USING MBSE TO INTEGRATE ENGINEERING UNDERGRADUATE COURSES CURRICULUM

CapellaDays


Prof. Dr. Christopher S. Cerqueira
Prof. Dr. Eduardo E. Bürger

IA UFSM

2021

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A LITTLE ABOUT THE PRESENTERS

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PROF. DR. **CHRISTOPHER** SHNEIDER CERQUEIRA

- BSc in Computer Engineering at UNIFEI (2010)
- MSc and PhD in Space Systems Engineering and Management at INPE (2014 and 2018)
- Currently lecturing at ITA and collaborating with ITA Space Center
- Research domains:
  - Concurrent Engineering,
  - (Model Based) Systems Engineering,
  - Human-Machine Interaction,
    - Tangible Artifacts, Augmented Reality,
  - Industry-Space 4.0.

- Lattes: http://lattes.cnpq.br/6516110599667954
- E-mail: chris@ita.br

INSTITUTO
TECNOLÓGICO
DE AERONÁUTICA
1950

CENTRO
ESPACIAL
ITA

PROF. DR. **EDUARDO** ESCOBAR BÜRGER

- BSc in Mechanical Engineering at UFSM (2011)
- MSc and PhD in Space Systems Engineering and Management at INPE (2014 and 2018)
- Currently lecturing at UFSM and Coordinating the NCBR Program (INPE/UFSM) Engineering Team
- Research domains:
  - Concurrent Engineering,
  - (Model Based) Systems Engineering,
  - V&V (and AIT),
  - Small Spacecrafts,

- Lattes: http://lattes.cnpq.br/1319354899633248
- E-mail: **eduardo.burger@ufsm.br**

Universidade Federal de Santa Maria

SEDES SAPIENTIÆ

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SUMMARY

SUMMARY

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FRAMING SYSTEMS ENGINEERING DEFINITION

WHAT IS SYSTEMS ENGINEERING?

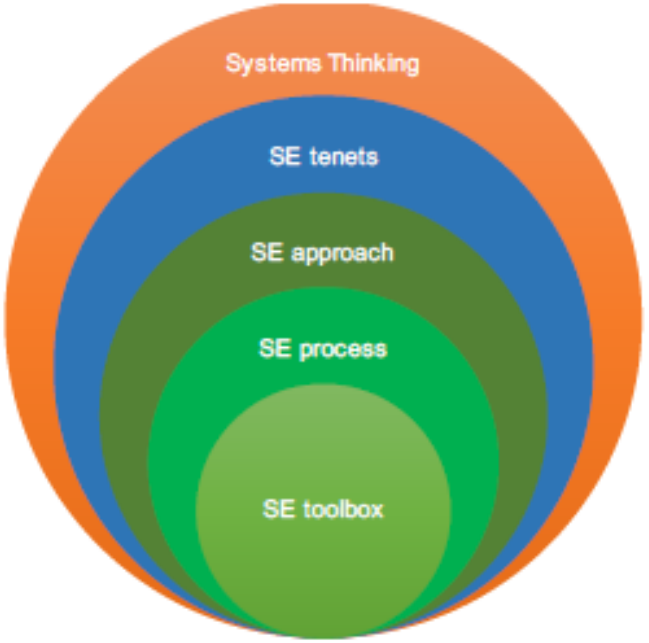
"Systems Engineering is a *TRANSDISCIPLINARY* approach and means, based on systems principles and concepts, to enable the successful realization, use and retiral of engineered systems.

It focuses on

- establishing stakeholders' **purpose and success criteria**, and defining actual or anticipated customer needs and required functionality early in the development cycle,
- establishing an **appropriate lifecycle model** and process approach considering the levels of complexity, uncertainty and change
- documenting and **modelling requirements** and **solution architecture** for each phase of the endeavour
- proceeding with **design synthesis and system validation**
- while considering the **complete problem** and **all necessary enabling systems and services**.

Systems Engineering provides facilitation, guidance and leadership to integrate all the disciplines and specialty groups into a team effort forming an appropriately structured development process that proceeds from concept to production to operation, evolution and eventual disposal.

Systems Engineering considers both the business and the technical needs of all customers with the goal of providing a quality solution that meets the needs of users and other stakeholders and is fit for the intended purpose in real-world operation, and avoids or minimizes adverse unintended consequences."



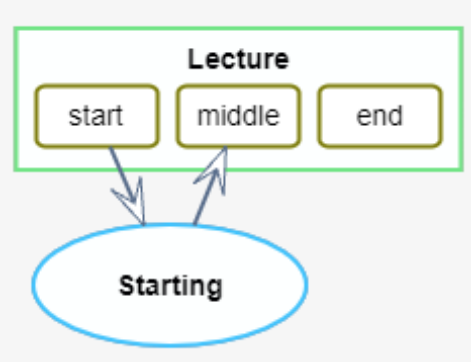
Systems Engineering Principles | NASA

Principles of Systems Thinking - SEBoK (sebokwiki.org)

Envisioning Systems Engineering as a Transdisciplinary Venture
28th Annual INCOSE International Symposium - 2018

A fresh look at Systems Engineering – what is it, how should it work?
28th Annual INCOSE International Symposium - 2018

MBSE



“Model-based systems engineering (MBSE) is a **systems engineering** that focuses on creating and exploiting **domain models as the primary means of information exchange** between engineers, rather than on document-based information exchange.”

“the formalized application of modelling to support system requirements, design, analysis, verification and validation activities beginning in the conceptual design phase and continuing throughout development and later life cycle phases. MBSE is part of a long-term trend **toward model-centric approaches** adopted by other engineering disciplines, including mechanical, electrical and software. In particular, MBSE is expected to **replace the document-centric** approach that has been practiced by systems engineers in the past and to influence the future practice of systems engineering by being fully integrated into the definition of systems engineering processes.”

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start [MBSE Wiki] (omgwiki.org)

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ENGINEERING UNDERGRADUATE COURSE

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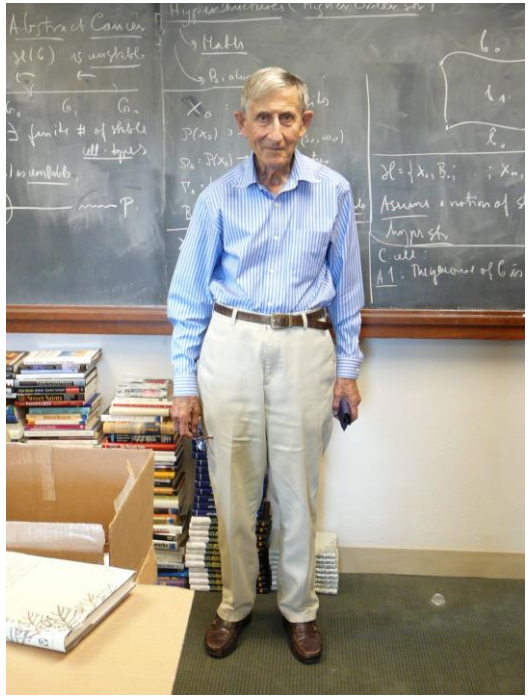
FROM GUILDS

https://en.wikipedia.org/wiki/Food_history#/media/File:Medieval_baker.jpg

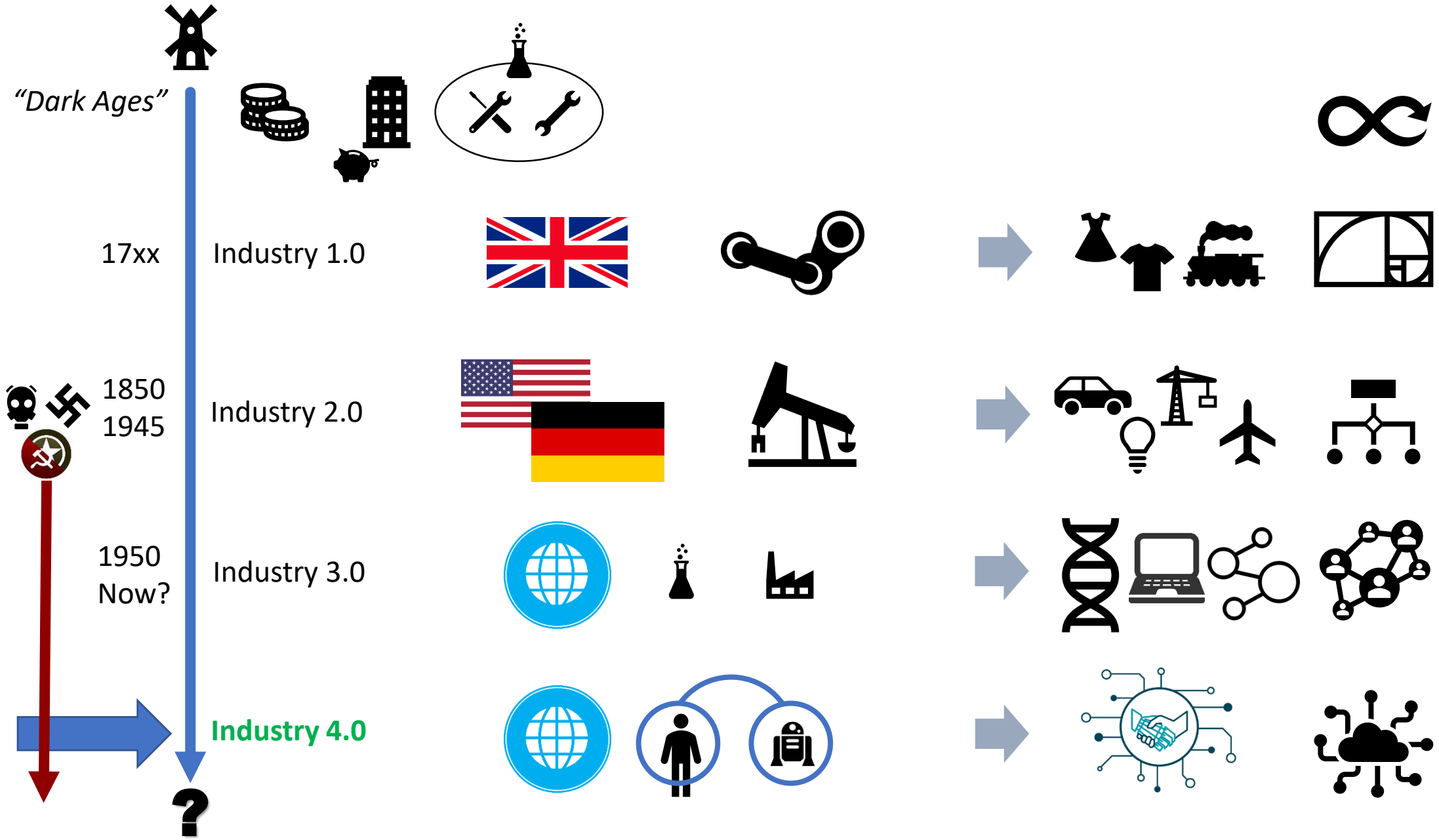
TO ENGINEERING

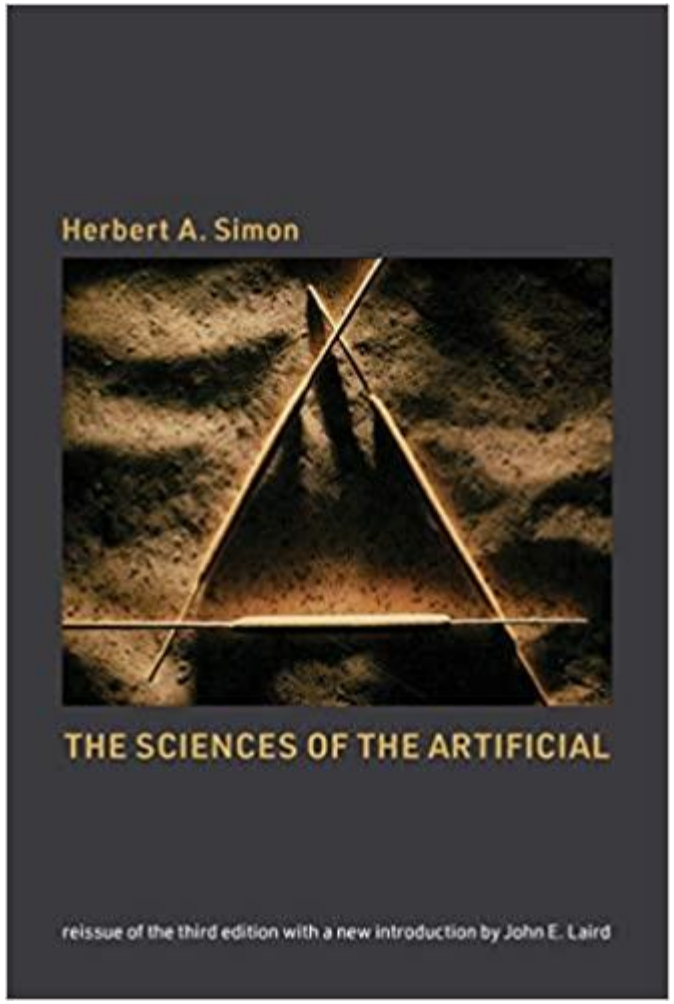
- In **Disturbing the Universe** (Sloan Foundation, 1981), Freeman Dyson wrote:



File:Freeman dyson.jpg - Wikimedia Commons

"I particularly enjoyed being immersed in the ethos of engineering, which is very different from the ethos of science. A good scientist is a person with original ideas. ***A good engineer is a person who makes a design that works with as few original ideas as possible.*** *There are no prima donnas in engineering."*


"Dark Ages"
17xx
Industry 1.0
1850
1945
Industry 2.0
1950
Now?
Industry 3.0
Industry 4.0
?



The Sciences of the Artificial, Reissue of the Third Edition with a New Introduction by John Laird | Amazon.com.br

Creating the Artificial Historically and traditionally, it has been the task of the science disciplines to teach about natural things: how they are and how they work. **It has been the task of engineering schools to teach about artificial things: how to make artifacts that have desired properties and how to design.**

Engineers are not the only professional designers. Everyone designs who devises courses of action aimed at changing existing situations into preferred ones. The intellectual activity that produces material artifacts is no different fundamentally from the one that prescribes remedies for a sick patient or the one that devises a new sales plan for a company or a social welfare policy for a state. Design, so construed, is the core of all professional training; it is the principal mark that distinguishes the professions from the sciences. Schools of engineering, as well as schools of architecture, business, education, law, and medicine, are all centrally concerned with the process of design.

In view of the key role of design in professional activity, it is ironic that in this century the natural sciences almost drove the sciences of the artificial from professional school curricula, a development that peaked about two or three decades after the Second World War. Engineering schools gradually became schools of physics and mathematics; medical schools became schools of biological science; business schools became schools of finite mathematics. The use of adjectives like "applied" concealed, but did not change, the fact. It simply meant that in the professional schools those topics were selected from mathematics and the natural sciences for emphasis which were thought to be most nearly relevant to professional practice. It did not mean that design continued to be taught, as distinguished from analysis

BRAZILIAN COURSES PANORAMA

- Currently there are **three “”””Systems Engineering”””** Graduation Courses.

- Courses that **might have Systems Engineering** through the curriculum: Aeronautics, Naval, Automobile, Airspace, Agricultural, Biomedical and Railway

Instituição - IES	Sigla	Curso	Grau	Modalidade	Índices	Vagas Anuais	Data Início
(367) UNIVERSIDADE ESTADUAL DE MONTES CLAROS	UNIMONTES	(1154906) ENGENHARIA DE SISTEMAS	Bacharelado	Presencial	CC: - CPC: 4(2019) ENADE: 3(2019) IDD: 3(2019)	28	19/02/2011
(575) UNIVERSIDADE FEDERAL DE MINAS GERAIS	UFMG	(5000059) ENGENHARIA DE SISTEMAS	Bacharelado	Presencial	CC: 5(2015) CPC: 4(2017) ENADE: 4(2017) IDD: 3(2017)	50	01/03/2010
(1557) UNIVERSIDADE FUMEC	FUMEC	(1290488) ENGENHARIA DE SISTEMAS	Bacharelado	Presencial	CC: - CPC: - ENADE: - IDD: -	110	Não iniciado
(1666) CENTRO UNIVERSITÁRIO UNIHORIZONTES	-	(1399054) ENGENHARIA DE SISTEMAS	Bacharelado	Presencial	CC: - CPC: - ENADE: - IDD: -	200	Não iniciado
(3649) CENTRO UNIVERSITÁRIO CIDADE VERDE Adesão ao PROIES: Lei 12.688/2012	UNIFCV	(1541953) ENGENHARIA DE SISTEMAS	Bacharelado	Presencial	CC: - CPC: - ENADE: - IDD: -	100	Não iniciado
(3649) CENTRO UNIVERSITÁRIO CIDADE VERDE Adesão ao PROIES: Lei 12.688/2012	UNIFCV	(1541954) ENGENHARIA DE SISTEMAS	Bacharelado	A Distância	CC: - CPC: - ENADE: - IDD: -	500	Não iniciado
(546) PONTIFÍCIA UNIVERSIDADE CATÓLICA DE SÃO PAULO	PUCSP	(1550898) ENGENHARIA DE SISTEMAS CIBER FÍSICOS	Bacharelado	Presencial	CC: - CPC: - ENADE: - IDD: -	25	01/03/2021

[e-MEC - Sistema de Regulação do Ensino Superior]

[Cursos e instituições - Ministério da Educação (mec.gov.br)]

FROM THIS CONTEXT RESEARCH

- There are a lot of so called “Systems Engineering”.
- .... but the majority are not Systems Engineering... they lecture about engineered systems

BEFORE GOING INTO THE EXPERIENCES...

- A disclaimer about our stakeholders:
  - Highly **hard skilled** students.
  - **Competitive** groups.
  - Shared time with **{really harder} ^mol** hard-disciplines.
  - Ages: **16-26**.
  - We have students from a **myriad of backgrounds and cultures** (Brazil is quite big).

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ITA EXPERIENCES

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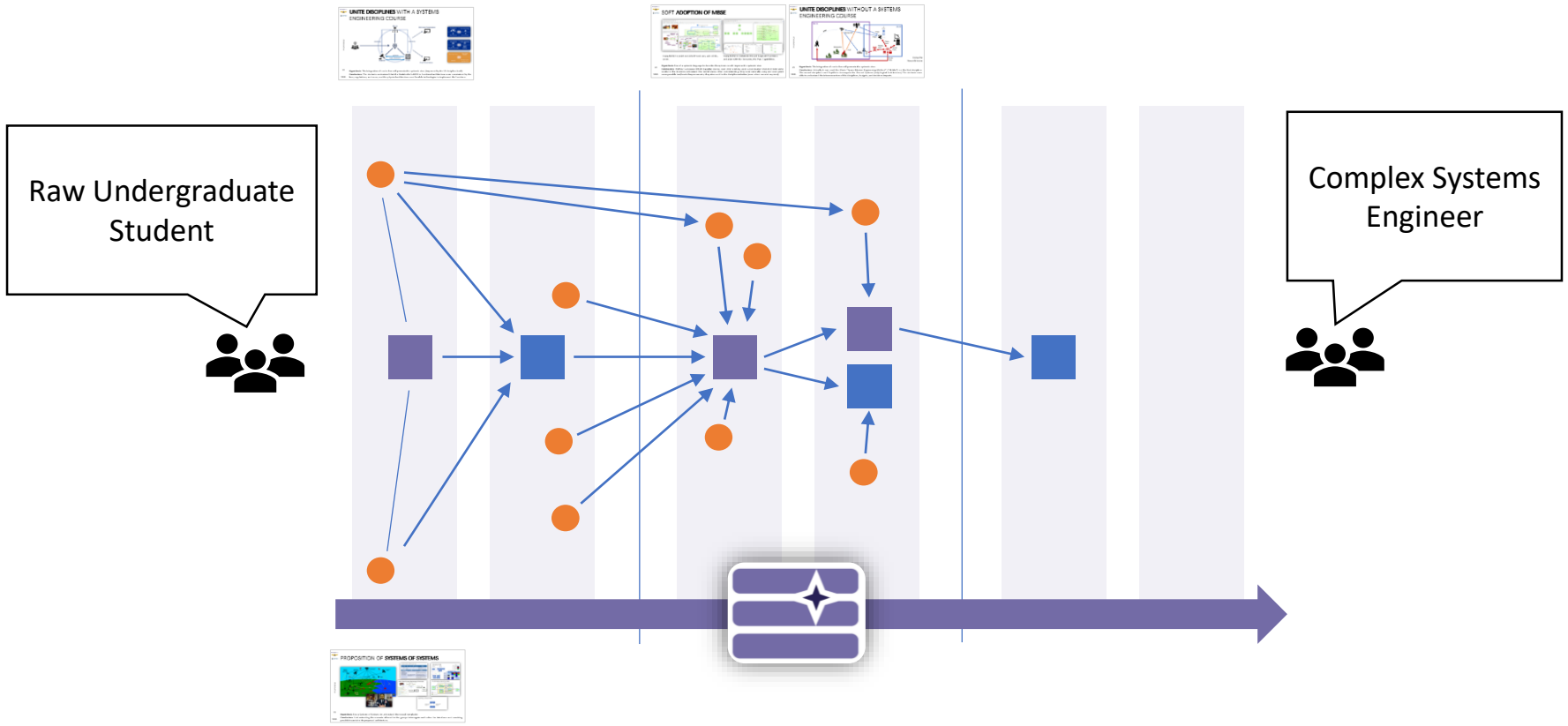
CORE PROBLEM/PROJECT ALONG THE YEARS



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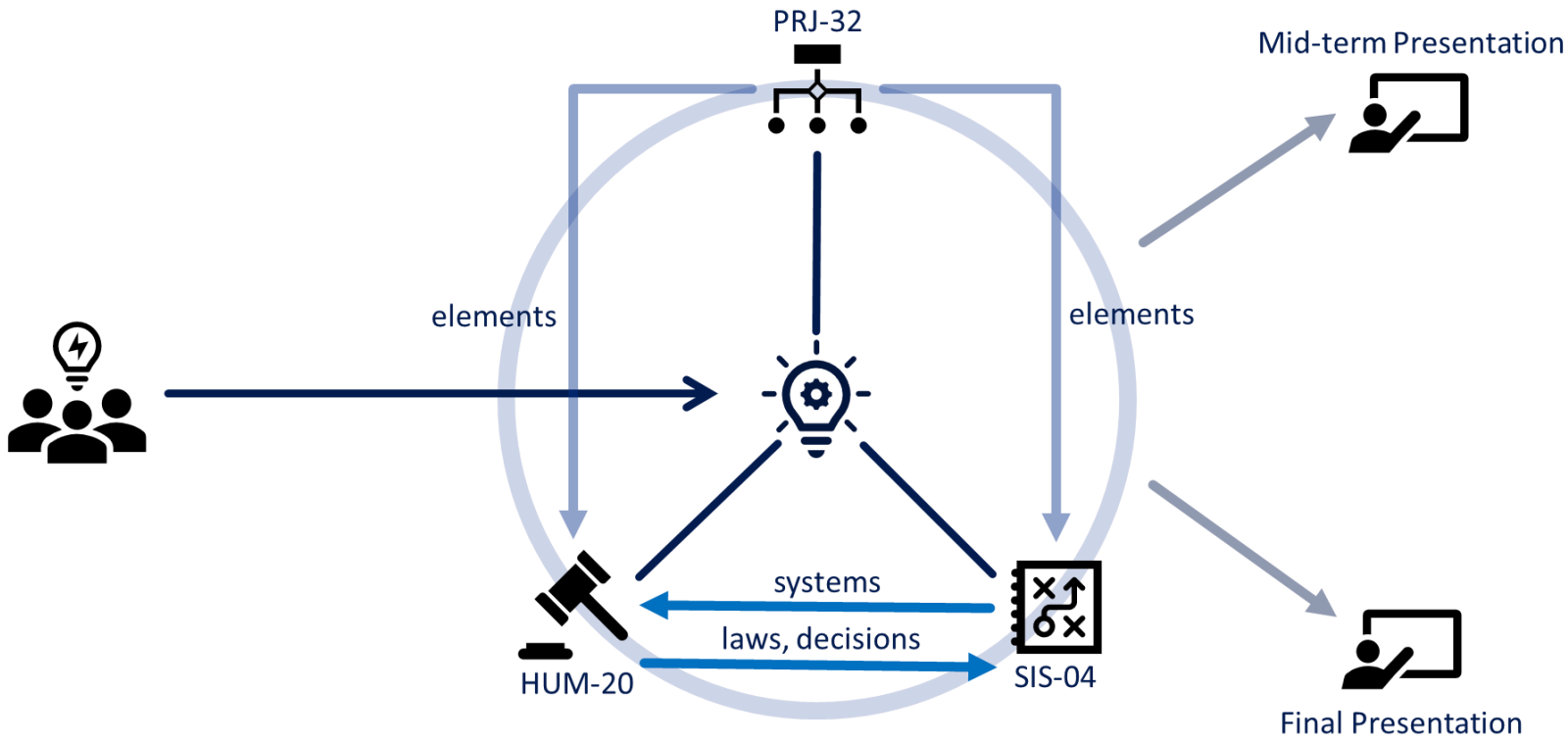
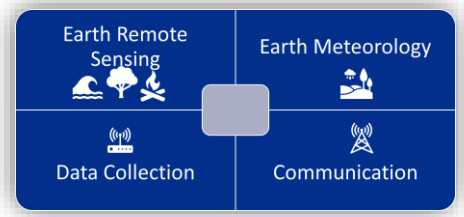
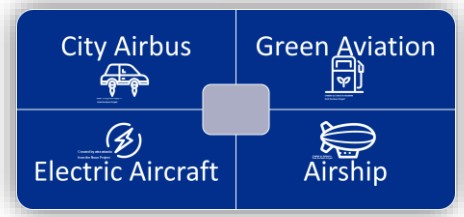
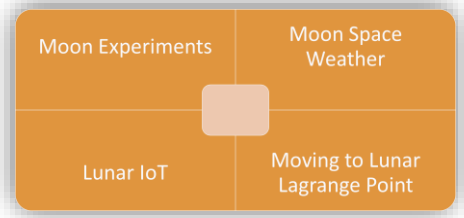
UNITE DISCIPLINES WITH A SYSTEMS ENGINEERING COURSE



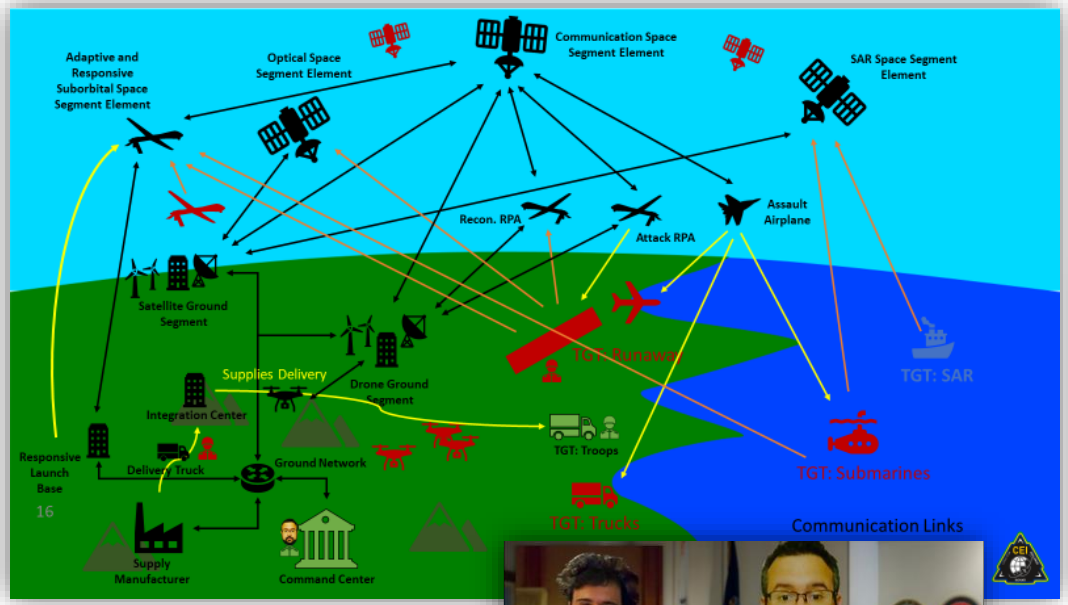


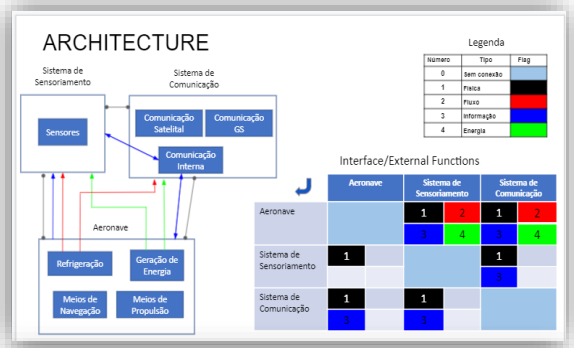


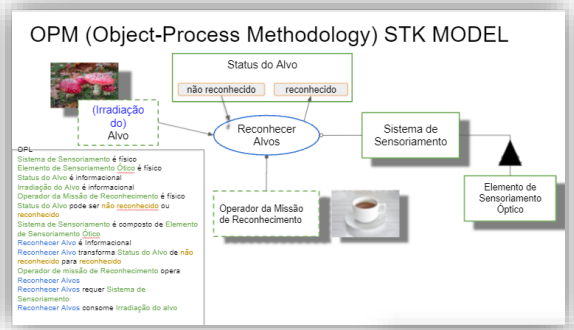


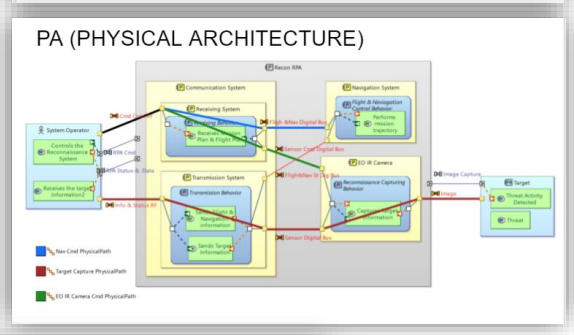
Hypothesis: The Integration of curriculum will promote the systemic view (improved by the SE discipline itself)
Conclusions: The students understood that the Stakeholder's-NGO to functional architecture were constrained by the laws, regulations, and so on; and the physical architecture used feasible technologies to implement the functions.

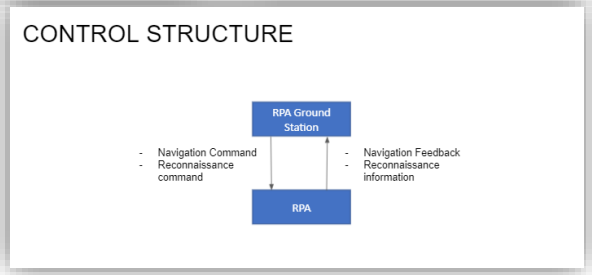
PROPOSITION OF **SYSTEMS OF SYSTEMS**







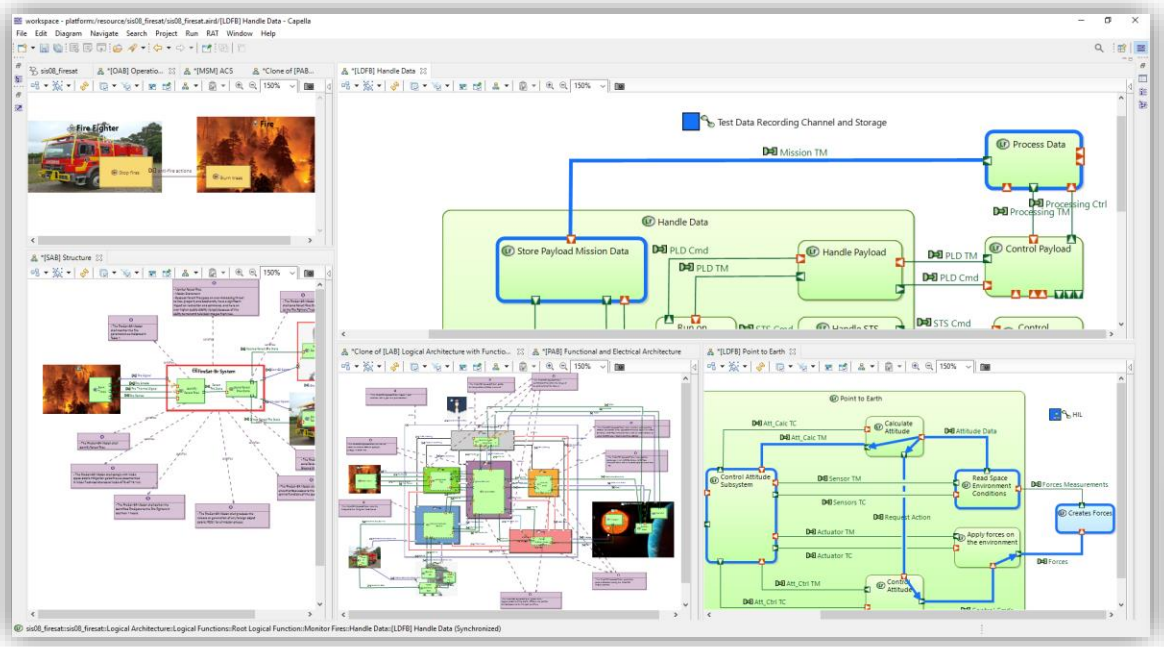




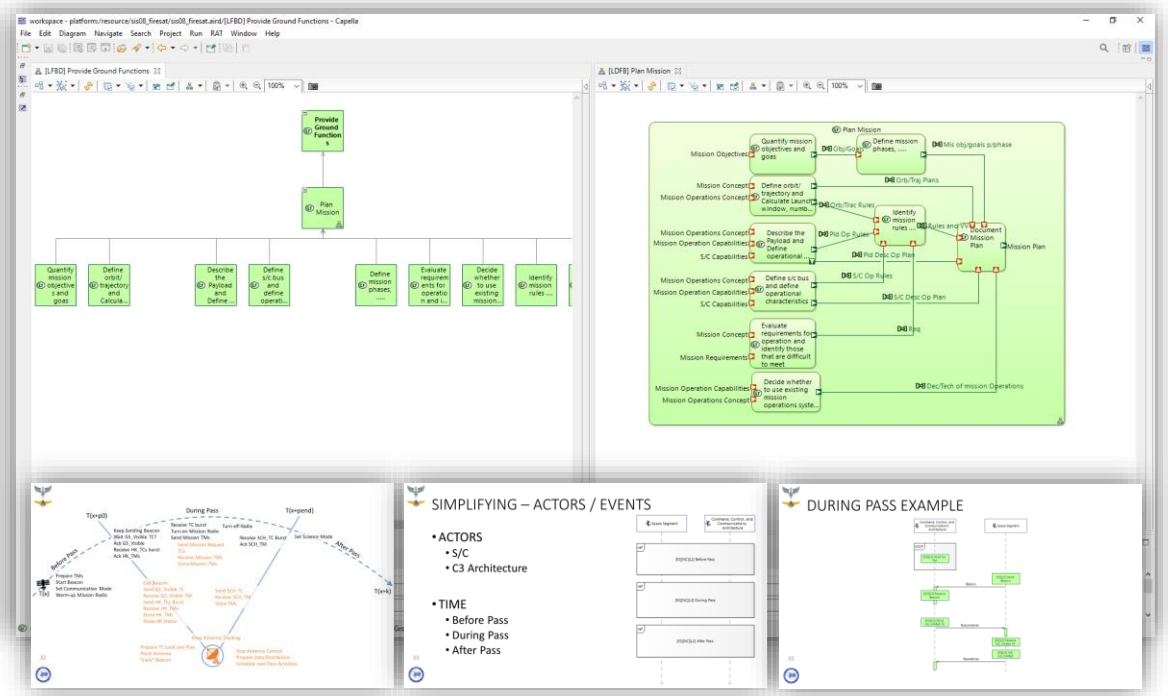
Hypothesis: Use a Systems of Systems to understand the overall complexity

Conclusions: Understanding the scenario allowed to the groups interrogate each other for interfaces and searching possible hazards to the proposed architecture.

SOFT **ADOPTION OF MBSE**



Using MBSE to point out AIVV Procedures, add xGSEs, so on.

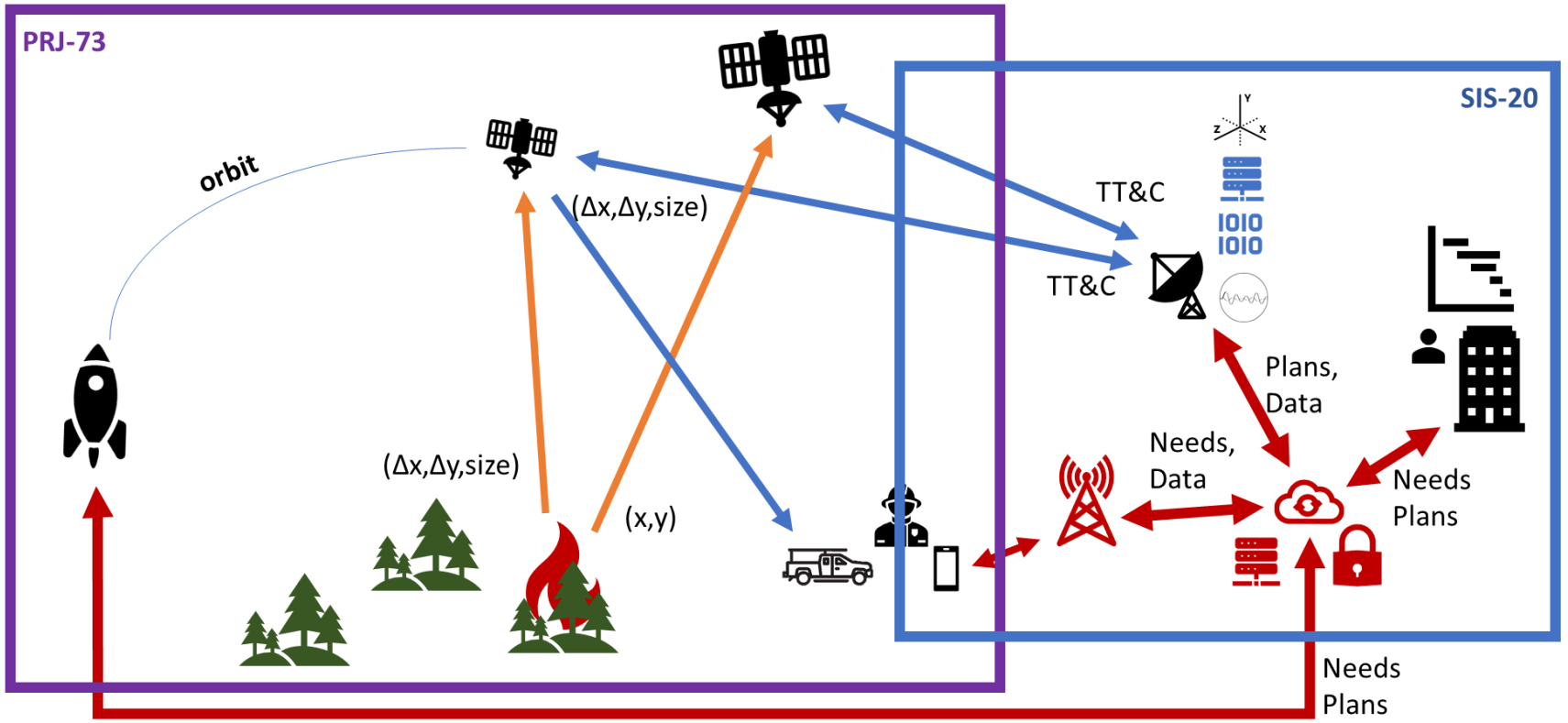


Using MBSE to distribute Ground Segment Functions and plan with the Scenarios, the Pass Capabilities.

Hypothesis: Use of a systemic language to describe the systems would improve the systemic view

Conclusions: Without a preview MBSE (Capella) course, even only working upon a pre-created model, it took some weeks to the students understand the model views. After understanding, they were naturally using and even point some possible tool/model improvements, they also use it to the discipline activities (even when was not required).

UNITE DISCIPLINES WITHOUT A SYSTEMS ENGINEERING COURSE

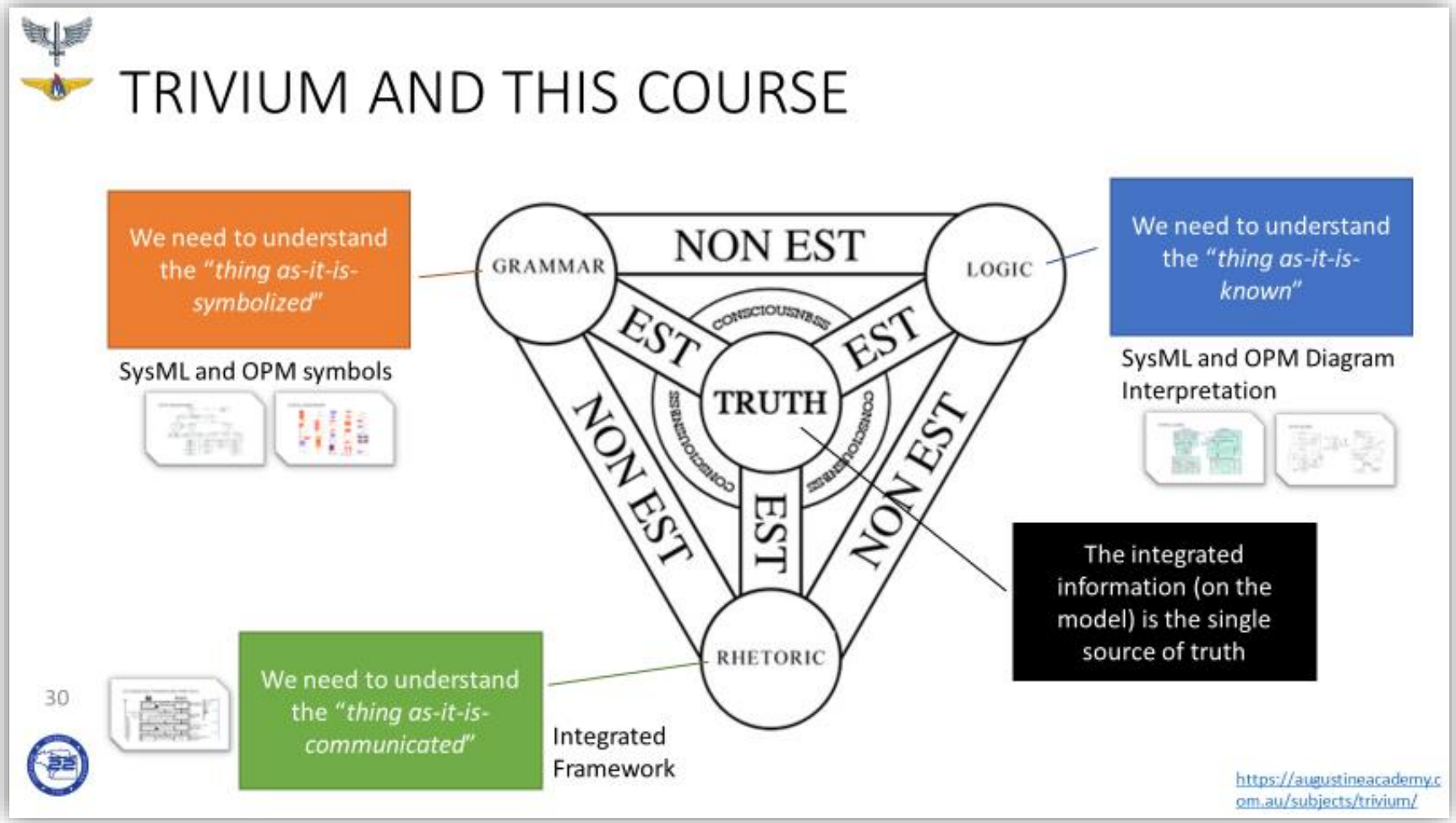


Using the Firesat Mission

Hypothesis: The Integration of curriculum will promote the systemic view.

Conclusions: Actually it was used the Wertz "Space Mission Engineering Method" ("SE-Like") on the first discipline. The second discipline used Capella to decompose the Ground Systems (only Logical Architecture). The students were able to understand the interconnection of the disciplines, budgets, and decisions impacts.

LECTURING MBSE AS A **LANGUAGE** (ON GOING)



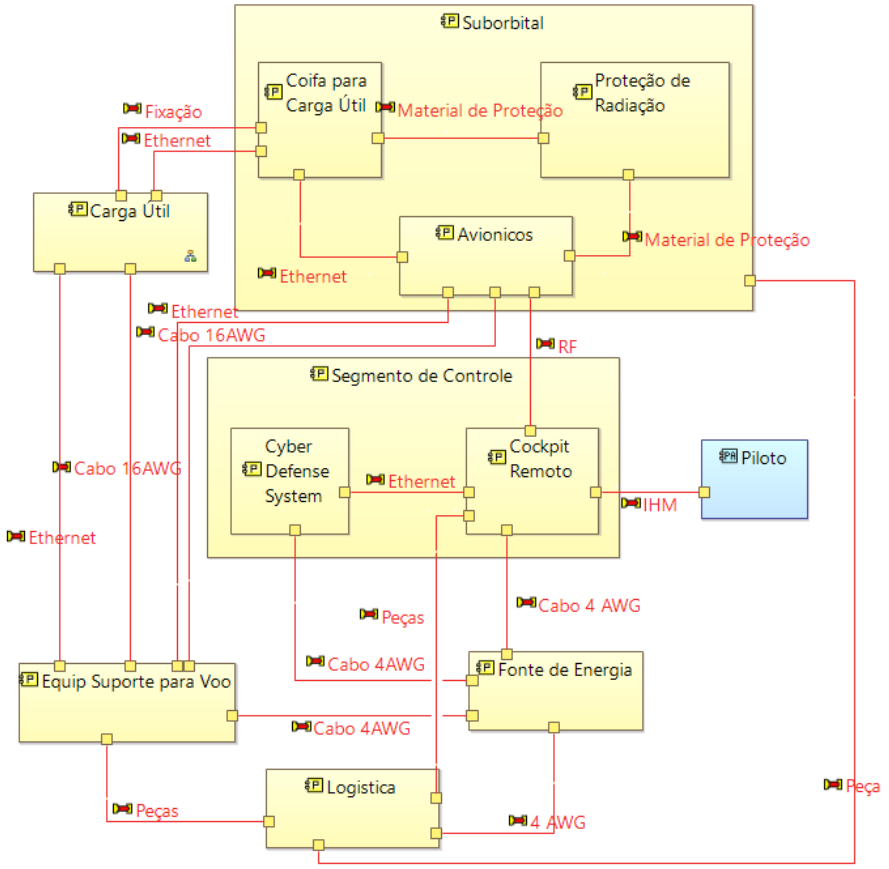
Hypothesis: Learn MBSE as the lower Liberal Arts (Grammar/Logic/Rhetoric) will improve learning speed

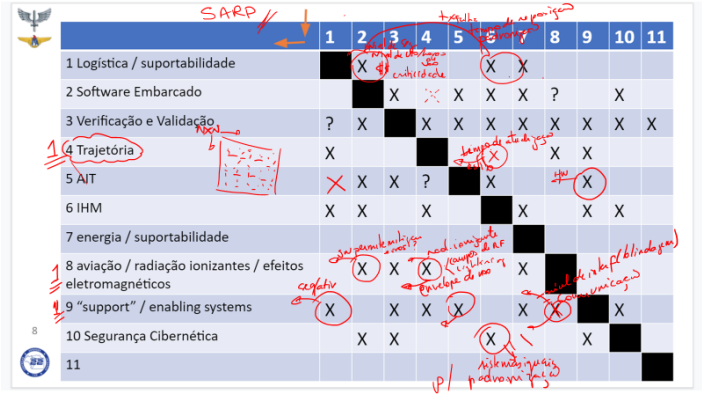
Conclusions: on going

(c) Constraints

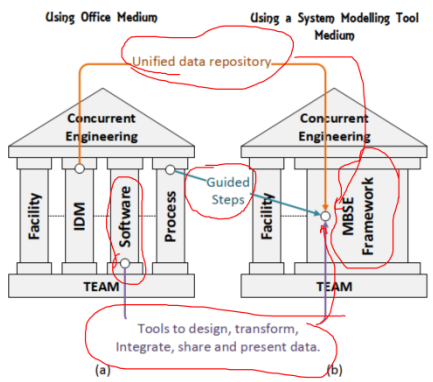
- Finishing to collect data to publish.

USING MBSE TO **CO-ENGINEERING** (ON GOING)



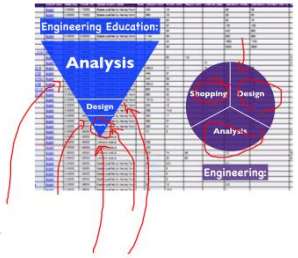


	1	2	3	4	5	6	7	8	9	10	11
1 Logística / suportabilidade		X				X	X				
2 Software Embarcado			X	X	X	X	X	?		X	
3 Verificação e Validação	?	X		X	X	X	X	X	X	X	X
4 Trajetória	X							X	X		
5 AIT	X	X	X	?		X			X		
6 IHM	X	X		X			X		X	X	
7 energia / suportabilidade											
8 aviação / radiação ionizantes / efeitos eletromagnéticos		X	X	X			X				
9 "support" / enabling systems	X		X	X	X		X	X		X	
10 Segurança Cibernética		X	X			X			X		
11											



ACTIONS

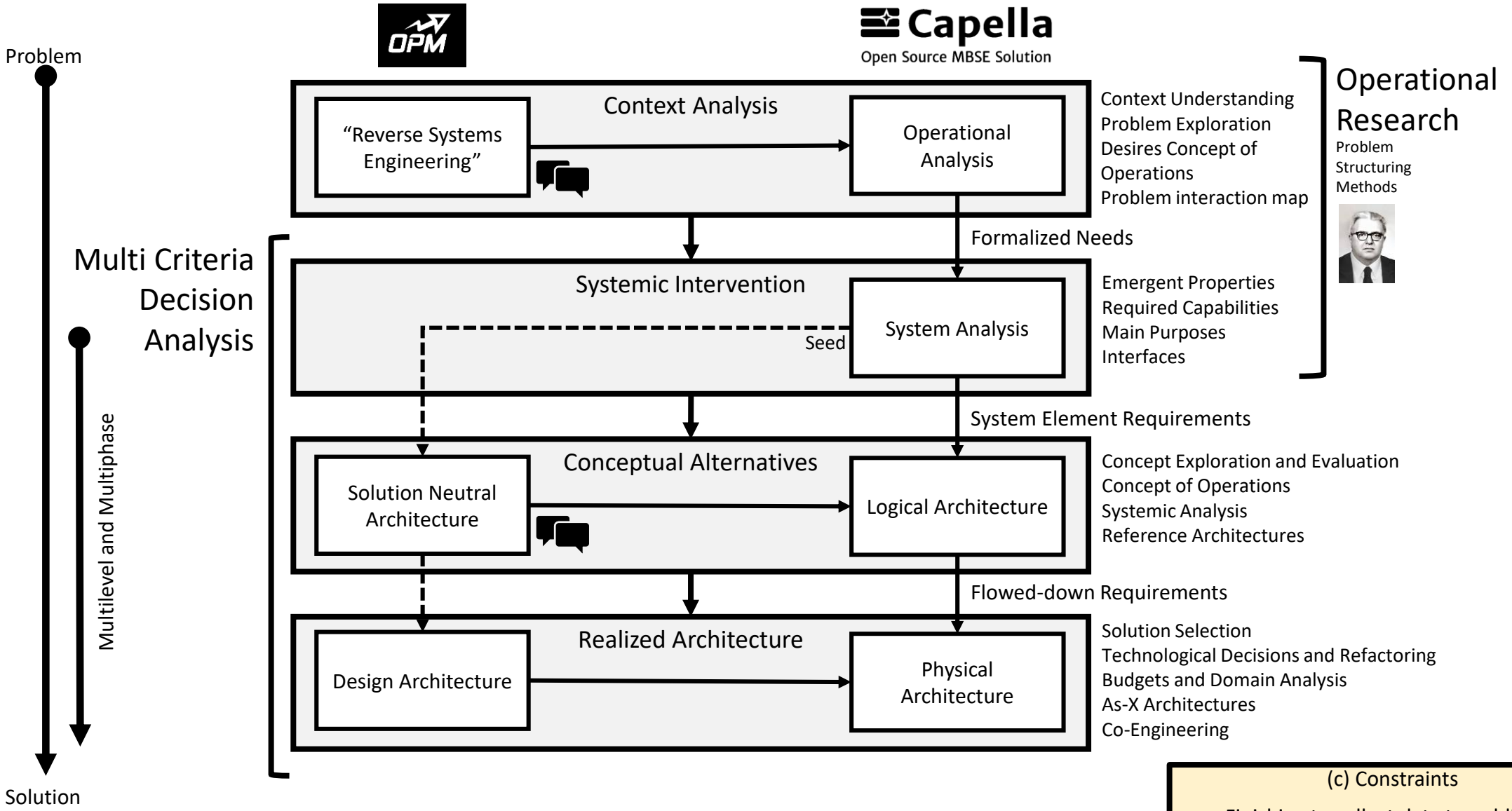
- Shop
  - It has equal importance than Design
- Integrate
  - Repositories of modelled-mapped SS/ Equip/ Components
- Deliver
  - Sets of viable solutions that might fit into the mission.



Hypothesis: Use MBSE will improve the understanding of the interface and information flow of CE

Conclusions: on going

IN TERMS OF **SE RESEARCH**: MMMF (MULTI-METHODOLOGY MBSE FRAMEWORK)



(c) Constraints

- Finishing to collect data to publish.

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UFSM EXPERIENCES

SOME CONTEXT...

MINISTÉRIO DA EDUCAÇÃO
CONSELHO NACIONAL DE EDUCAÇÃO
CÂMARA DE EDUCAÇÃO SUPERIOR

RESOLUÇÃO Nº 2, DE 24 DE ABRIL DE 2019 (*)

Institui as Diretrizes Curriculares Nacionais do Curso de Graduação em Engenharia.

O Presidente da Câmara de Educação Superior do Conselho Nacional de Educação, no uso de suas atribuições legais, com fundamento no art. 9º, § 2º, alínea "c", da Lei nº 4.024, de 20 de dezembro de 1961, com a redação dada pela Lei nº 9.131, de 25 de novembro de 1995, e nas Diretrizes Curriculares Nacionais (DCNs), elaboradas pela Comissão das Diretrizes Curriculares Nacionais do Curso de Graduação em Engenharia (DCNs de Engenharia), propostas ao CNE/CES pela Secretaria de Regulação e Supervisão da Educação Superior do Ministério da Educação (SERES/MEC), e com fundamento no Parecer CNE/CES nº 1/2019, homologado por Despacho do Senhor Ministro de Estado da Educação, publicado no DOU de 23 de abril de 2019, resolve:

- New National curriculum guidelines for Engineering education (DCNs)
- Objectives: "to meet future demands on **more and better engineers**"
- Main Characteristics: Competency-based learning (tech/pers./interpersonal skills), **focus on practice**, **active learning**, **interdisciplinarity**, and greater flexibility in the curriculum constitution

Art. 3º O perfil do egresso do curso de graduação em Engenharia deve compreender, entre outras, as seguintes características:

I – ter visão holística e humanista, ser crítico, reflexivo, criativo, cooperativo e ético e com forte formação técnica;

II – estar apto a pesquisar, desenvolver, adaptar e utilizar novas tecnologias, com atuação inovadora e empreendedora;

III – ser capaz de reconhecer as necessidades dos usuários, formular e analisar e resolver, de forma criativa, os problemas de Engenharia;

IV – adotar perspectivas multidisciplinares e transdisciplinares em sua prática;

V – considerar os aspectos globais, políticos, econômicos, sociais, ambientais, culturais e de segurança e saúde no trabalho;

VI – atuar com isenção e comprometido com a responsabilidade social e com o desenvolvimento sustentável.

To have Holistic thinking

To be able to identify stakeholders needs

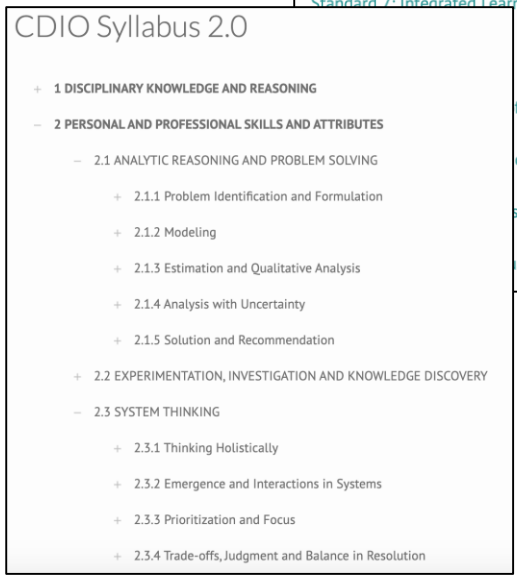
To adopt multi/trans-disciplinary approaches

SOME (MORE) CONTEXT...

- CDIO – Conceive Design Implement and Operate
- International Initiative, proposes an Educational framework focused on CDIO real-world systems
- Based on the principle that **system lifecycle development is the context for engineering education**, in which technical knowledge and other skills (personal/interpersonal) are taught, practiced and learned.
- CDIO Syllabus: skills for undergraduate engineering education. Disciplinary fundamentals, personal, interpersonal and system development skills
- CDIO Standards: principles to implement CDIO in an engineering programme

UFSM's CDIO application approved on Oct/2020

cdio
CONCEIVE DESIGN IMPLEMENT OPERATE™

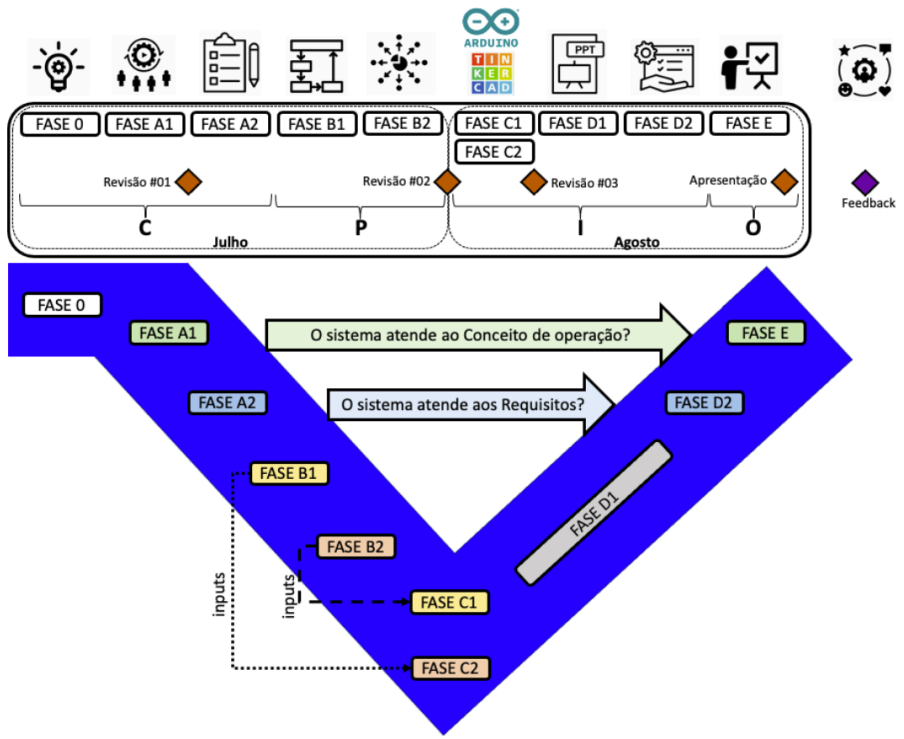


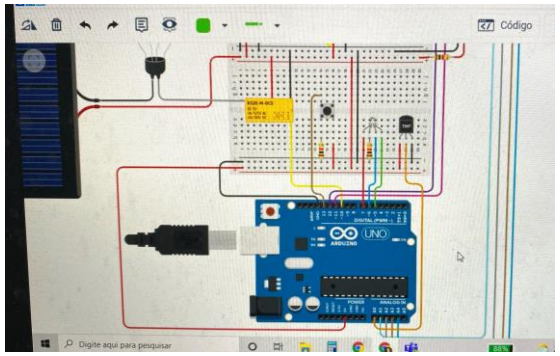
UFSM CURRENT EXPERIENCES WITH CAPELLA

- Program Courses
  - Introduction to Aerospace Engineering

- Interdisciplinary Project
- SE basic concepts
- Prepares freshman for CDIO and SE
- Project-based Learning (simulated CanSat)

like → ARCADIA

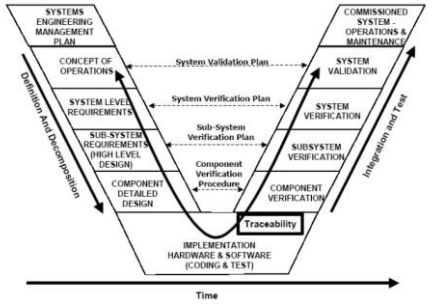




UFSM CURRENT EXPERIENCES WITH CAPELLA

- Program Courses
  - Fundamentals of Systems Engineering

- Project Based Learning
- SE and MBSE concepts (theory)



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- Outcomes:

Capella™

YouTube

GPESC Channel

Capella Modelling (practice)

Capella learning through students course (CDIO)

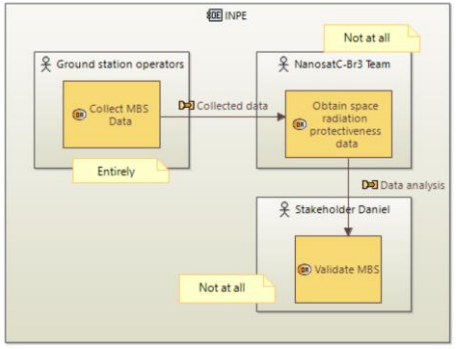
UFSM CURRENT EXPERIENCES WITH CAPELLA

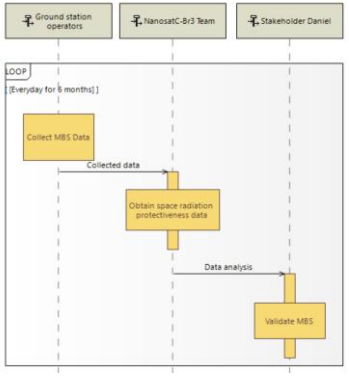
- Program Courses
  - Space Systems Concept Design

Space System concepts → Capella™

CubeSat Concept Design

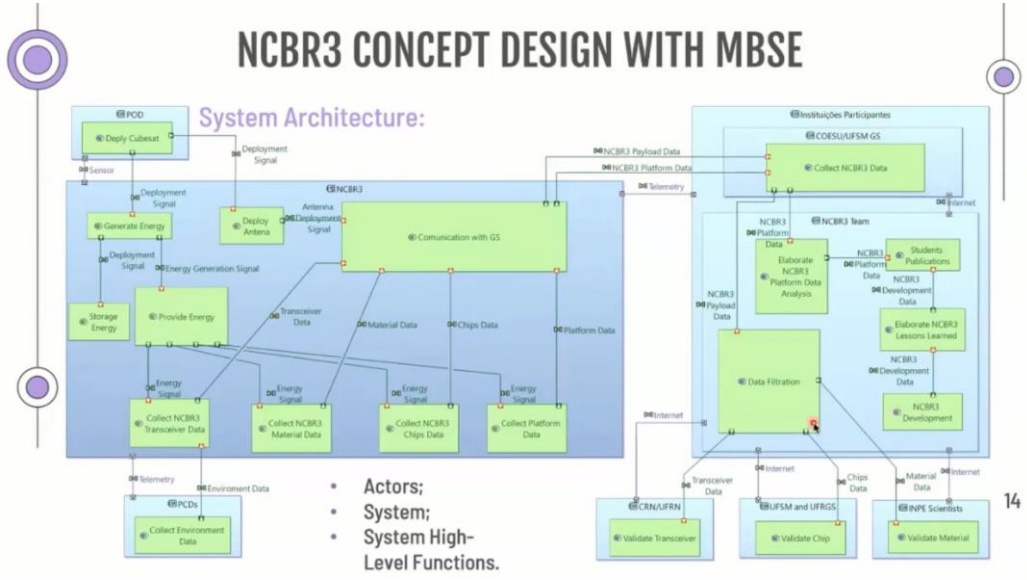
- Project Based Learning
- Some SE concepts and tools (not the focus)
- Capella as a design tool for Course Project
- Modelling is self-taught (by senior undergrads)





UFSM CURRENT EXPERIENCES WITH CAPELLA

- Nanossatellite Project
  - NanoSatC-BR3 3U CubeSat



- INPE and UFSM cooperation Program
- Beginning the transition to model-centric
- Defining Mission and preparing for MDR (2022)
- Modelling made by Aerospace engineering undergrads

Capella™ YouTube

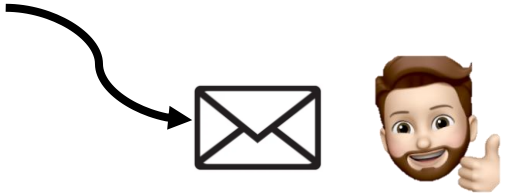
UFSM CURRENT EXPERIENCES WITH CAPELLA

- CDIO Projects
  - MBSE Course (pt-br)

- Intro. to Systems Engineering
- Intro. to MBSE and Arcadia method
- Capella Modelling Practical Exercises

- CDIO Projects = 4 Program Courses (4 Semesters)
- Teams of 2~5 students
- Focus on Practical Problems

- To promote SE and MBSE for Brazilian Engineering Programs
- Theory and Practice Course for absolute begginers
- Intermediate Course in progress..
- Open to receive needs by Capella Community/industry for new CDIO Projects

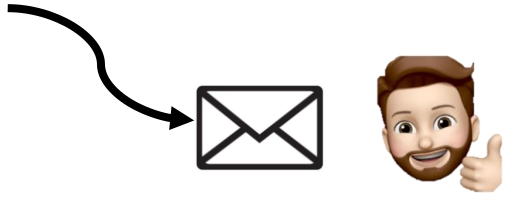


UFSM CURRENT EXPERIENCES WITH CAPELLA

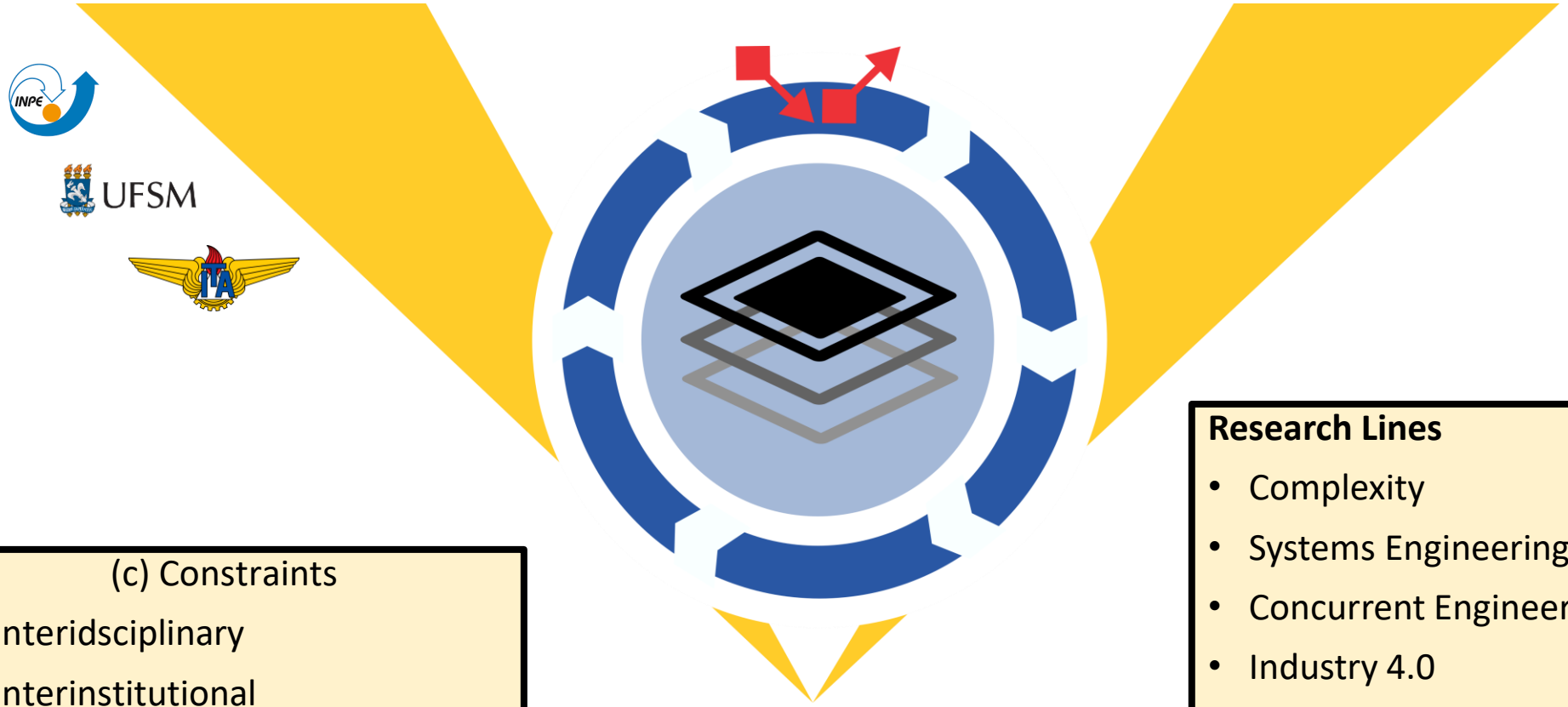
- Final Course Thesis
  - MBSE x production line (MBPLE)

Thesis = 2 Semesters Projects
Research or development Projects
Usually 1 student

- Research objective: How MBSE may support product-line improvements?
- Using a real industry (mechanical engineering) case as use case application
- Thesis presentation scheduled for middle February 2022 (open access)
- (also) Open to receive needs by Capella Community/industry for new Thesis Projects



SYSTEMS ENGINEERING AND COMPLEXITY RESEARCH GROUP



(c) Constraints

- Interidsciplinary
- Interinstitutional
- Integrate SE Researchers in different Projects
- To Promote SE in Brazilian Academic field

Research Lines

- Complexity
- Systems Engineering / MBSE
- Concurrent Engineering
- Industry 4.0
- Engineering Teaching Methodologies
- Nanosatellites
- Defense and Security Systems

SESSION ENDING

5min

FINAL THOUGHTS

- The courses have been using **several approaches**.
  - ITA and UFSM has experimented some.
- Each College/University have its own DNA and **must** use its own approaches

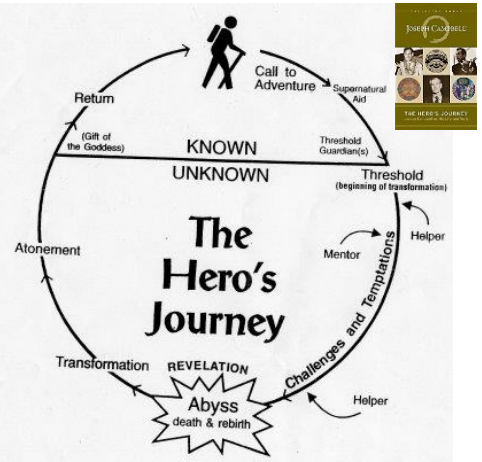
FINAL THOUGHTS

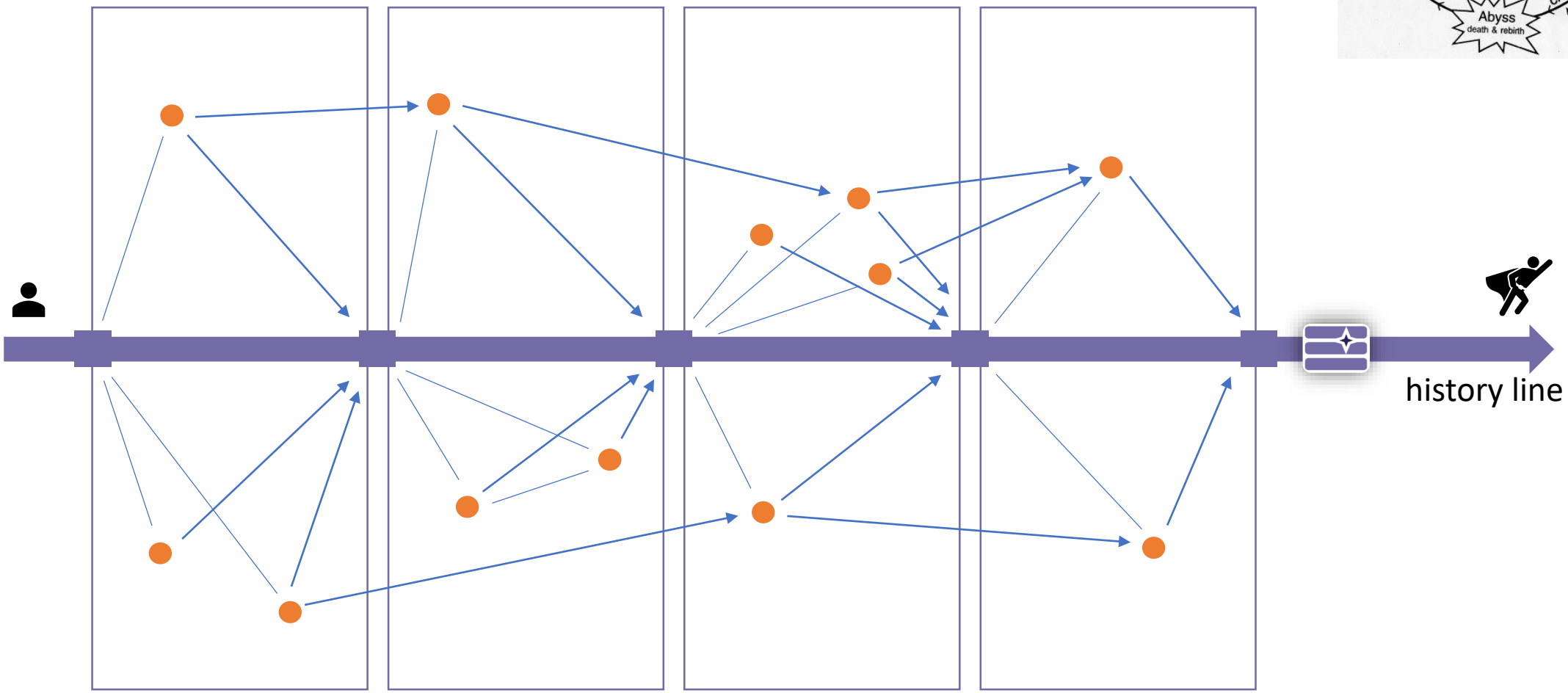
- A couple take-outs from the courses experiences
  - Add systems ** disciplines
    - Add **Soft Operational Research and/or Systems Engineering**
    - Add **Systems Thinking**
  - **Project/problem**-based learning
  - Adopt a **Transversal Project**
  - Use **CDIO** (or similar approach) and integrate the curriculum
  - “Legacy SE” or MBSE
  - Consider the selection from **tenet->tools**
  - **Gamification**
  - SE Laboratory (**check the University of Michigan Initiative**)

FINAL THOUGHTS

- There is a **HUGE gap on Brazilian education** regarding the systemic competences.
- The new reality requires those **skills**.
  - We are making an **easy to follow steps** to educators.
  - We are, linguistically, adapting **Arcadia/Capella** to Portuguese.
    - *(INCOSE/Portuguese Speaking Capella Community is invited to contribute)*
    - Capella should be **translatable to several languages**!!!! ☺
- You are all invited to **visit our labs** (at ITA and at UFSM)
  - We can guarantee a lot of good stories, laughs, MBSE, CE, and coffee.

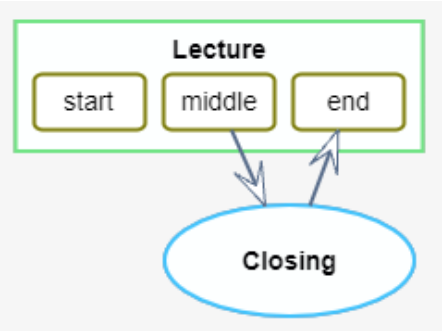
EVERY COURSE IS A HISTORY OF DISCIPLINES'S INTEGRATIONS





SESSION ENDING

2021



Questions & (maybe) Answers

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ORDEM E PROGRESSO