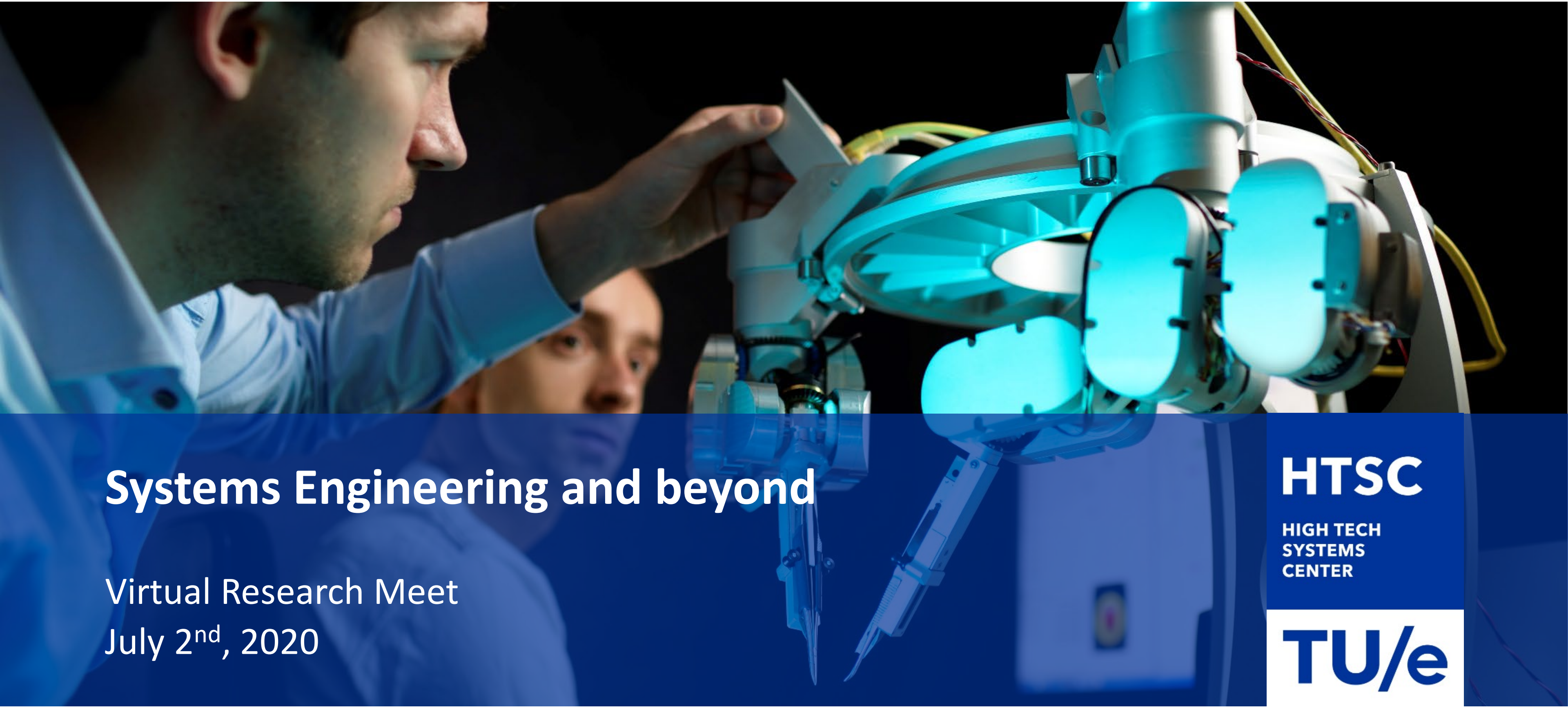


Systems Engineering and beyond

Virtual Research Meet

July 2nd, 2020

HTSC

HIGH TECH SYSTEMS CENTER

TU/e

PROGRAM

09:30	Welcome	Ton Peijnenburg
09:35	Systems Engineering and System Thinking	Ton Peijnenburg
09:50	Q&A	
10:00	Digital Engineering	Marc Hamilton
10:20	Q&A	
10:30	AI in Engineering	Albert van Breemen
10:50	Q&A	
11:00	Closing	Ton Peijnenburg

Systems Engineering and System Thinking

Systems Engineering (SE) has been a key element of the strategy of HTSC since the center was officially kicked off in early 2015. We have identified that SE, in addition to multi-disciplinary working, is required to deal with the challenges inherent in the development and realization of technical systems of increasing complexity. An important element of SE is systems thinking, a skill required to solve problems in complex systems. In high-tech equipment development, we use a special flavor of SE that has evolved over decades in our ecosystem and enabled us to develop the world's most complex equipment. This presentation will discuss aspects of our special flavor of SE, challenges of the current state-of-practice and how HTSC intends to train and further improve the SE way-of-working, equipping future engineers with important skills to deal with increasing complexity.

Ton Peijnenburg, a.t.a.peijnenburg@tue.nl
Fellow TU/e HTSC and Deputy General Manager VDL-ETG

Digital Engineering

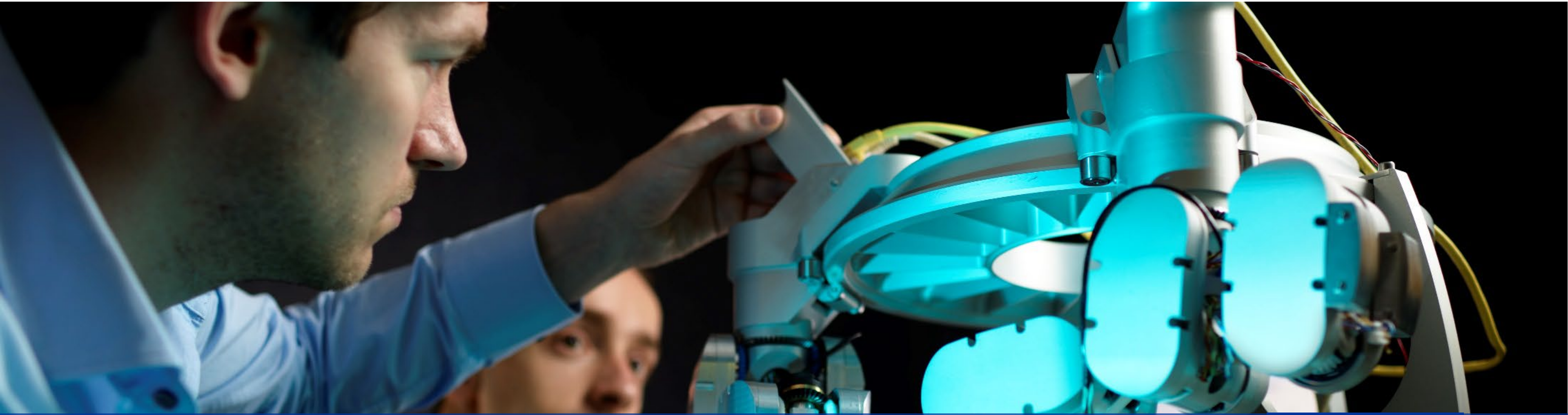
In high tech systems engineering, the collaboration between data and models of various disciplines is crucial. In current engineering practice, silos of computerization are present by a variety of tools. The transfer of tooling results, the cross-disciplinary and cross-paradigm interaction between models and the interpretation and feedback of data generated by virtualized or operational systems are largely left to human intervention. Digital engineering will further improve the efficiency of engineering processes. It in addition enables the application of Artificial Intelligence (AI) to support engineering processes (AI4SE) and to develop next generation systems (SE4AI). However, where humans are very flexible in the interpretation of languages, computers are not. This presentation will address how this further digitalization of multi-disciplinary engineering processes will impact systems engineering.

Marc Hamilton, m.a.m.hamilton@tue.nl
Fellow TU/e HTSC and MDE Expert at Altran Netherlands

AI in Engineering

Recent developments in the field of Artificial Intelligence led to a new mature technology called 'deep learning'. Deep learning is a combination of big data, supercomputing and algorithm innovations. The technology had many breakthroughs by outperforming human experts in areas such as vision, speech recognition and game play. This presentation explores the possibilities of AI for engineering. AI seems a new tool for the engineer to deal with the ever growing engineering design challenges on precision, productivity and intelligence. However, many barriers need to be taken before the engineer can start applying AI.

Albert van Breemen, a.j.n.v.breemen@tue.nl
AI progam manager TU/e HTSC and EAISI



Systems Engineering and systems thinking

Ton Peijnenburg
a.t.a.peijnenburg@tue.nl
July 2nd, 2020

HTSC
HIGH TECH SYSTEMS CENTER
TU/e

About myself

TU/e electrical engineering (1992)

Philips CFT – mechatronics department

- Linear motors: from CD player to stepper
- TwinScan™ pre-development
- Systems Engineering
- USA – Silicon Valley and Pittsburgh, PA

FEI – Phenom desktop SEM

VDL ETG – deputy managing director – technology

\+ 20% TU/e – HTSC fellow

High Tech Systems Center

Maarten Steinbuch
Scientific Director

Katja Pahnke
Managing Director

- A true multidisciplinary research center
- Single entry point for Dutch High Tech Systems industry
- With a strong international reputation as a top-class research center
- 200 PhD students, 20 PDEng trainees and 20 Postdocs
- Industrial Fellows as program leaders
- Located on the TU/e-campus with shared facilities
- Applied Physics, Computer Science, Electrical Engineering, Mechanical Engineering

Building consortia

- **Contamination control** – Ton Peijnenburg, Jan-Jaap Koning
- **Digital Engineering** – Marc Hamilton
- **Industrial Internet of Things** – Georgo Angelis
- **AI in Engineering** – Albert van Breemen
- **Robotics** – Jesse Scholtes
- **Scientific Instrumentation & Metrology** – Frank Sperling, Marco van Beijersbergen
- **Opto-mechatronics** – Anton van Dijsseldonk
- **Additive Manufacturing** – Katja Pahnke
- **AgroFoodTech** – Jeannette Lankhaar, Edwin de Zeeuw

Where in high-tech equipment supply chains…

Systems become more complex

Timelines become shorter

Capital investment grows higher

  Prototypes are sold to customers…

Design teams grow (much) larger

Embedded software becomes (much) more dominant

Suppliers are involved earlier, with higher-level capabilities

Consolidation is ongoing

International competition is increasing

We do our best to apply Systems Engineering, but…

We define SE in our own way – Philips, Stork, Océ, ASML, … heritage

We use elements of SE, but not all well balanced

We tend to train system architects, not system engineers

We tend to focus on analysis rather than design

We do not rationalize and/or quantify trade-offs

We do not manage requirements well (heck, we don't even discover them well enough…)

Models are opportunistic, not well managed, not co-evolving

We tend to blame project management for project overruns and bad estimates

We work mostly document based: *.docx, *.xlsx and (even) *.pptx

High-Tech systems

High-tech – at the cutting edge, the most advanced technology available

System – an object studied in some field

Complex system – highly composite, very large numbers of mutually interacting subunits

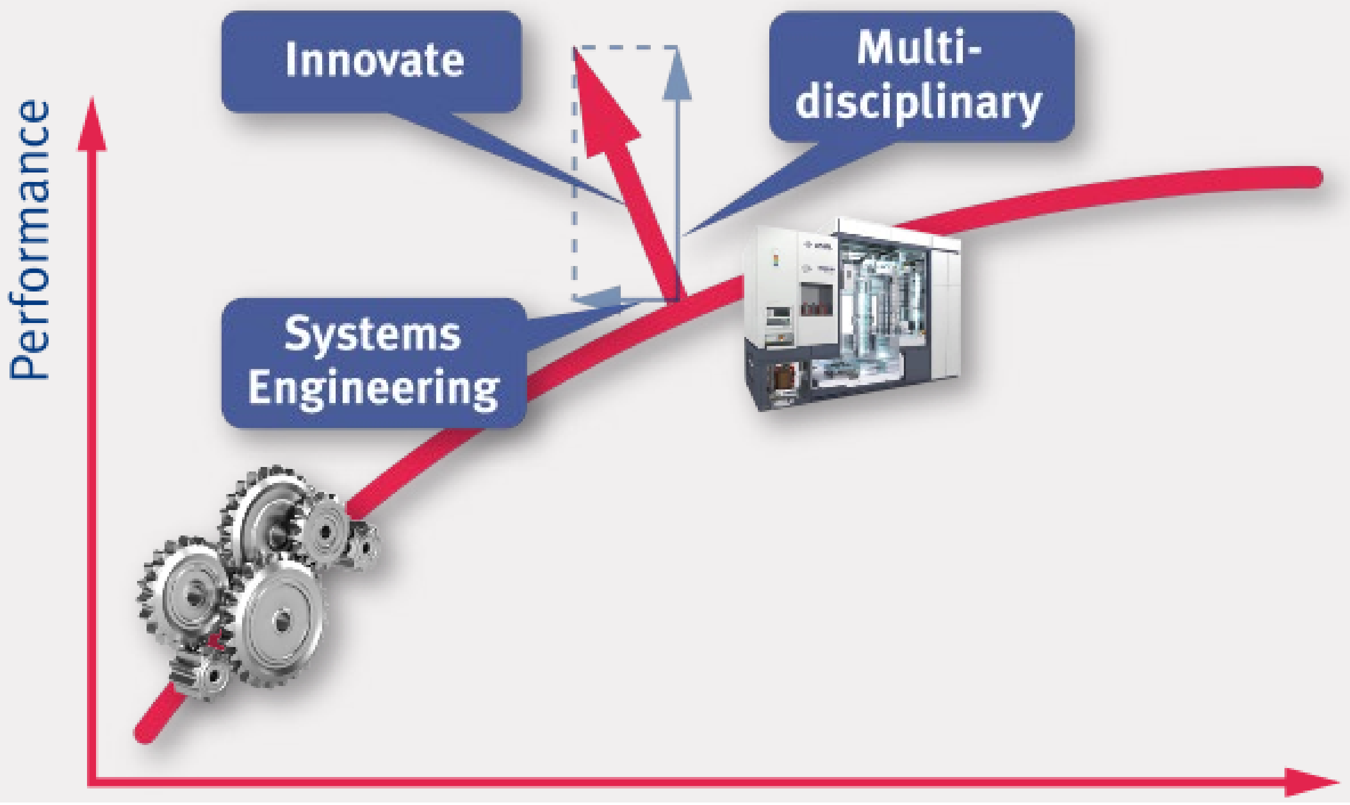
Chaotic system – maybe few interacting units, intricate dynamics

Simple system – few parts, simple laws

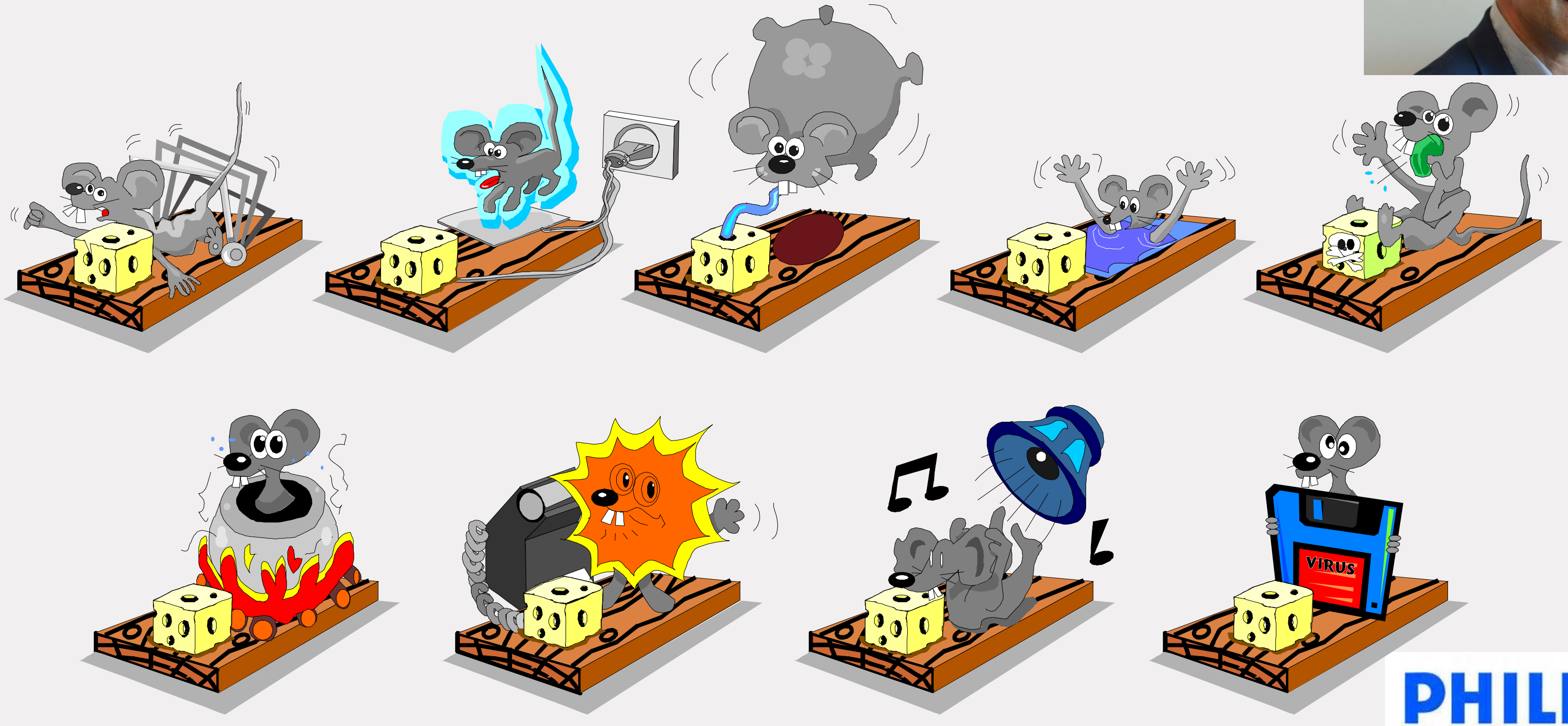
Complicated system – many parts, specific functional roles, simple rules

A simple guide to chaos and complexity, Dean Rickles, Penelope Hawe, Alan Shiell
J Epidemiol Community Health 2007; 61 :933–937. doi: 10.1136/jech.2006.054254

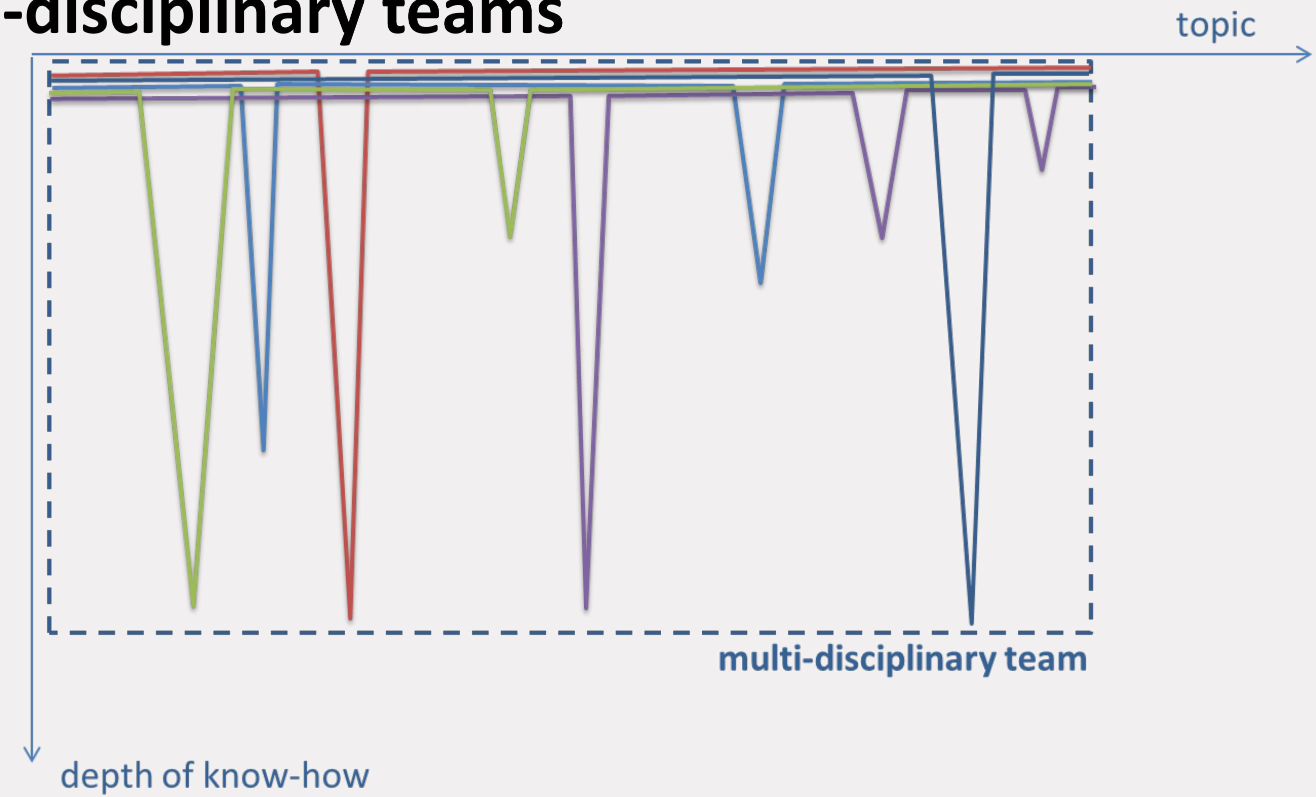
Resources versus Performance



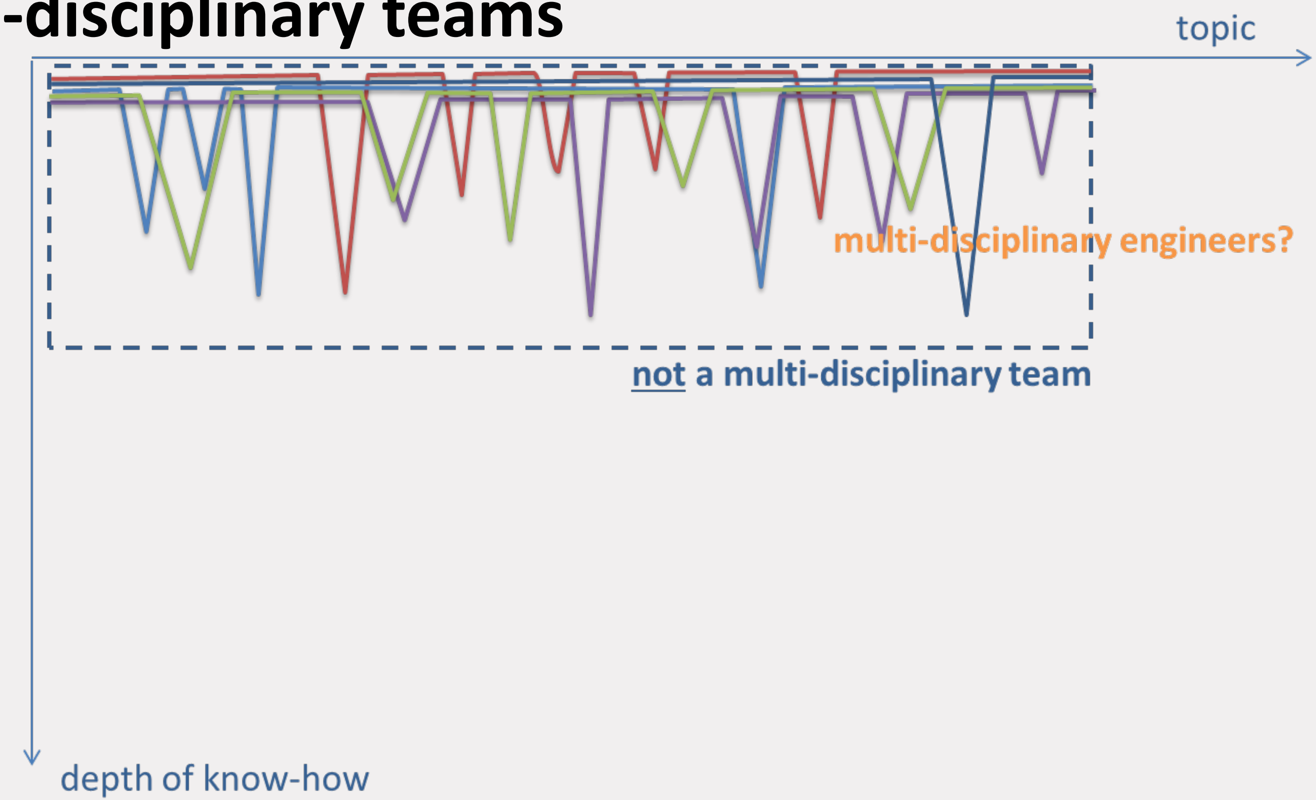
Multi-disciplinary – mechatronics



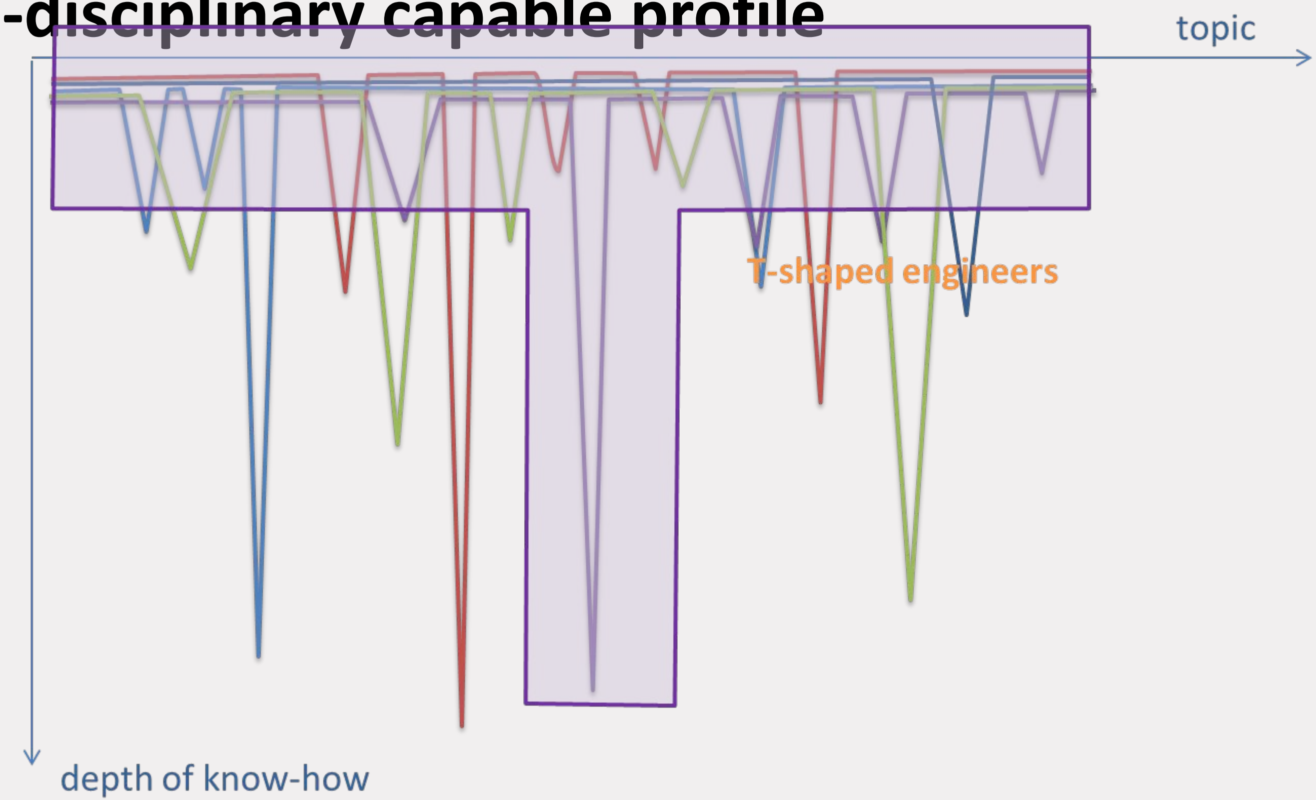
Multi-disciplinary teams



Multi-disciplinary teams



Multi-disciplinary capable profile



Systems Engineering

Analysis is the understanding of the world, through measuring the functional elements and construct complex models to describe reality.

Synthesis is to create coherent solutions by reviewing alternatives and create new elements or relationships between them.

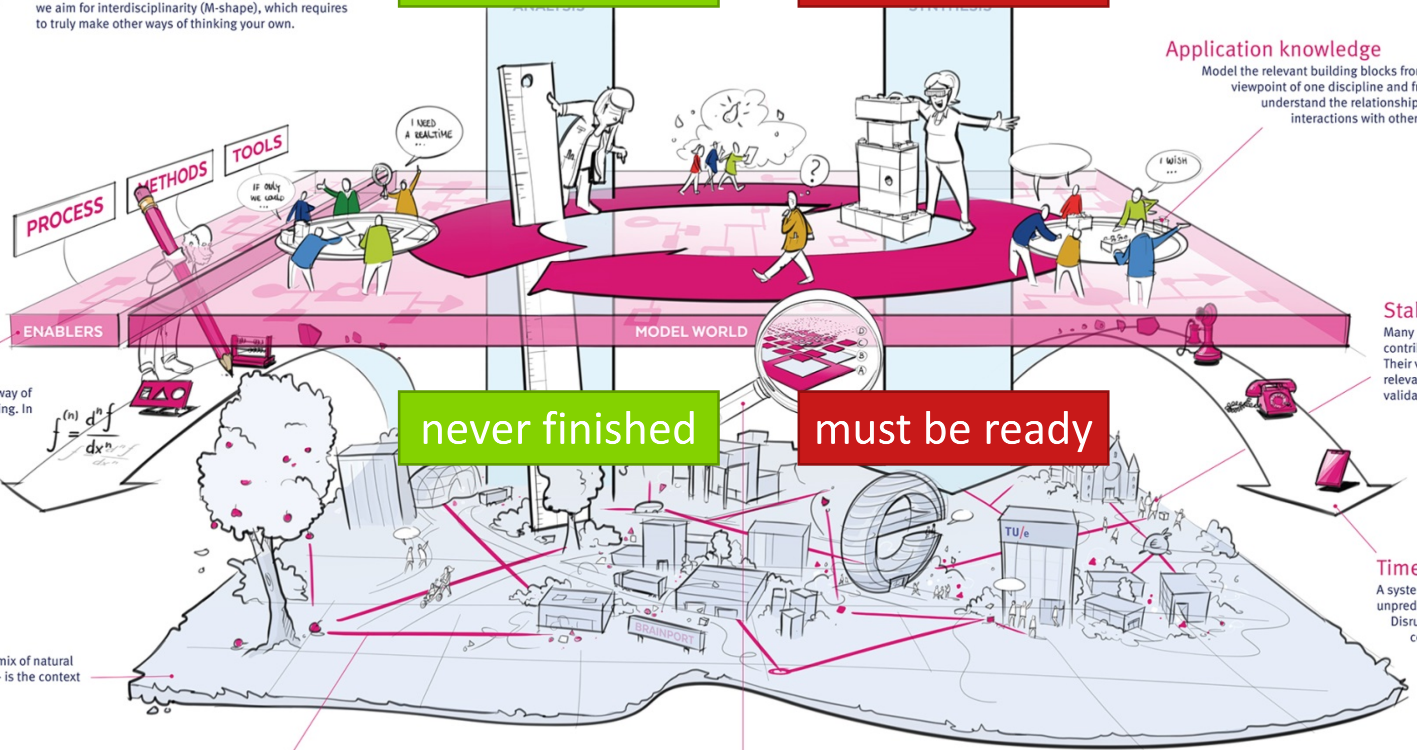
M-Shape
Systems cross disciplines. Multidisciplinary cooperation (T-shape) requires understanding each other and making yourself understandable. In the end, we aim for interdisciplinarity (M-shape), which requires to truly make other ways of thinking your own.

perfection

compromise

never finished

must be ready



Application knowledge
Model the relevant building blocks from the viewpoint of one discipline and from there understand the relationships and interactions with other domains.

Stakeholders
Many and different stakeholders contribute and influence the system. Their viewpoints and concerns are relevant to the constraints and the validation of solutions.

Enablers determine the way of looking, analysing and predicting. In addition to process, tools and methods, they also define the boundaries of the modelling potential and therefore have to be developed along on time.

Time
A system evolves over time on an unpredictable and unforeseen path. Disruptive technologies or a combination of new insights can also lead to a revolution.

The **real world** - a mix of natural and man-made systems - is the context of grand challenges.

A **system** is an interconnected set of elements that are coherently organized, interact together and jointly achieve something.

Levels of aggregation support the understanding of the larger (complex) whole within which the question and the answer play. Zooming in and out, alternating different complementary views and exploring alternatives, supports the choice without exactly knowing.

TU/expedition - System Thinking - version November 06 - 2017

Design versus Analysis

ANALYSIS

- Studying an *existing* situation/thing/effect
- In-depth
- Creating knowledge
- Single “correct” answer
- Descartian

Truths that are attained by reason are broken down into elements that intuition can grasp, which, through a purely deductive process, will result in clear truths about reality.
https://en.wikipedia.org/wiki/Rationalism

DESIGN

- Creating something *new*
- Big picture
- Creating knowledge
- Many possible “correct” answers
- Holistic

Holism (from Greek ὅλος *holos* "all, whole, entire") is the idea that systems (physical, biological, hemical, social, economic, mental, linguistic, etc.) and their properties should be viewed as wholes, not just as a collection of parts.
https://en.wikipedia.org/wiki/Holism

Systems Engineering

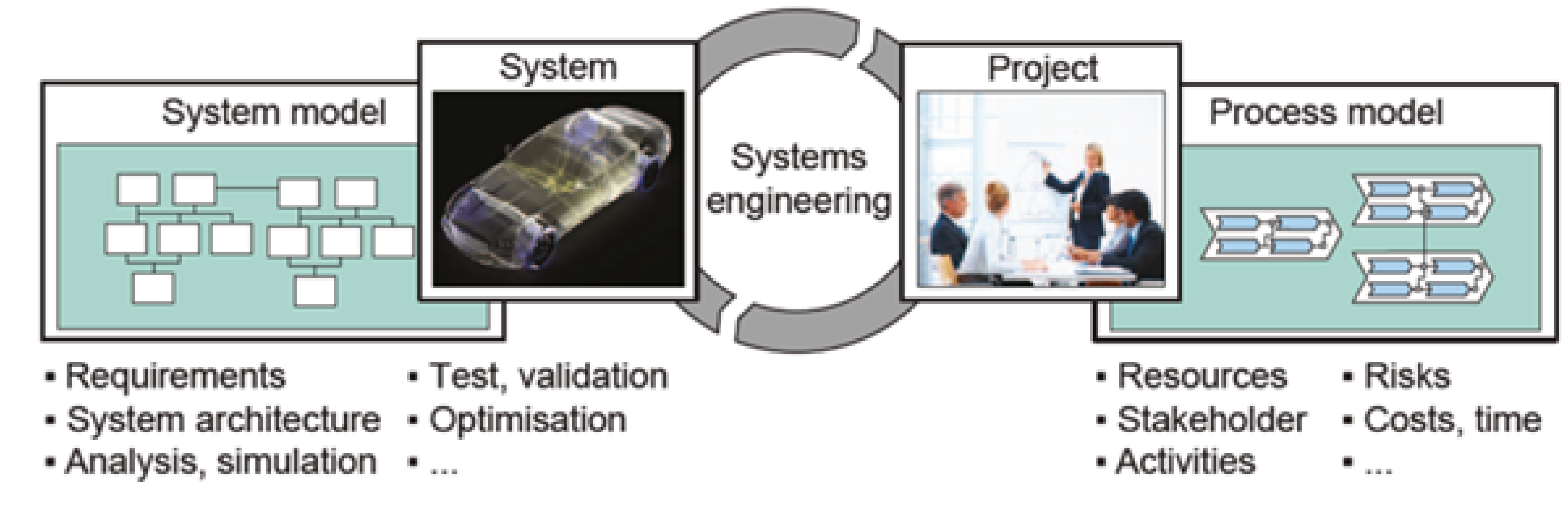
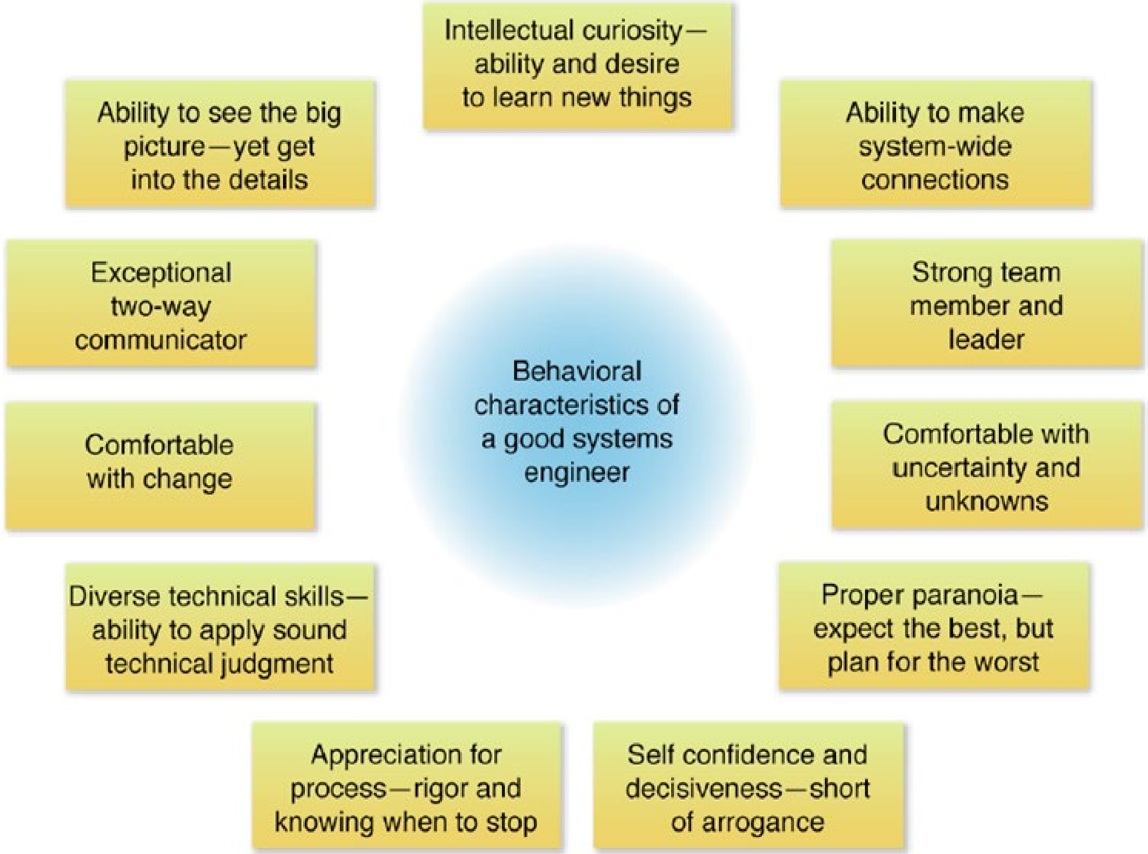


Figure 2-1: Joint analysis of system and project – the core aspects of SE

SYSTEMS ENGINEERING in industrial practice, Heinz Nixdorf, Fraunhofer IPT, https://www.iem.fraunhofer.de/content/dam/iem/de/documents/Studie%20Systems%20Engineering_englisch.pdf



Michael Ryschkewitsch, Dawn Schaible and Wiley Larson, The Art and Science of Systems Engineering, Systems Research Forum, Volume 03, Issue 02, December 2009

Context

- Systems Engineering is required to industrial-scale design problems
- Systems thinking is required to do proper SE
- Dutch high-tech companies use an implicit SE approach, different from established SE*
- Each sector use their own domain specific variation, language, modeling approach, …
- Dutch companies need more systems engineers
- Established SE promotes tools, while these are not widely used in Dutch high-tech
- SE (design engineering, …) is a key mindset for future engineers, as is systems thinking
- TU/e should teach and research SE, to train and to innovate

* Although established SE is innovating at this moment

HTSC HIGH TECH SYSTEMS CENTER TU/e

SE in high-tech equipment

There is a wide gap between SotA and SotP for SE in high-tech equipment industries

The applied systems engineering methodologies differ from “regular” SE

We need:

- Systems thinking
- Model-based design
- Requirements-centered development → Digital Engineering
- Quantified trade-offs
- Truly multi-disciplinary, e.g. bridging the gap between software and other disciplines
- Sufficient agility

SW in high-tech equipment

Software discipline becomes ever more dominant in high-tech equipment:

- More functionality is implemented in software
- Advanced control approaches, advanced algorithms
- More data driven operation of equipment, e.g. diagnostics → AI in Engineering
- Machine control state space increase, exception handling → AI in Engineering
- Support and automation of design → Digital Engineering
- Managing legacy is a pain → AI in Engineering?

We should:

- Merge thinking → Domain Specific (modeling) Language

Engineering Design Spine

At the heart of the core curriculum is a series of eight design courses, one each semester, that is referred to as the Design Spine. The Design Spine courses are the major vehicle for developing a set of competencies to meet educational goals in areas such as creative thinking, problem solving, teamwork, economics of engineering, project management, communication skills, ethics, and environmental awareness. In most cases, they are also linked to the engineering science courses taken concurrently each semester. This is done so that experiments and design projects provide a tangible context for the engineering science lecture materials and thus are an aid to learning.

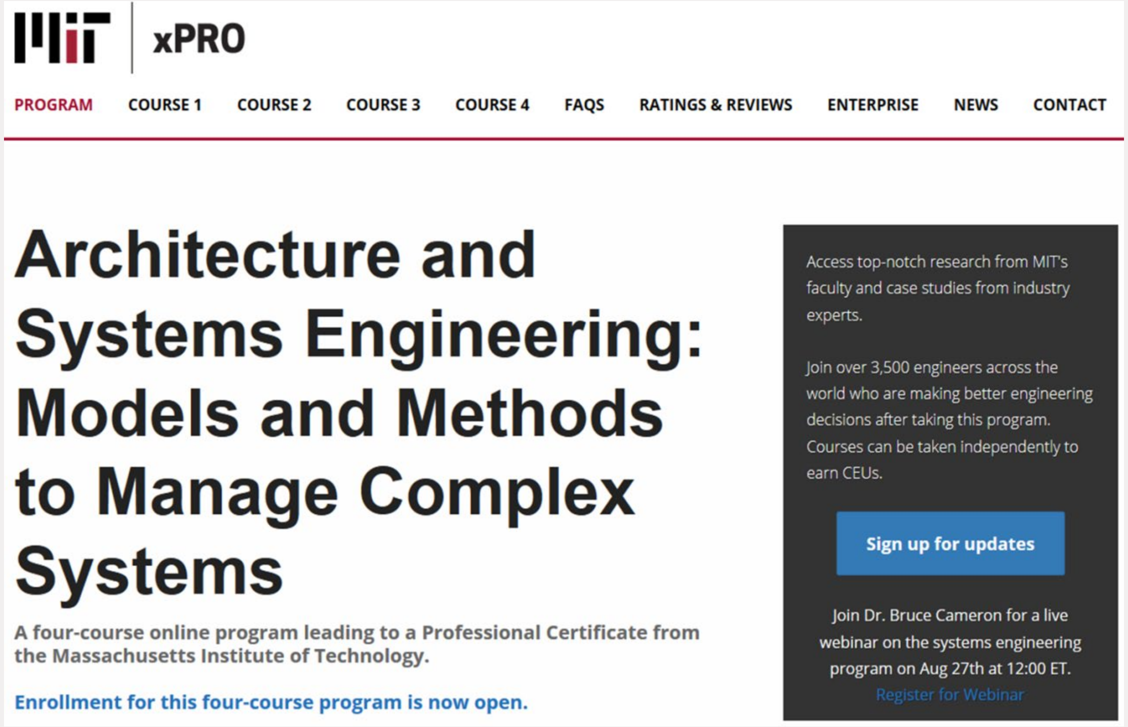
The first five core design courses are taken by all students and are taught by adjunct engineers who bring the benefit of their industry-based design experience into the classroom. The last three courses are taken within their discipline - a junior course followed by a 2-semester capstone senior project.

Academics

UNDERGRADUATE STUDIES

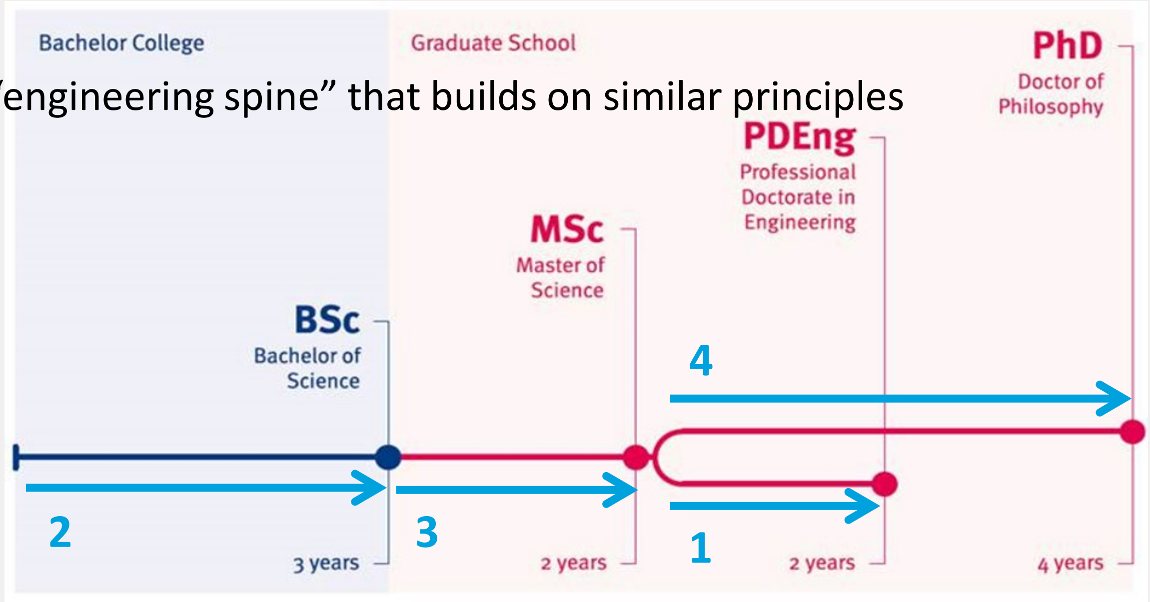
Undergraduate Majors
Special Programs
The Freshman Experience
Innovation, Design and Entrepreneurship (IDEaS) Program
Senior Capstone Projects
Engineering Design Spine
Study Abroad
Office of Undergraduate Academics
Undergraduate Research
Foreign Language Study
Writing & Communications Center

MIT – MOOC on Systems Engineering



PDEng training on Systems Engineering

- Use PDEng as starting point – it is a designer school
- Expand
- Create an "engineering spine" that builds on similar principles



Systems Engineering and Systems Thinking

- SE is a methodology to design and realize systems and their components
- Systems Thinking is a cognitive orientation to view problems as part of a greater context, and devise solutions suitable for the system and its greater context

- All students should be trained in systems thinking
- Students should be exposed to state-of-the-art SE
- Companies should use state-of-the-art SE methodologies
- True systems engineers require training PLUS years of practice
- Industrial professionals may want additional training in SE

Thank you!