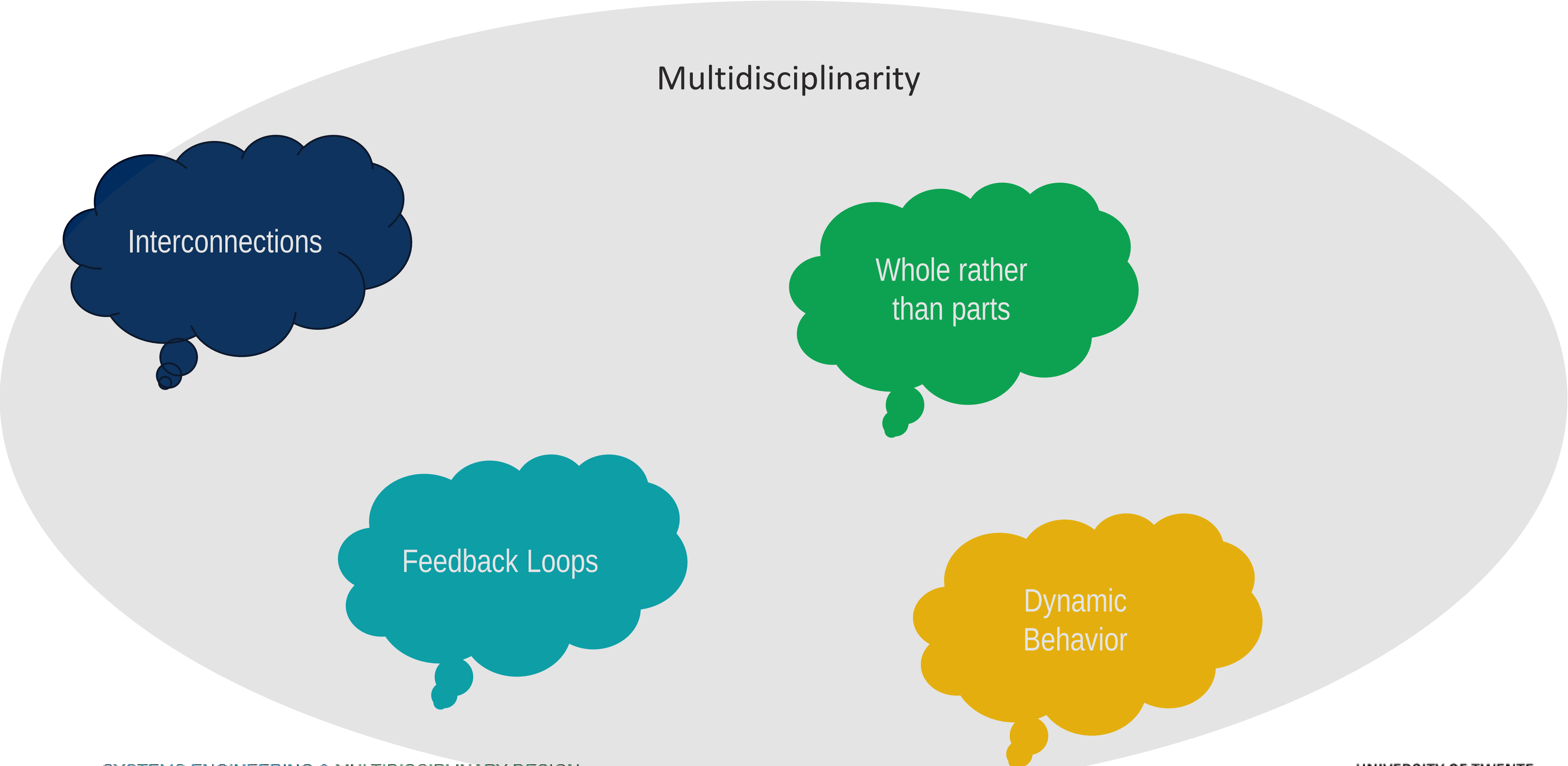
Systems thinking is the ability to **think abstractly** in order to (Squires, Wade, Dominick, & Gelosh, 2011):

1. incorporate **multiple perspectives**;
2. work within a space where the **boundary** or scope of problem or system may be "**fuzzy**";
3. understand **diverse operational contexts** of the system;
4. identify **inter-** and **intrarelationships** and **dependencies**;
5. understand **complex** system behavior;
6. and most important of all, reliably predict the **impact of change** to the system.

Arnold, R. D., & Wade, J. P. (2015). A Definition of Systems Thinking: A Systems Approach. Procedia Computer Science, 44, 669–678. https://doi.org/https://doi.org/10.1016/j.procs.2015.03.050

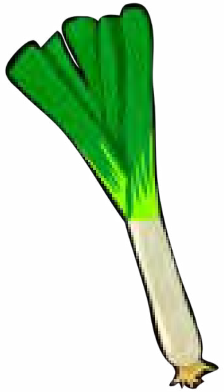
FORMAL DEFINITIONS - OVERVIEW

What do you think?



EXAMPLE






EXAMPLE


Interconnections
Whole rather than parts
Feedback Loops
Dynamic Behavior

LET’S THINK TOGETHER

Images generated using OpenAI (ChatGPT/DALL·E)

You are the owner of an office building, and your tenants are complaining about the elevator. It is old and slow, and they have to wait a lot in the lobby. Several tenants are threatening to break their leases if you do not fix the problem.

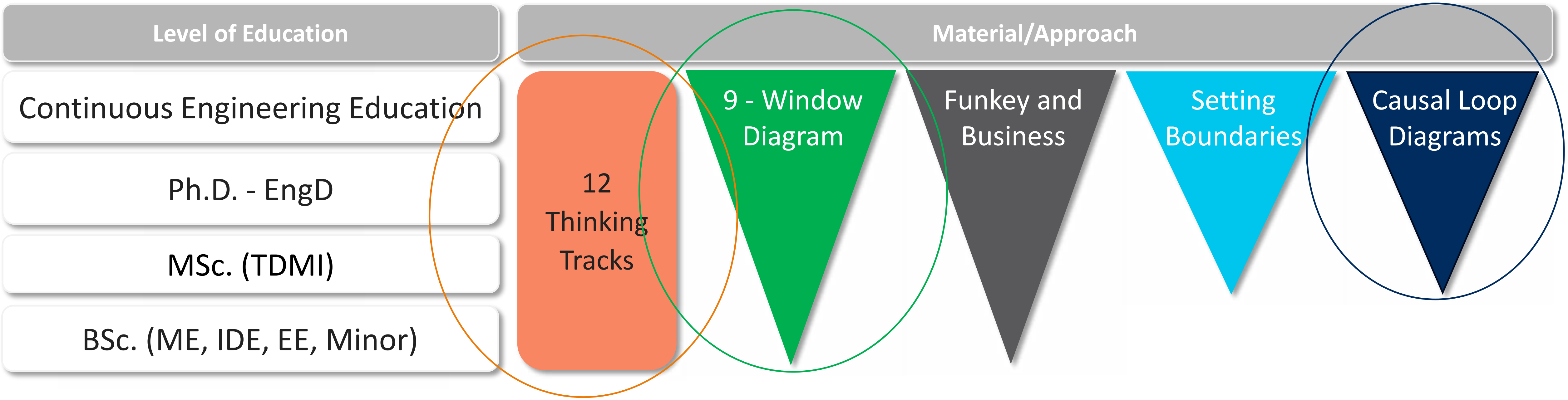
- What is the root problem?
- Is it a logistics problem, a psychological problem, an engineering problem, or something else?
- How should a Systems Thinker approach this problem?

“Problems are universal. No discipline owns a problem. Those adjectives show the point of view of the person(s) identifying a problem. Sometimes our education is not organized the way reality is, or vice-versa”

Dr. Russell Ackoff – Systems Thinking Speech

SYSTEMS THINKING - EDUCATION

EDUCATION - OVERVIEW



THE 12 THINKING TRACKS

In (Systems) Engineering, we have:
Processes, Architecting, Tools, Requirements, and Risks:

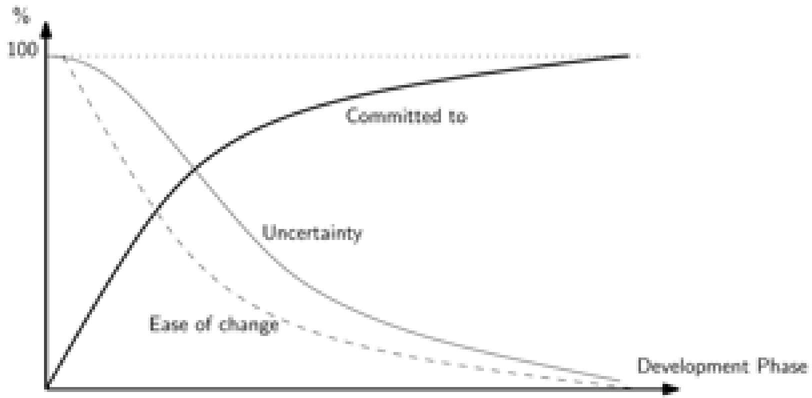
- means to organize what we are doing
- help to direct our effort

Where is the fresh view?
➔ systems thinking

THE 12 THINKING TRACKS

In the early phases:

- The playing field is too wide and too deep to fully comprehend
- Decisions have a large impact
- So, the design space has to be *probed*
- How do we know where the interesting places are?
  - Experience
  - Making a quick scan
  - Reasoning
  - Looking at what others are doing/have done



THE 12 THINKING TRACKS

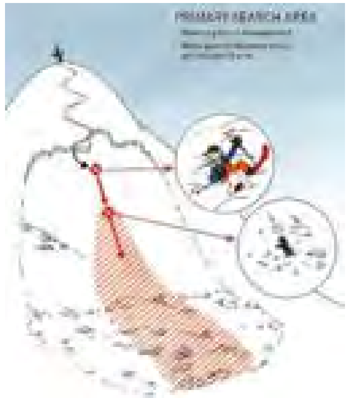
"[T]here are known knowns; there are things we know we know.
We also know there are known unknowns; that is to say we know there are some things we do not know.
But there are also unknown unknowns – there are things we do not know we don't know."

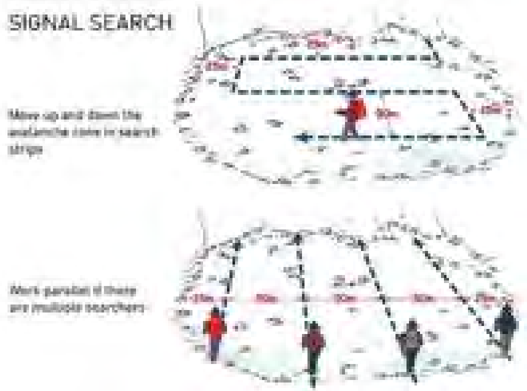
—United States Secretary of Defense Donald Rumsfeld

http://en.wikipedia.org/wiki/There_are_known_knowns

THE 12 THINKING TRACKS

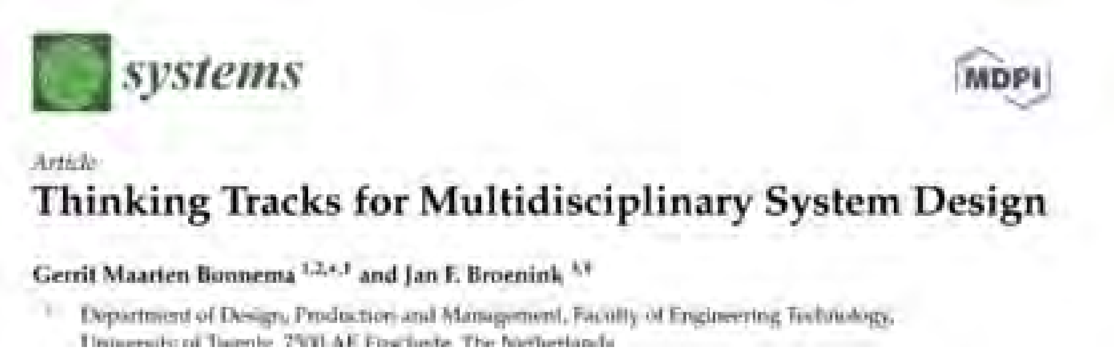
- Finding a victim of an avalanche:
  - scanning the area quickly, but thoroughly;
  - then zoom in on the spot of interest
- But in system design, there are multiple spots of interest (many “victims”)





THE 12 THINKING TRACKS

1. Dynamic Thinking
2. Feedback Thinking
3. Specific-Generic Thinking
4. Operational Thinking
5. Scales Thinking
6. Scientific Thinking
7. Decomposition-Composition Thinking
8. Hierarchical Thinking
9. Organizational Thinking
10. Life-Cycle Thinking
    - Product life-cycle
    - Resource life-cycle
    - Organization life-cycle
11. Safety Thinking
12. Risk Thinking


systems

MDPI

Article

Thinking Tracks for Multidisciplinary System Design

Gerrit Maarten Bonnema [1,2,*,†] and Jan F. Broenink [3,†]

1 Department of Design, Production and Management, Faculty of Engineering Technology,

These may not be complete. However, they cover most of the systems realm

See: http://dx.doi.org/10.3390/systems4040036

THE 12 THINKING TRACKS

Dynamic Thinking

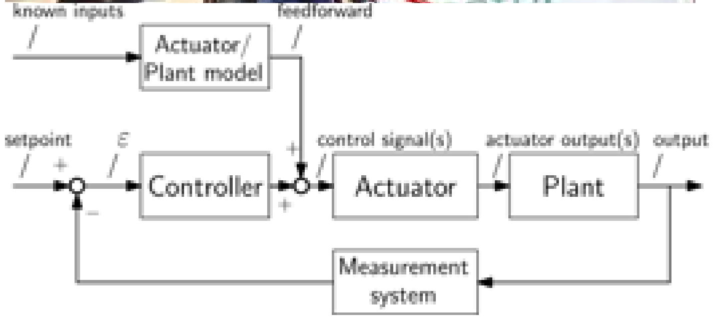
Questions to ask:

- How does the ***system*** change over time?
- How does the ***environment*** change over time?
- How does the ***user*** change over time?
- When a change in input/output occurs, what are the effects?

- Use different time scales
- Use frequency domain analysis

Feedback Thinking

Look at the system from a control engineer's eyes:
Many systems, subsystems and projects can be seen as feedback loops



Specific – Generic Thinking

Reasoning about the scale of the problem and the scale of the solution

➔ exception handling or dealing with normal operation?

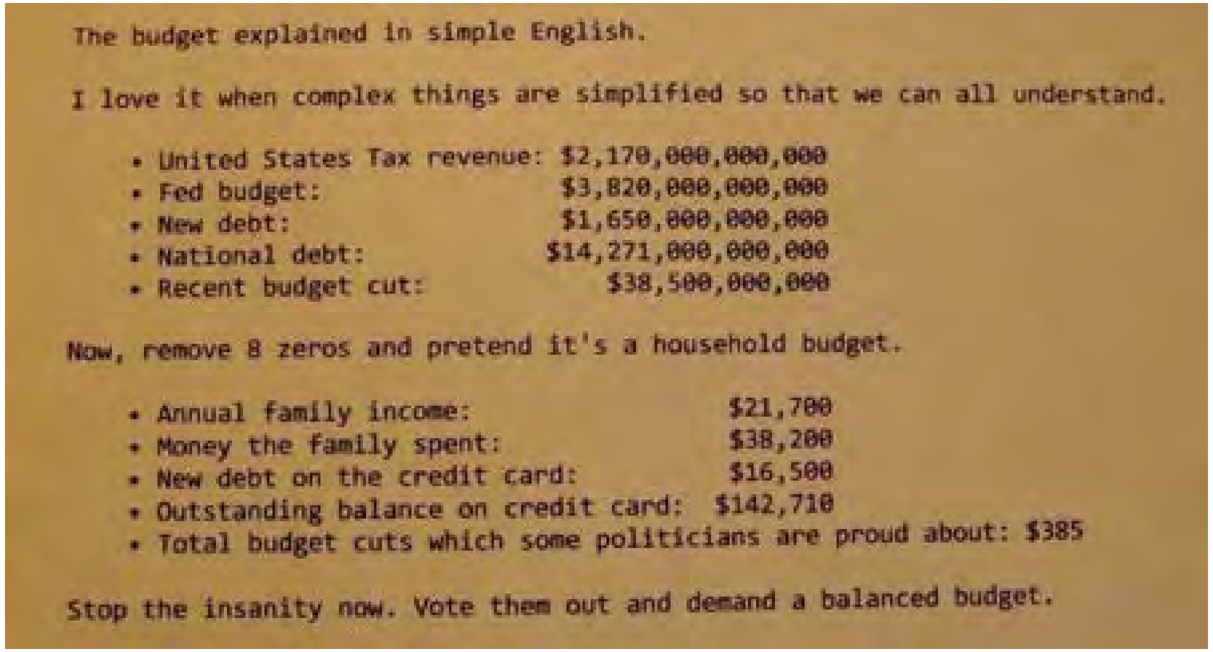
THE 12 THINKING TRACKS

Operational Thinking

Get your feet on the ground
Look at the real world
How is it done "in the real world"?
Not only Excel-engineering

Scales Thinking

Finding nuances in arguments and avoiding opposing camps:
Switching between black/white scales and shades of grey
Understanding limits of known (often assumed linear) relationships/scales/assumptions



The budget explained in simple English.

I love it when complex things are simplified so that we can all understand.

- United States Tax revenue: $2,170,000,000,000
- Fed budget: $3,820,000,000,000
- New debt: $1,650,000,000,000
- National debt: $14,271,000,000,000
- Recent budget cut: $38,500,000,000

Now, remove 8 zeros and pretend it's a household budget.

- Annual family income: $21,700
- Money the family spent: $38,200
- New debt on the credit card: $16,500
- Outstanding balance on credit card: $142,710
- Total budget cuts which some politicians are proud about: $385

Stop the insanity now. Vote them out and demand a balanced budget.

THE 12 THINKING TRACKS

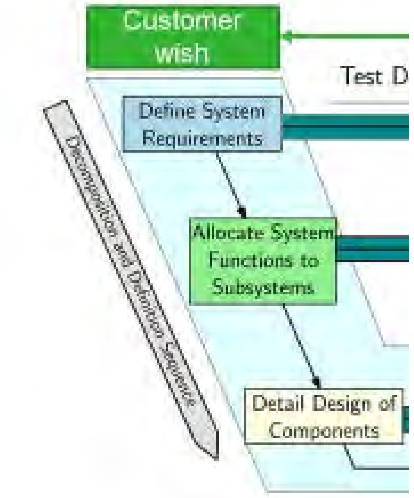
Scientific ... inking

Verification is essential!

1. Observ...
2. Formulate ... stion;
3. Formulate a ... esis,
4. Create an exper... that can be used to verify the hypothes...
5. Analyse the results
6. Draw conclusions about the hypothesis

Decomposition – Composition Thinking

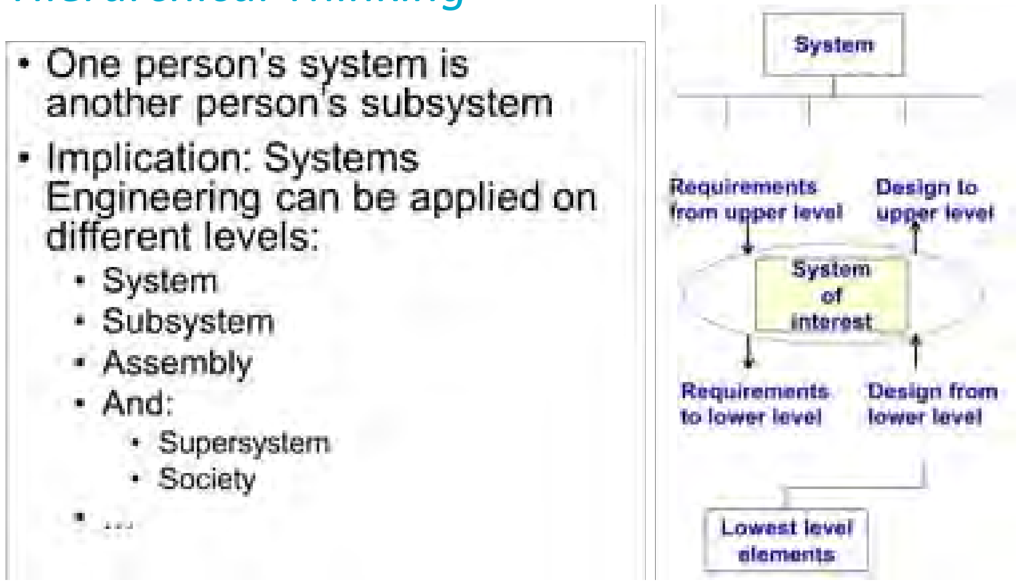
Expanding the left-side of the Vee …
to the right



Education is – still – very much reductionistic oriented: explaining the whole from studying the parts

THE 12 THINKING TRACKS

Hierarchical Thinking



Organizational Thinking

Design decisions impact the organization's structure and *vice versa*

Project layers impact design flow

Conway's law:

Any organization that designs a system will inevitably produce a design whose structure is a copy of the organization's communication structure.

http://www.melconway.com/research/committees.html

Life-Cycle Thinking

Product life-cycle (design, production, deployment, use, retirement)

Resource life-cycle (material, energy, and other resource usage)

Project life-cycle (the project organization that is instantiated to create and sustain the system)

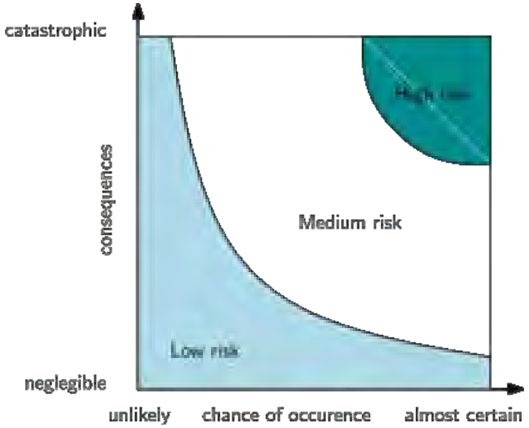
THE 12 THINKING TRACKS

Safety Thinking

Reasoning about the safety of the product, the user, and the environment
Implement “circuit breakers”: designed weakest links to avoid larger damage

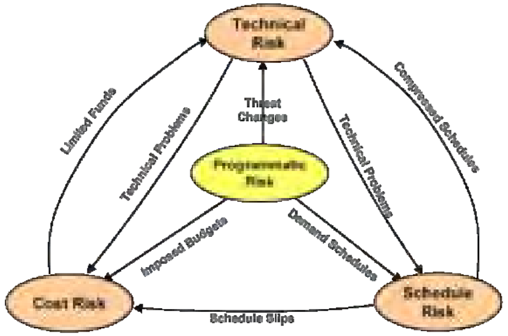
Tempi train crash
https://www.bbc.com/news/world-europe-64808123

Risk Thinking



- Risks are inherent to product development
  (no pain, no gain)
- Control the risk to an acceptable level

- Be aware of more than technical risks:
  - Technical
  - Cost
  - Planning
  - Program



THE 12 THINKING TRACKS

On a regular basis, apply the 12TT to your case.

- Alone
- In a small team

In a review, check whether all 12TT have been applied

Use the 12TT as a common frame of reference:

- ask your colleague: what was the result of <dynamic> thinking?

Use the 12TT as a creativity starter:

- What would be the result if we focus on <hierarchical> thinking

THE 9-WINDOW DIAGRAM

Put the system central, instead of focusing on details

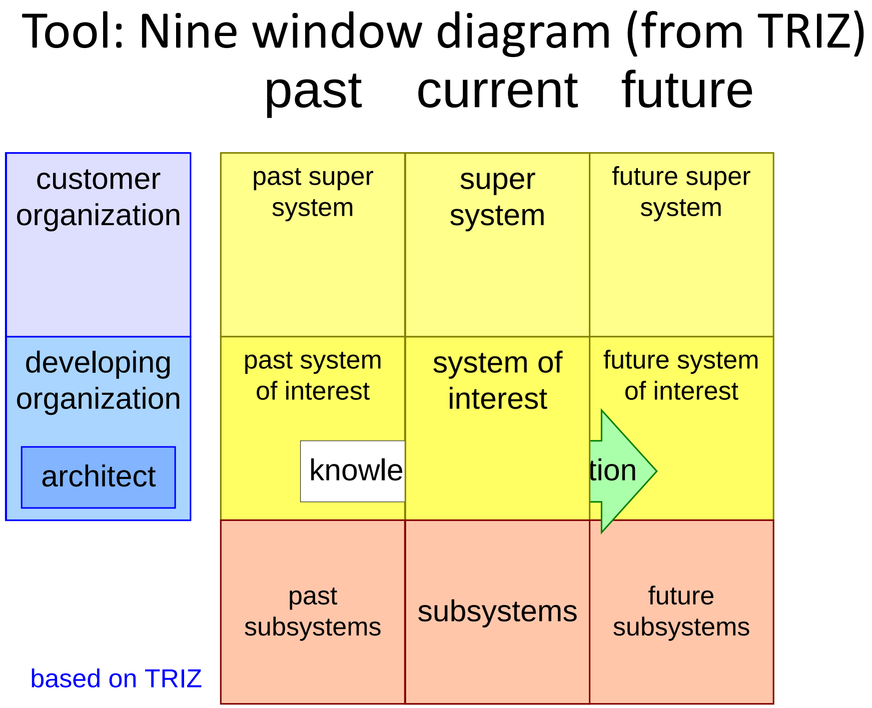
Zoom out to see the whole

Zoom in on crucial issues only

Holistic thinking

Big picture; also, time-wise

Pitfall: stay too general or superficial.



THE 9-WINDOW DIAGRAM

A 9-window diagram allows for exploring different futures

	Past	Present	Future
Super-system	Medical treatment in hospital	Medical Treatment by medication	?
System	Nurse	Smart Pill Box	?
Sub-system	Recipes, Procedures	Dose boxes, Reminder, Water	?

THE 9-WINDOW DIAGRAM

	Past	Present	Near Future	Distant Future
Super-system	Medical treatment in hospital	Medical Treatment by medication	?	?
System	Nurse	Smart Pill Box	?	?
Sub-system	Recipes, Procedures	Dose boxes, Reminder, Water	?	?

THE 9-WINDOW DIAGRAM

	Past	Present	Future
Super-system	Medical treatment in hospital	Medical Treatment by medication	Continuous diagnosing and treatment
System	Nurse	Smart Pill Box	Personalized delivery
Sub-system	Recipes, Procedures	Dose boxes, Reminder, Water	Ampuls, Doser, IV

CAUSAL LOOP DIAGRAMS

We are quick problem solvers. We quickly determine a cause for any event that we think is a problem. Usually, we conclude that the cause is another event.

- Example: Sales are poor (event) because staff are insufficiently motivated (cause); staff are insufficiently motivated (event) because ...

Difficulty: You can always find yet another event that caused the one that you thought was the cause. This makes it very difficult to determine what to do to improve performance.

CAUSAL LOOP DIAGRAMS

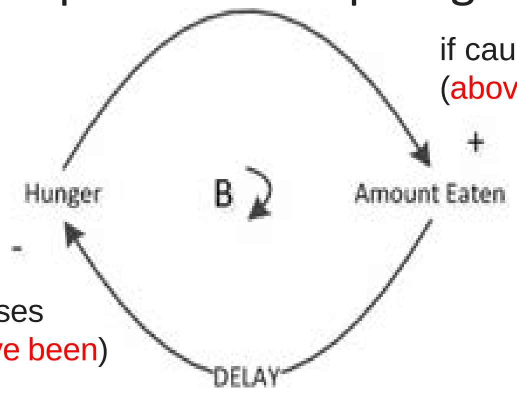
Can be used for:

- Exploring the system's behaviour
- Communication/discussion
- Simulation

Model representations

- Causal loop diagrams (qualitative)
- Stock and Flow diagrams (quantitative)

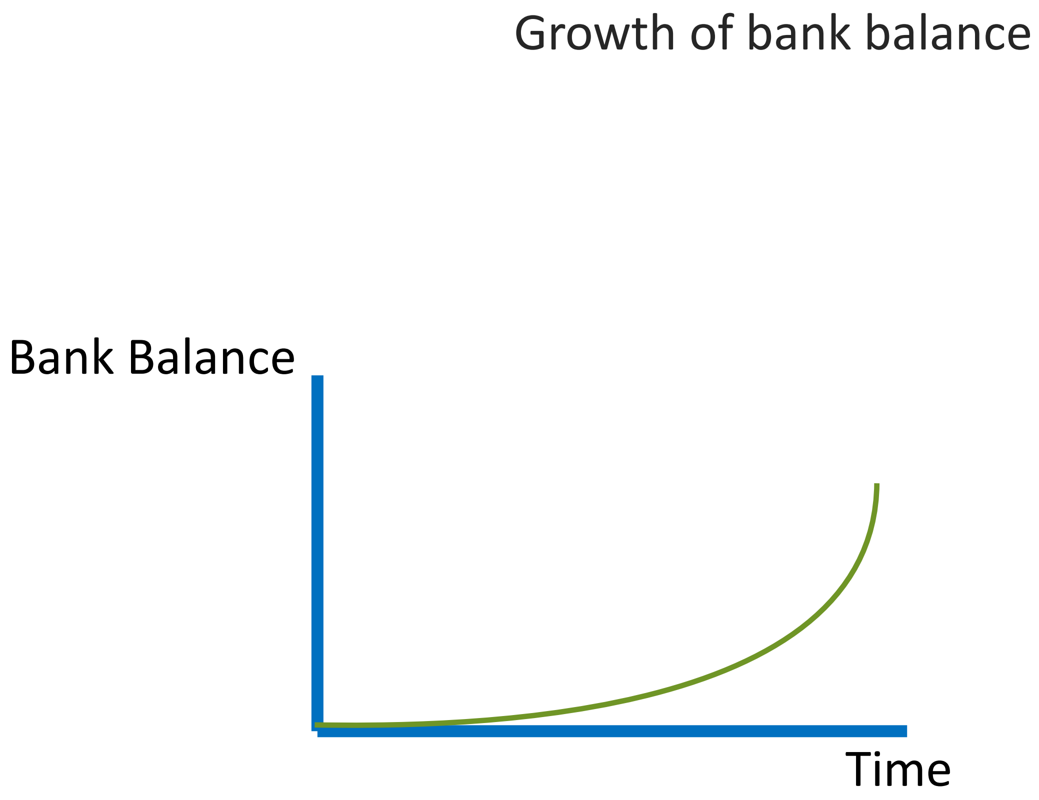
Example: Simple causal loop diagram of food intake [Morecroft 2007]

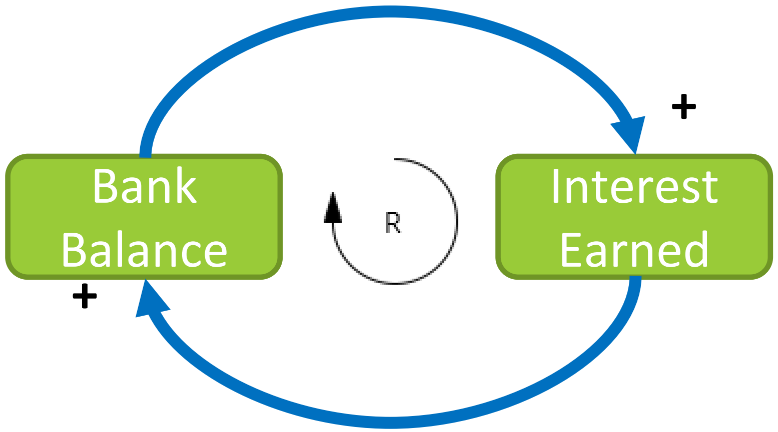


if cause increases ... effect increases
(above what it would otherwise have been)

if cause increases ... effect decreases
(below what it would otherwise have been)

CAUSAL LOOP DIAGRAMS - REINFORCING

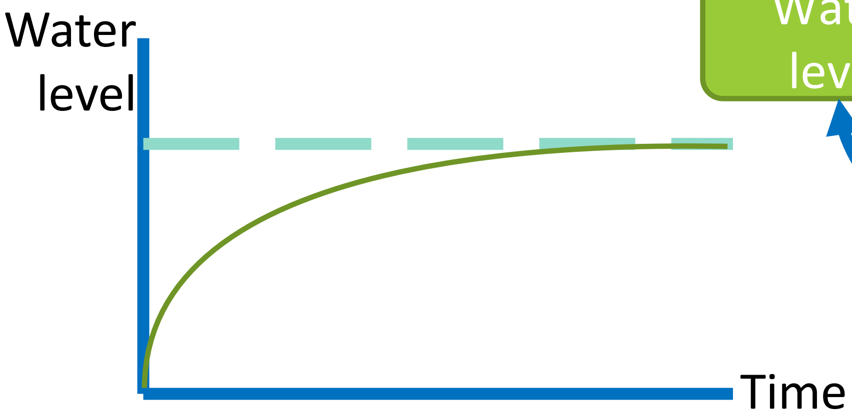


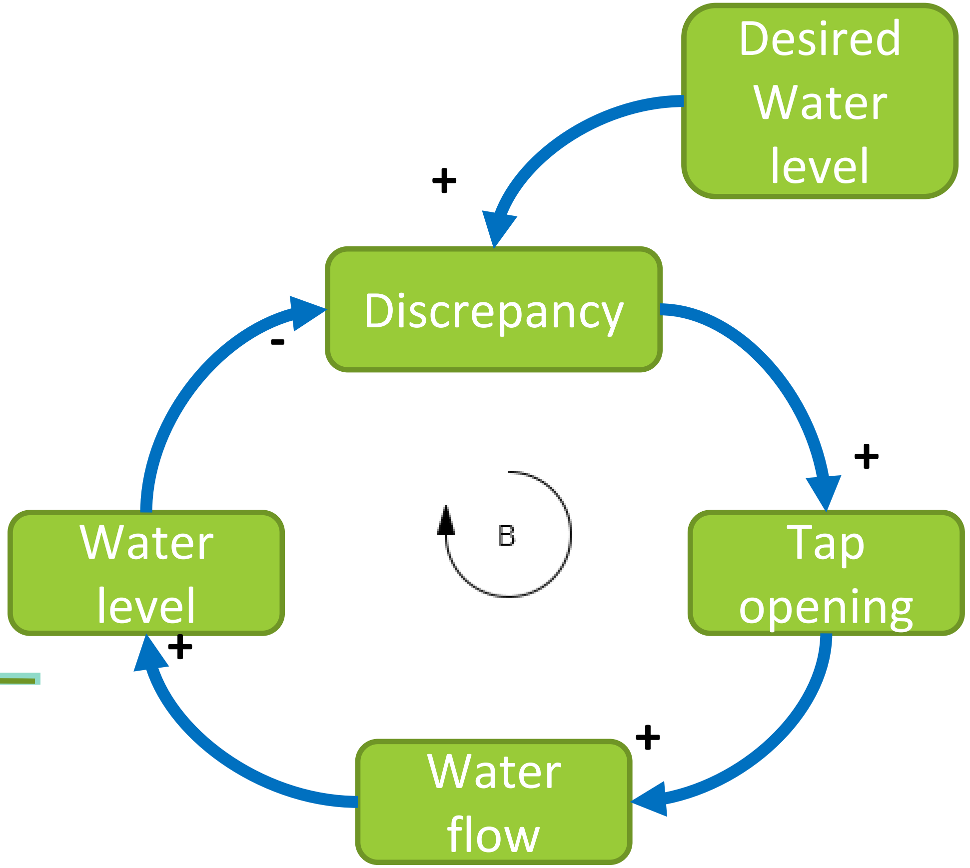


CAUSAL LOOP DIAGRAMS - BALANCING

Add a desired goal

Filling a glass of water/ toilet reservoir





CAUSAL LOOP DIAGRAMS

Facilitating discussion/creating common ground

Avoiding vagueness in discussions; it is a formal tool

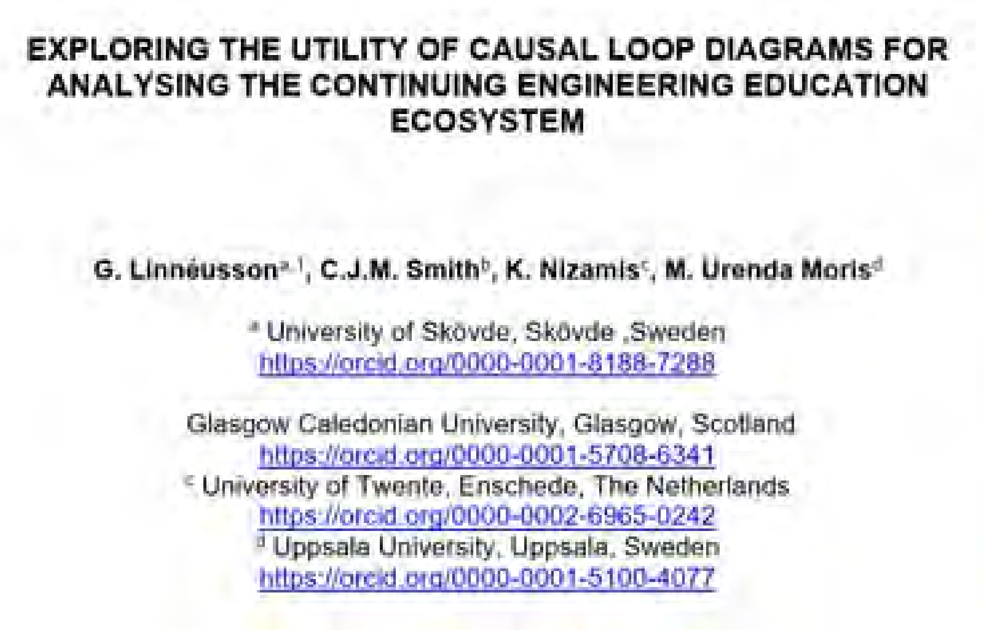
Create understanding:

- What is a positive or negative effect?
- What is the result of bringing together the effects: reinforcement or balancing?
- What closes the loop?
- …

In general, the results remain qualitative

SYSTEMS THINKING - RESEARCH

RESEARCH - CLD



EXPLORING THE UTILITY OF CAUSAL LOOP DIAGRAMS FOR ANALYSING THE CONTINUING ENGINEERING EDUCATION ECOSYSTEM

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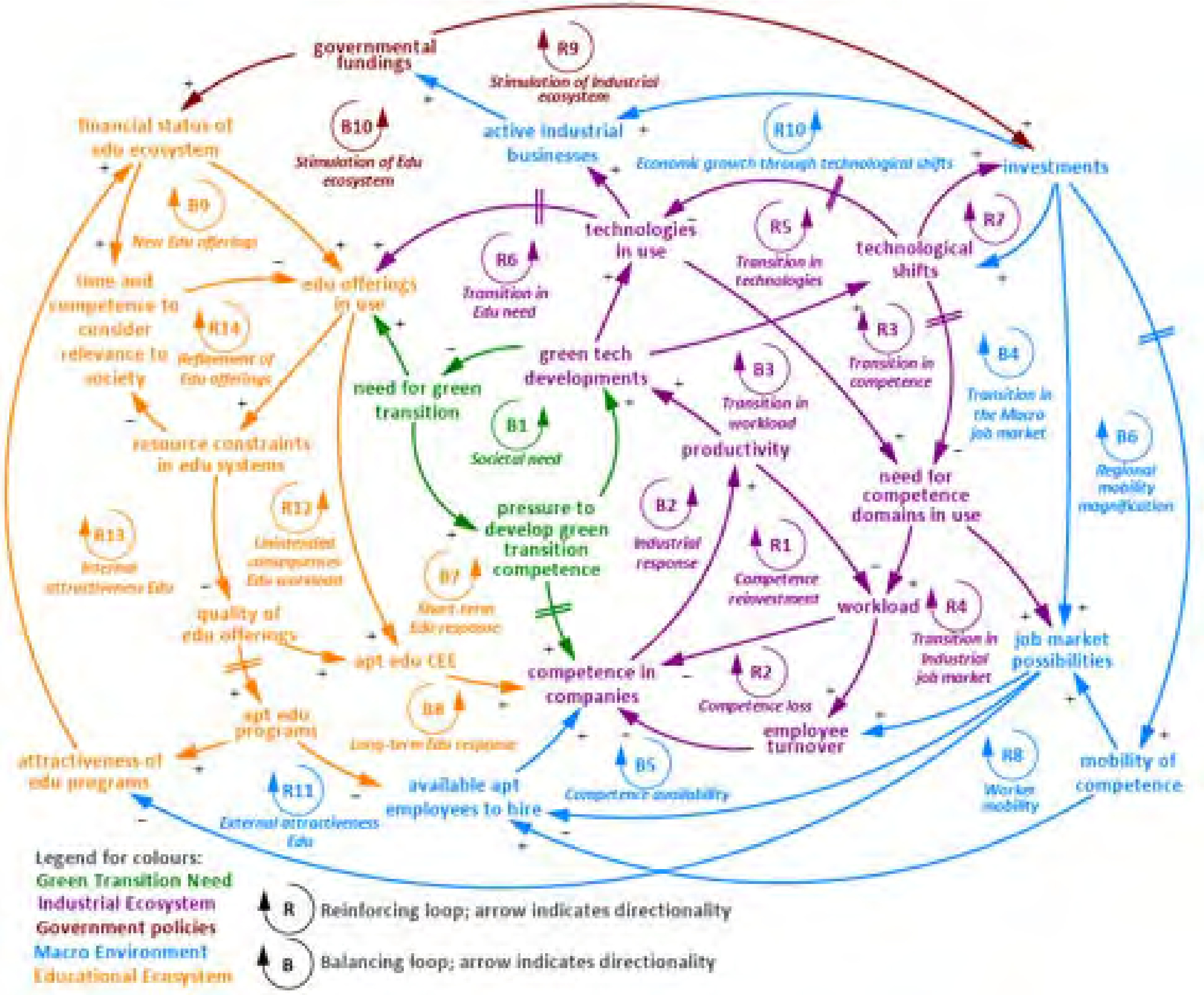

Linnéusson, G., Smith, C., Nizamis, K., & Urenda Moris, M. (2025). Exploring The Utility of Causal Loop Diagrams for Analysing the Continuing Engineering Education Ecosystem. SEFI 53rd Annual Conference (SEFI 2025), Tampere, Finland. https://doi.org/10.5281/zenodo.17631581

EVALUATING SYSTEMS THINKING IN EDUCATION

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The International Journal of Management Education 24 (2026) 101360

Contents lists available at ScienceDirect

The International Journal of Management Education

journal homepage: www.elsevier.com/locate/ijme

ELSEVIER

Cocreating societal impact through transdisciplinary, challenge-based learning

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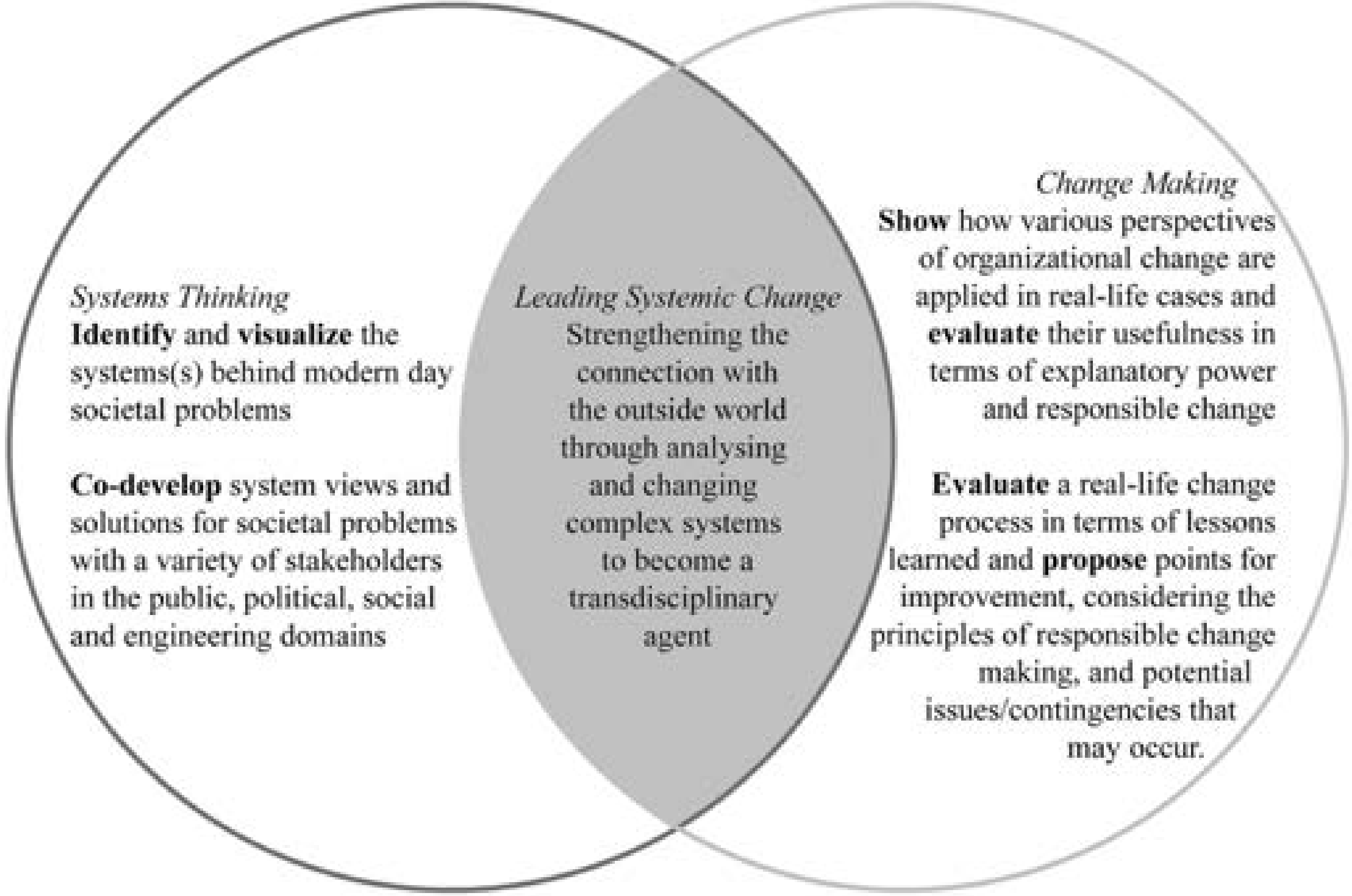
EVALUATING SYSTEMS THINKING IN EDUCATION



Conway's law:
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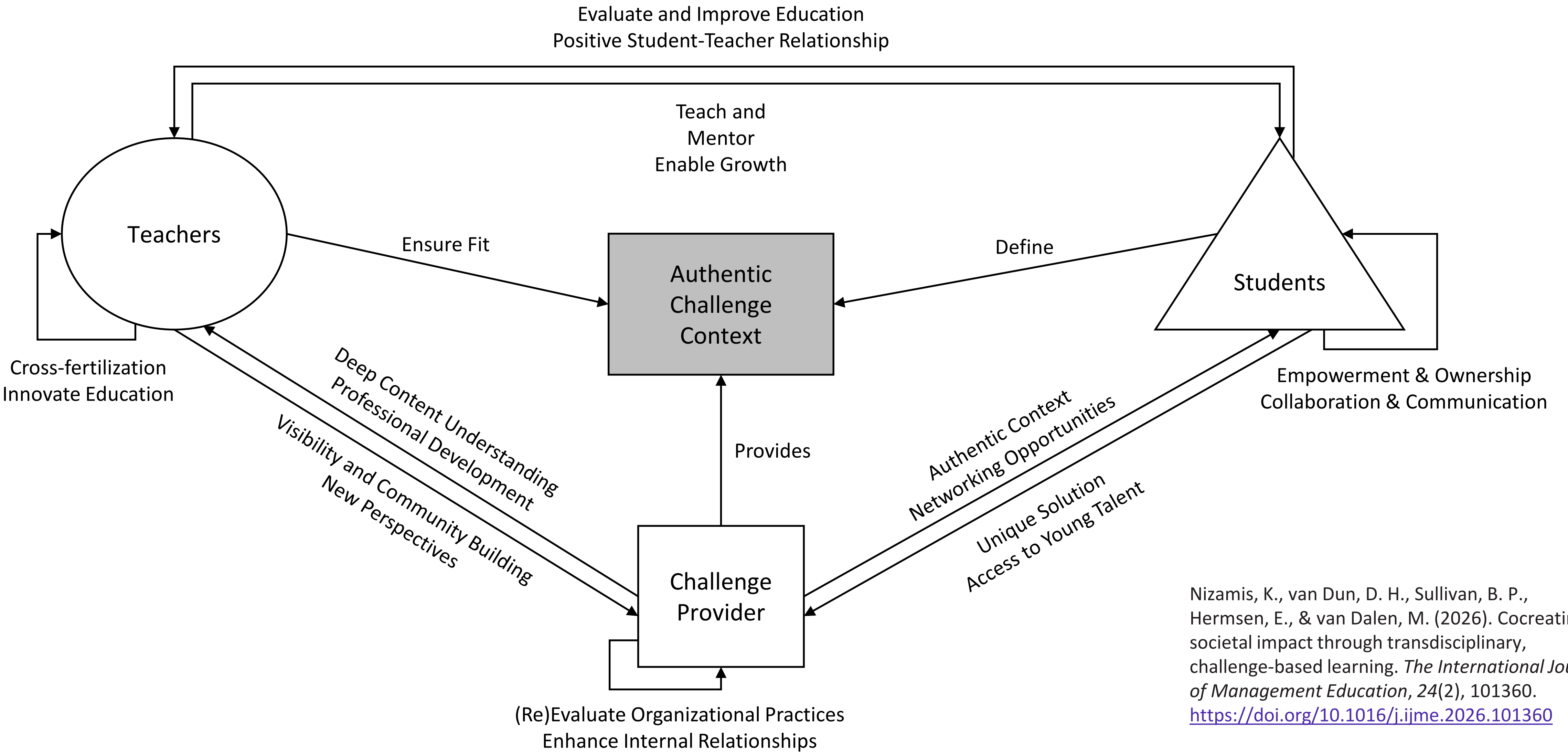

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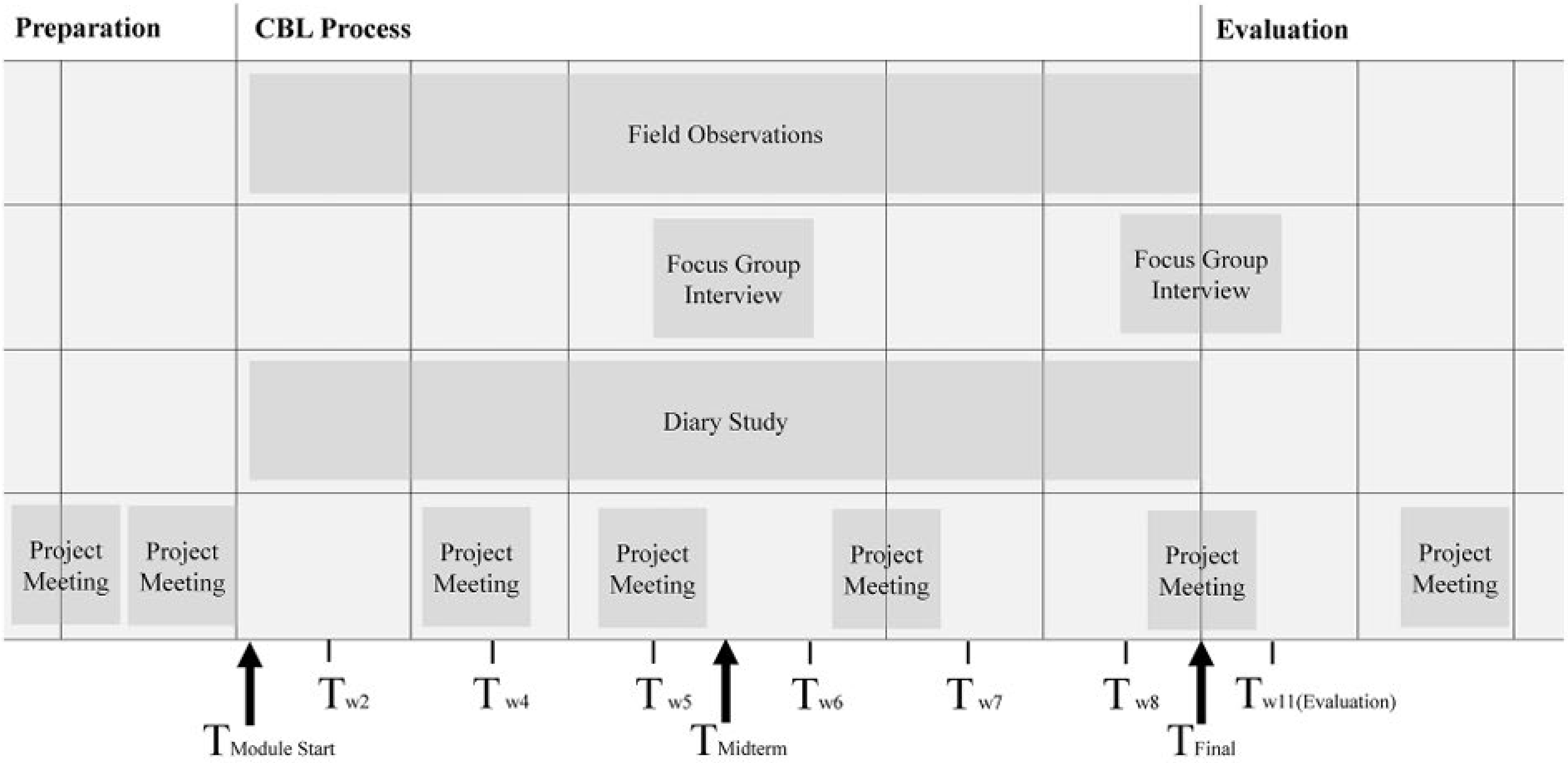

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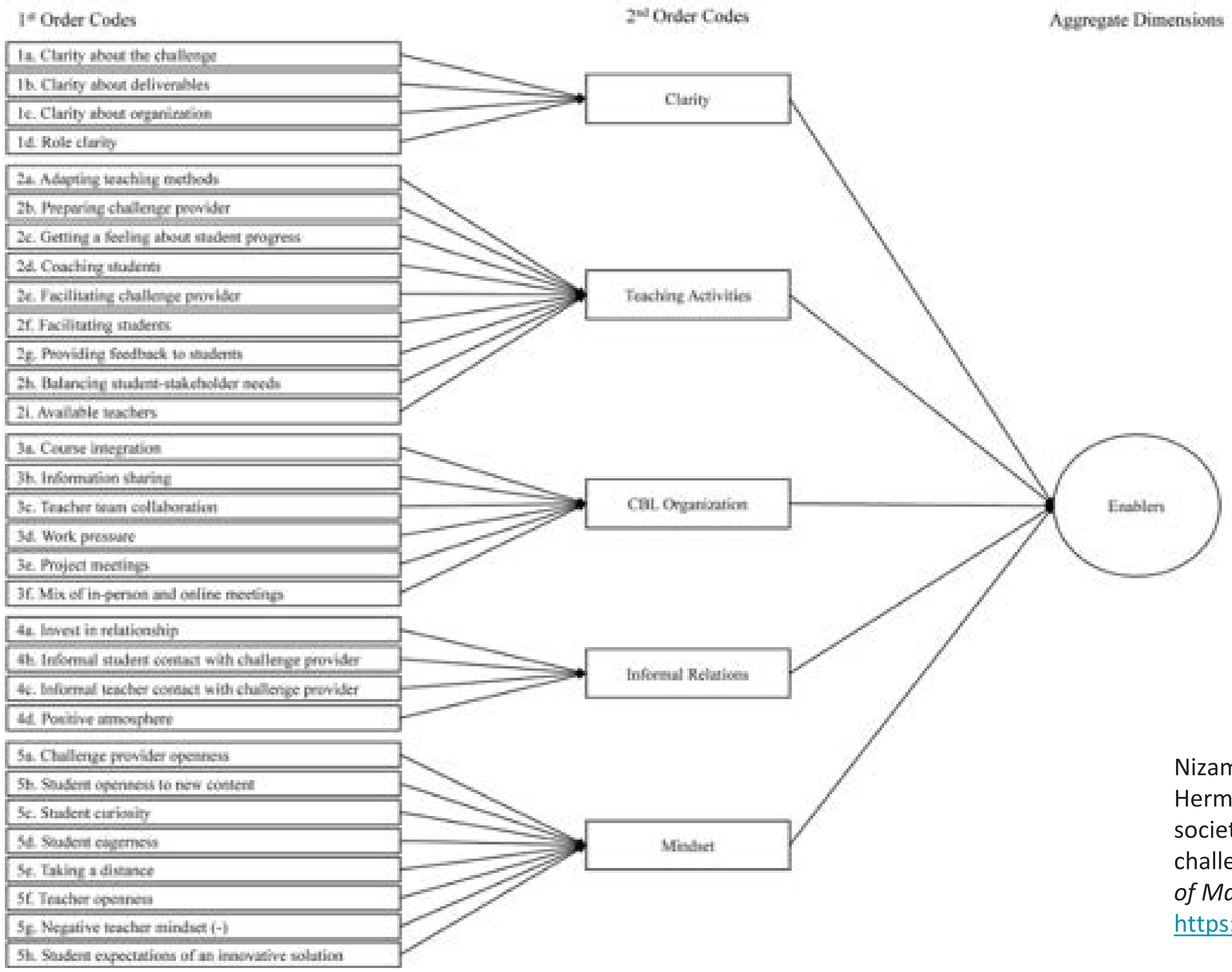

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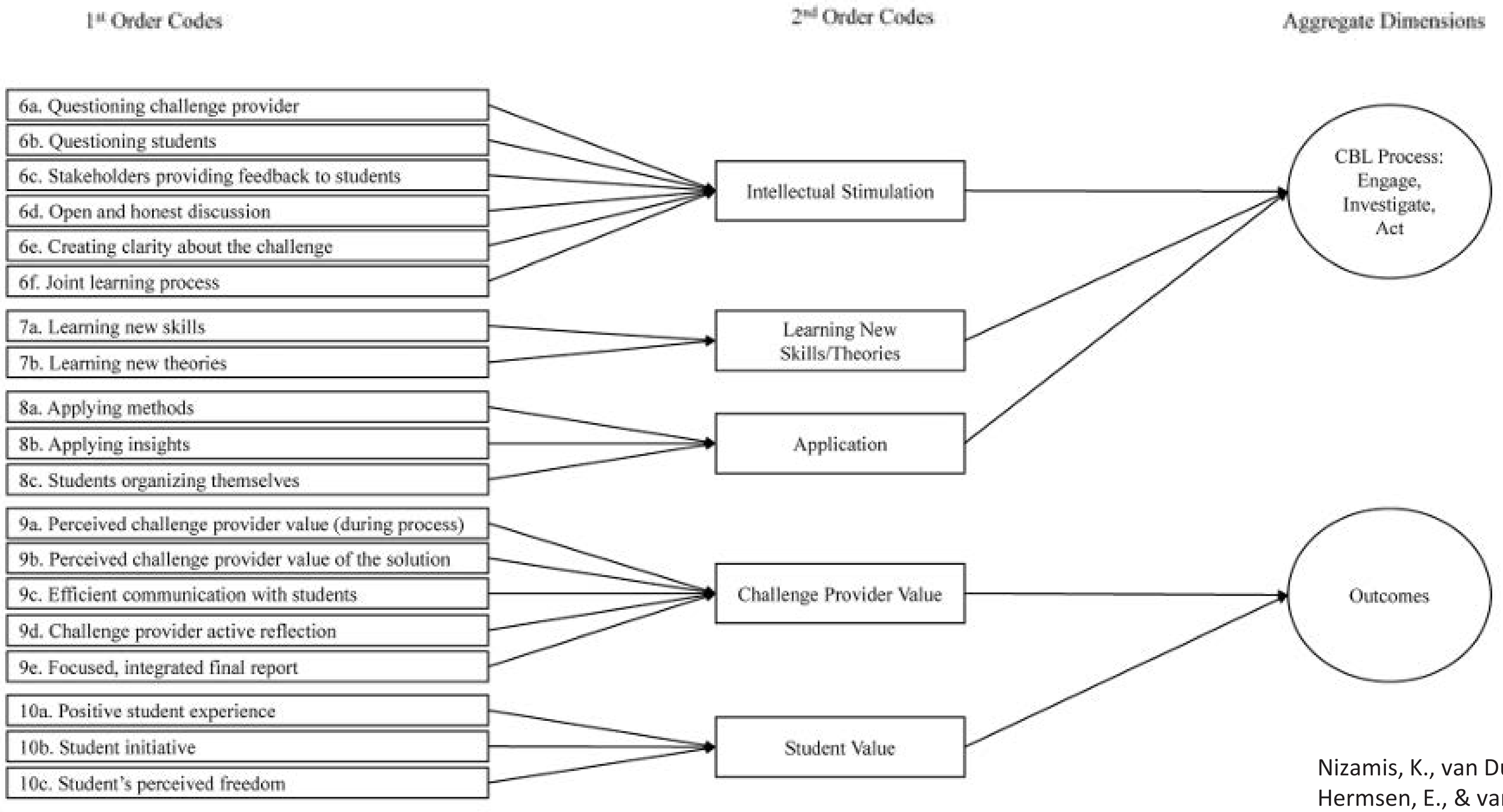

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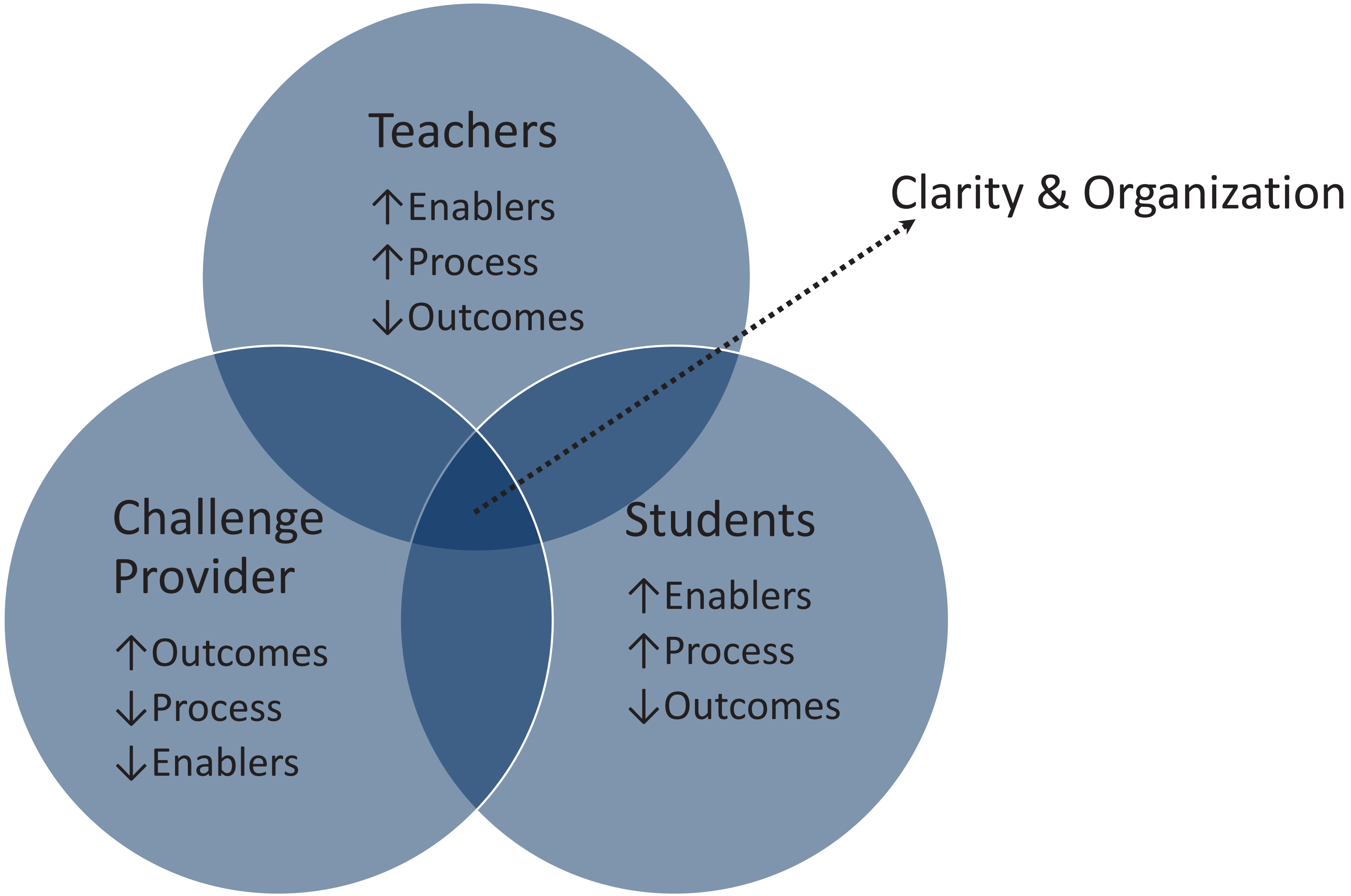

TAKE HOME

What are your key takeaways from this talk?

1. Bring your own interests or students' interests to make ST relatable and understandable (i.e., soup example)
2. Learn by doing, and do not be afraid of feedback
3. Diversify your audiences to understand broader aspects and implementations of ST
4. Preparation, preparation, preparation (and a bit of experience so practice ST regularly)

"Problems are universal. No discipline owns a problem. Those adjectives show the point of view of the person(s) identifying a problem. Sometimes our education is not organized the way reality is, or vice-versa"

Dr. Russell Ackoff – Systems Thinking Speech

UNIVERSITY OF TWENTE.

Let’s talk!

Dr. Ir. Kostas Nizamis
Assistant Professor of Multidisciplinary Design

Minisymposium Methodes voor het leren systeemdenken en werken|
Hogeschool Windesheim Zwolle – 5th of February 2026