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EXPERIENCE FROM INTRODUCING SYSTEMS ENGINEERING IN AN ACADEMIC ENVIRONMENT USING AN INDUSTRY TRAINING COURSE

Erik Herzog, Åsa Nordling-Larsson, Jad El-Khoury, Martin Törngren

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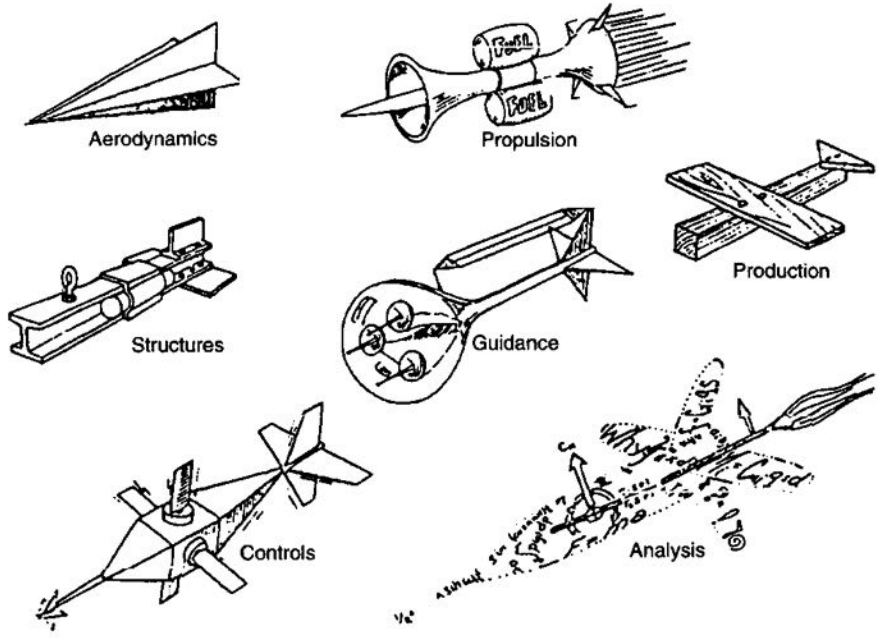
AGENDA

- What is a SAAB?
- What is the challenge in development of complex systems?
- Student competence mismatch
  - From the SAAB perspective
- State of the Swedish educational system
- Opportunities for introducing Systems Engineering in the Swedish educational system
- Experience from an initial experiment at KTH
- Conclusions

SAAB - THE DOMAIN

A LOOK AT REALITY

- Formal models, simulations results, proofs matter little if we aren't in agreement on what we are building
- Safety analyses, no matter how elaborate, of a system we do not intend to build has little value
- Parts designed and built, but not compatible in the intended configuration has little utility even though they may be fully verified
- The merit of the design solution is low if it not sufficiently safe or if it can't be maintained
- **Optimising the whole – not the parts**
  - **Mastering development is not about improving domain engineering methods but methodology for understanding and communicating system design**

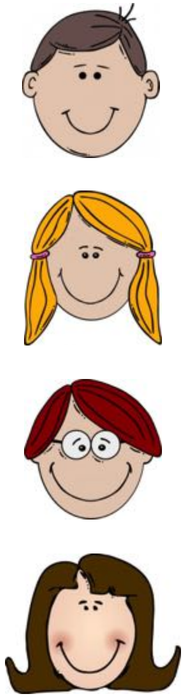


THE SITUATION FACING OUR NEW RECRUITS

Lifecycle management
Verification & Validation of heterogeneous systems
System of systems
Requirements management
Systems thinking
System integration
Systems architecting and design
Reliability, Availability & Maintainability
Systems engineering
System safety
Operations analysis
System modelling & simulation
Multi-disciplinary trade studies
Configuration management
Human system integration
Development of heterogeneous systems

Computer Science	Machine design	Electronics engineering	Engineering management	Material sciences	…	…	…	Logistics	Aeronautical engineering

Ecomics, HR, Law, …



SWEDEN AND THE SWEDISH EDUCATIONAL SYSTEM

- Strong and diverse economy
  - Leader in innovation
- Educational system is state financed
- No financial costs for enrollment
  - Subsidiced student loans
- Traditional universities in terms of faculties and institutions
- Strong collaboration between state, industry and academia
  - Triple helix
- No Systems Engineering educational tradition
  - Even though there is a strong systems based industry base
- Students generally have the opportunity to select from multiple elective courses
  - But these are generally discipline specific

TRADITIONAL ACADEMIA – INDUSTRY COMPARISON

Academia

- Builds knowledge and professionals
- Academics are rewarded for advancements in their own home discipline
  - Teaching is a low priority for making a successful career
- The challenge is in the complexity in the discipline
- Staff is eminently qualified in the their own respective disciplines

Industry

- Builds products and services
- Industry is rewarded for successful products
  - Increasingly heterogeneous
- The challenge is found in integrating contributions from multiple disciplines
  - Need to create multi-disciplinary awareness
- Staff need act to bridge across disciplines

CONTINUOUS COMPETENCE DEVELOPMENT – AT SAAB

- Internal training programs
- General Systems Engineering courses
  - 6h introduction
  - 20h basic course
  - Systems Engineering and Project Management introduction
  - INCOSE CSEP preparation courses
    - 20 students/year
  - Study circles
- Dedicated courses in
  - Safety
  - ILS
  - Architecture
  - Configuration management

Can such an introduction be valuable to students?

"To enhance the ability of engineering education to meet future societal needs by increasing the use of relevant Systems Engineering Knowledge, Skills and Attitudes (SE-KSA) in the university education of ALL engineers"
(Adcock, R., 2017 INCOSE International Workshop Townhall)

IDEA AND EXECUTION

- Test whether the standard SAAB Systems Engineering introduction course will make sense to senior engineering students
- Minimal modification to course contents
  - SAAB specific details removed
- Course given at the Mechatronics Master's program at KTH
  - Spring term, year 4
- Given for 60 students over three days
  - Non-consequtive
- An opportunity to communicate industrial challenges to students and faculty

THE SETUP

Engineering Design Programme 2017-19
Mechatronics Track

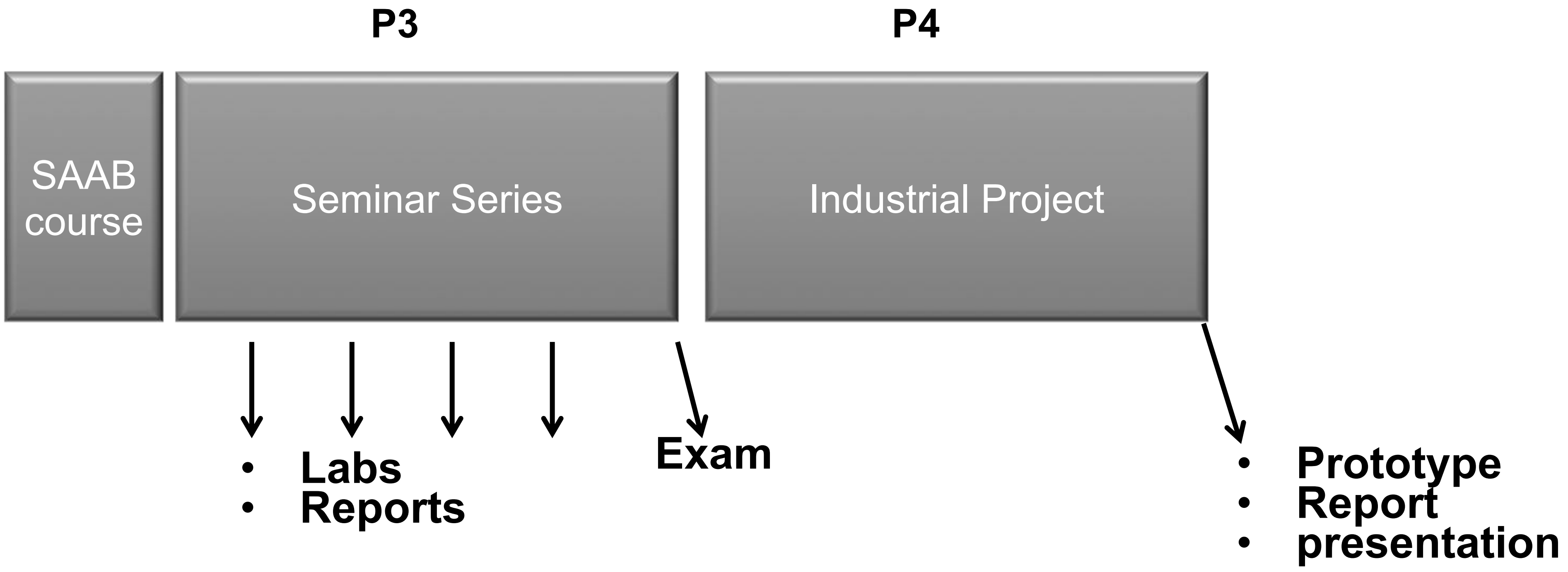
<table>
<tr><th colspan="4">Year 1 (60 hp credits)</th><th colspan="4">Year 2 (60 hp credits)</th></tr>
<tr><th colspan="2">Fall 2017</th><th colspan="2">Spring 2018</th><th colspan="2">Fall 2018</th><th colspan="2">Spring 2019</th></tr>
<tr><th>P1</th><th>P2</th><th>P3</th><th>P4</th><th>P1</th><th>P2</th><th>P3</th><th>P4</th></tr>
<tr><td>MF2095
C Programming for Embedded Systems (3hp)</td><td>MF2042
Embedded Systems I (6hp)</td><td colspan="2">free electives
(6hp)</td><td colspan="2">MF2071 Research Methodology in Mechatronics (4.5hp)</td><td colspan="2" rowspan="3">Master thesis project in Mechatronics (30hp)

MF214X
(CivIng students only)
MF224X
(MSc students only)</td></tr>
<tr><td>MF2030
Mechatronics Basic course (6hp)</td><td rowspan="2">free electives
(9hp)</td><td>MF2007
Dynamics and Motion Control (9hp)</td><td>MF2044
Embedded Systems II (6hp)</td><td colspan="2">free electives
(10.5hp)</td></tr>
<tr><td>MF2043
Robust Mechatronics (6hp)</td><td colspan="2">MF2058 Mechatronics Advanced Course part 1 (9hp)</td><td colspan="2">MF2059 Mechatronics Advanced Course part 2 (15hp)
OR
MF2091 Engineering Design Research Project (15hp)</td></tr>
</table>

Capstone course

Designed to allow students to show that they can apply acquited knowledge on real projects

MF2058 MECHATRONICS ADVANCED COURSE, PART I



SAAB COURSE SETUP

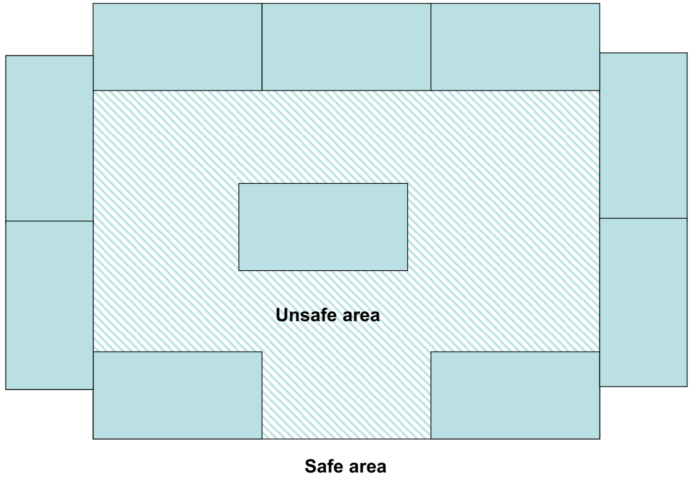
	Day 1	Day 2	Day 3
9:00	Introduction	Architecture properties & principles	Integration Driven Development
12:00	Systems Engineering – Process and lifecycle	ILS	Verification & Validation
13:00	Systems properties & trade-offs	Requirements & Design modeling	Practical work – up to SDR
	Systems safety	Practical work – up to CER	
17:00	Practical work – up to SPR		

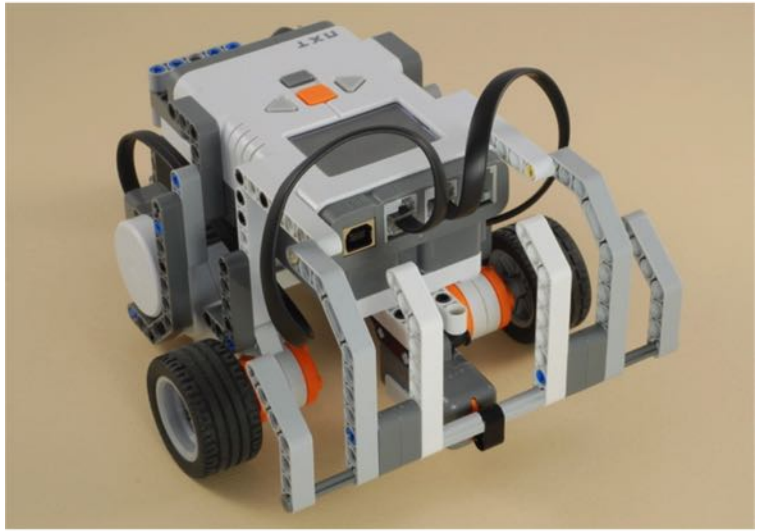
Course objectives

- Multi-domain example
    - Time pressure
- Process
- Importance of Planning
    - Follow the plan
- Non-functional properties
    - Safety!

THE PRACTICAL PART

- Extracting valuable objects from unsafe building
- Autonomous vehicle, must not move the walls of the building
  - Safety is an issue here
- Based on LEGO Mindstorms
- Reliability information for all LEGO sensors have been produced
- The task in to exercise the Engineering process
  - Requirements
  - Design
  - Integration
  - Verification and Validation
  - Technical reviews

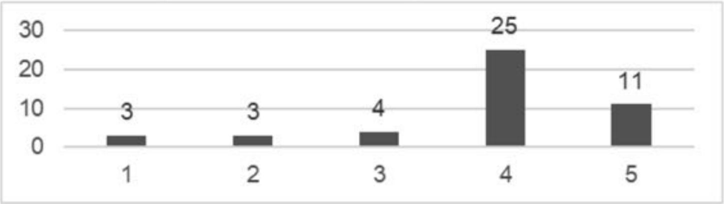




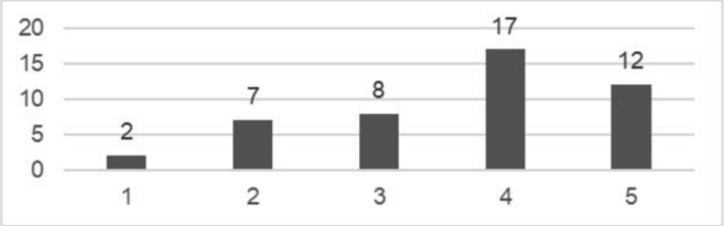
EVALUATION 2017

- Generally positive feedback
- First encounter for students for topics like
  - Systems Engineering
  - Safety
  - Reliability, Availability, Maintainability
  - Integration
  - Verification and Validation
- Observing the students
  - Used to receive well posed problems – and solve them
  - Unfamiliar to work to understand and scope the problem
  - Difficulty in understanding the importance of non-functional requirements
- Once the challenges was understood we saw an extraordinary level of creativity
  - Students complained that there was not sufficient time to fully implement their practical solution
- For SAAB, an excellent communication opportunity
  - Meeting the senior students that will soon be available for thesis work and employment

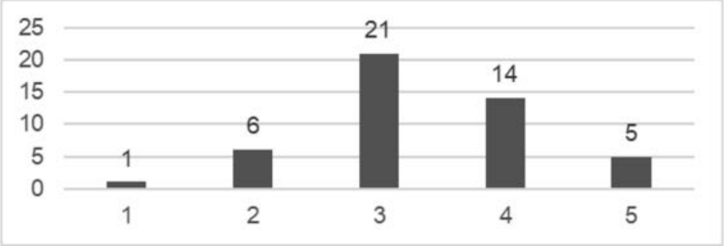
Coupling to course objectives – 5 optimal



Theory practise mixture – 5 optimal



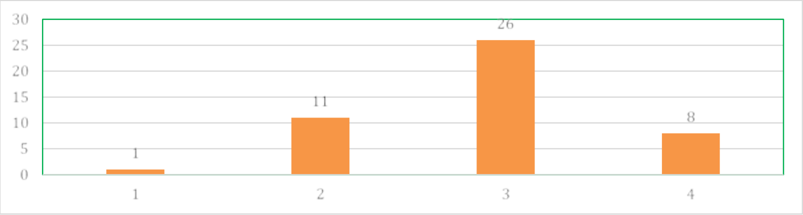
Course length – 3 optimal



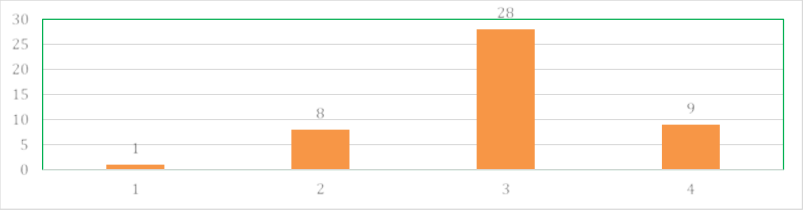
Course element integration – 5 optimal

FURTHER EVALUATION

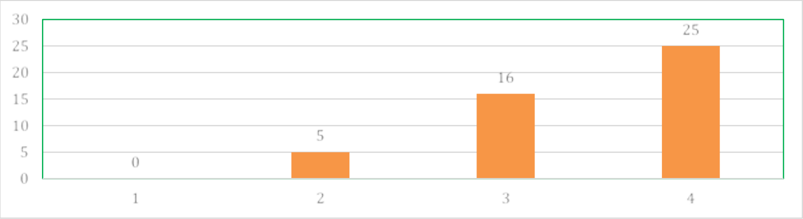
2.1 **Concepts and terminology**.



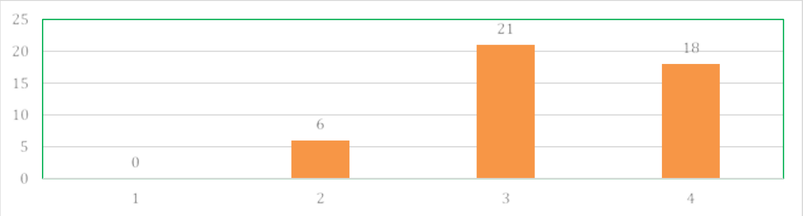
2.2 **System properties and trade off**.



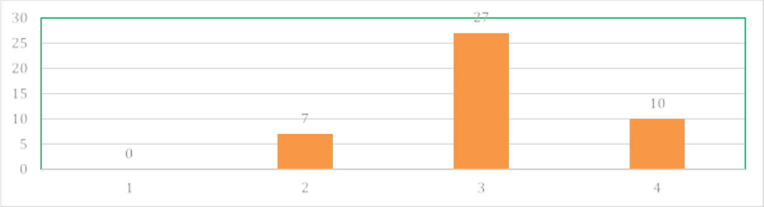
2.3 **System safety**.



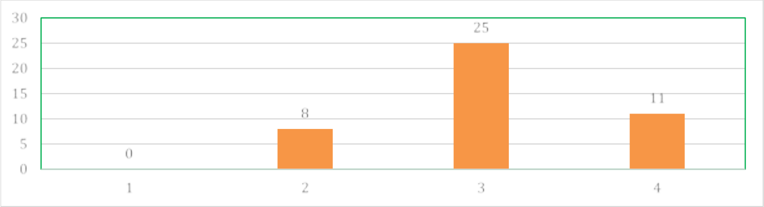
2.4 **Architecture properties and principles**.



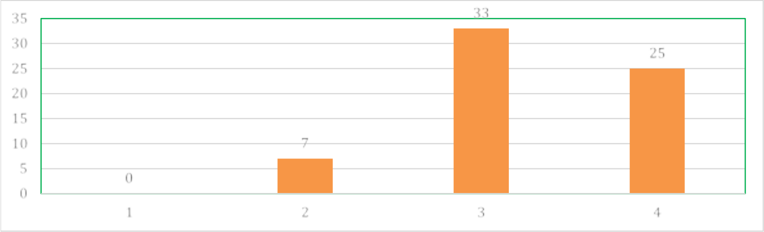
2.5 **Integration driven development**.



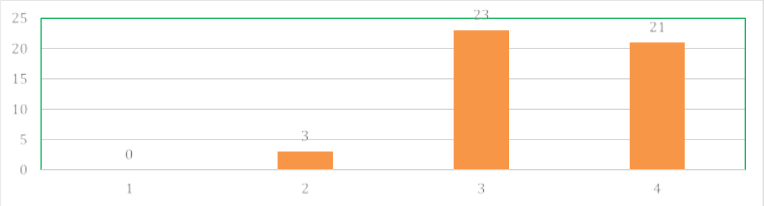
2.6 **Documenting requirements and design**.



2.7 **Availability performance/ILS**.



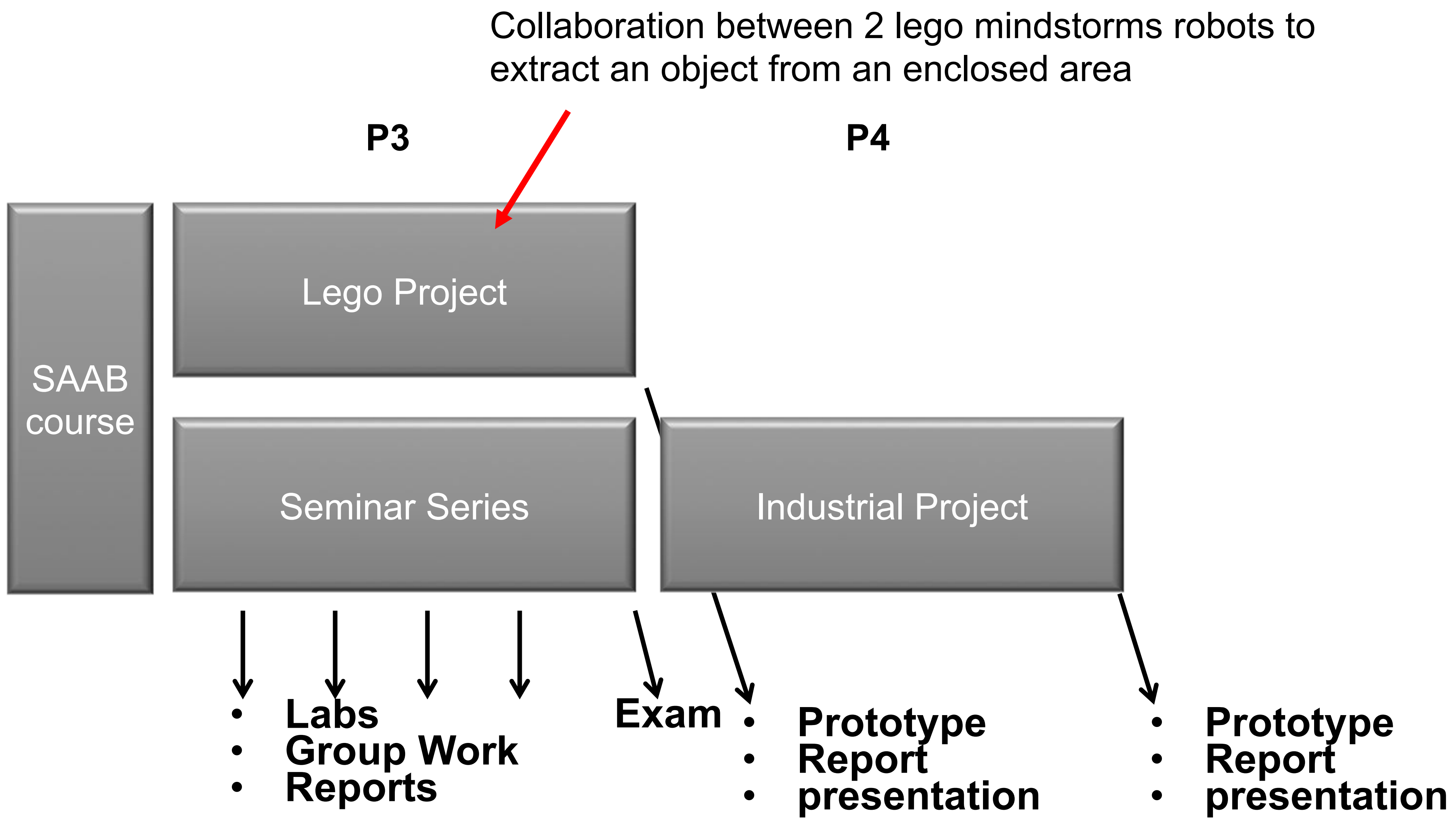
2.8 **Verification and Validation**.



CONCLUSIONS AND WAY AHEAD

- Value added to the KTH course and students
  - Real world perspective from credible people
  - Real world large scale examples
- Lecturing to students does add value for SAAB lecturers
  - Need to focus the message in a concise way
  - Early recruitment opportunity
- Need to strengthen the integration with the rest of the KTH course
  - Students requested a full implementation project to practise the application of Systems Engineering

2018 COURSE SETUP



SUMMARY

- Can Systems Engineering be taught to students?
  - Absolutely, preferably coupled with practical projects!
- Standard internal course
  - Minimal investment
  - Course content is tailored and simplified in order to not overwhelm the audience
- Excellent start for deeper collaboration with KTH
- Energy boost for the lecturers
  - Meet young, interested and creative students
- A good investment in SAAB's future!
- And, perhaps a good joint industry – academia model for introducing Systems Engineering in an environment with no Systems Engineering tradition?