# Supporting human engineering activities by Digital Triplet

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RESEARCH INTO ARTIFACTS, CENTER FOR ENGINEERING

# RACE: Research into Artifacts, Center for Engineering



- “Manufacturing in the next generation”
  - Education programs (for students and for retraining)
  - Learning Factory
    - » Education
    - » Experiments with companies
  - Research
    - » Vision
    - » Digital Triplet (D3)
    - » AI applicable to industrial use
    - » Human recognition mechanism
    - » …
  - Networking
    - » International
    - » National

# Learning Factory [Abele et al. 2017]

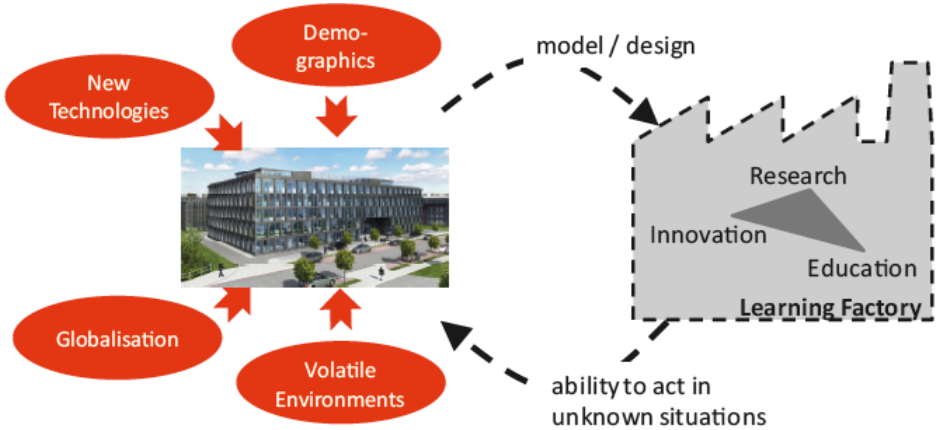



**Fig. 2.** The learning factory as a model of a real factory—incorporating the three poles of the "knowledge triangle" [11].

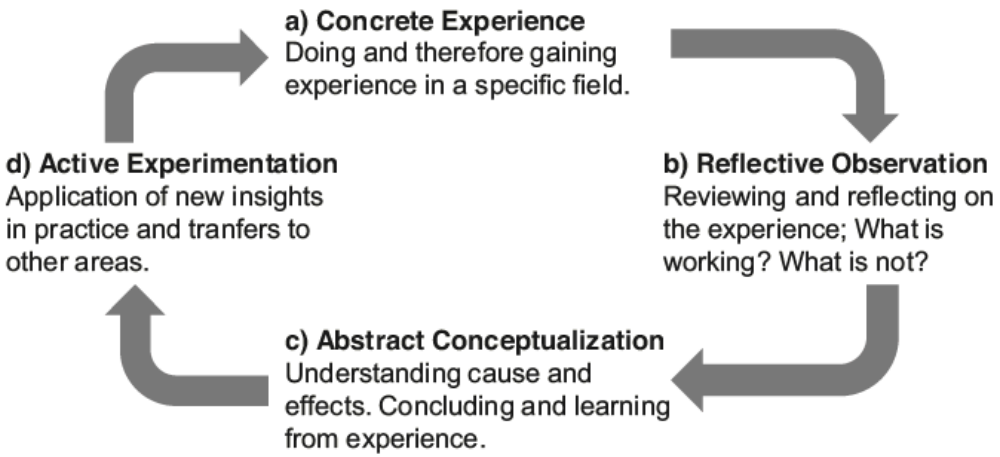



**Fig. 6.** Kolb's experiential learning cycle [181].

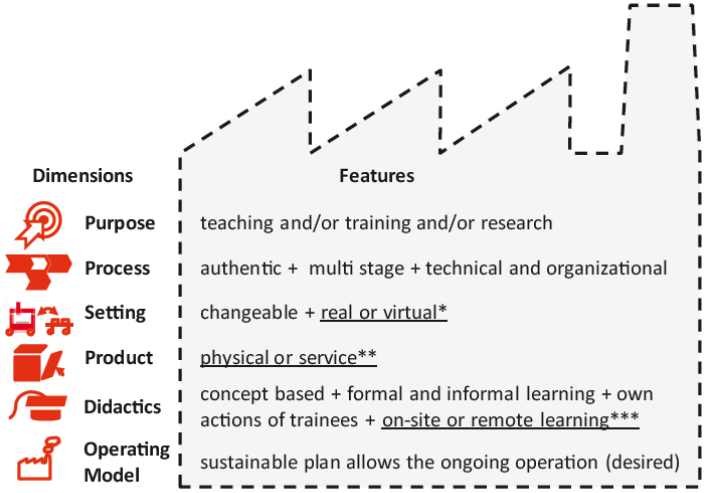



**Fig. 9.** Key characteristics of learning factories.

**Fig. 11.** The learning factory CiP at TU Darmstadt [238].

# Two Problems

1. The digital transformation in manufacturing might not fit the style of Japanese manufacturing industry
   - Exchanging data through the network among different companies
   - Standardized digital platform
2. Many engineers and technicians cannot follow the digital transformation
   - In the digitalized manufacturing systems, they should execute engineering activities (e.g., planning, design, development, construction, operation, maintenance, Kaizen (improvement), and replacement of manufacturing systems) by utilizing the cyber world in addition to the physical world

# What Shall We Do?

- We need new manufacturing strategies after mass production of high quality products
  - Transplanting the strengths of Japanese mfg. industry to the new vessel (IoT, CPS, and AI)

    Continuously pursuing high quality in manufacturing, which results in high quality products and no defect and continuous cost down in production
  - New education curriculum for manufacturing engineers
    - » The current curriculum for manufacturing engineers is old-fashioned
    - » Not only manufacturing science and technologies but also IoT, CPS, and AI, and system thinking

# Focus of This Presentation: Manufacturing System Engineers

- In a typical Japanese manufacturing company,
  - They are main intelligent workforce (key players) for conducting various engineering activities
  - They are always stationed at the shop floor and continuously improve manufacturing systems with workers

# Digital Triplet

- Background
  - Industrie4.0 takes a top-down approach
  - CPPS (Cyber Physical Production System) do not change frequently, since they have enough margins and robustness
  - Automation as much as possible
  - Perhaps, it is not assumed that CPPS is modified at the site

    ⇕ Complementary

  - Strengths of Japanese manufacturers
    - » field experts' diligence, knowledge, and skill
    - » Everyday Kaizen: Production lines are kept improved under the "lean" concept

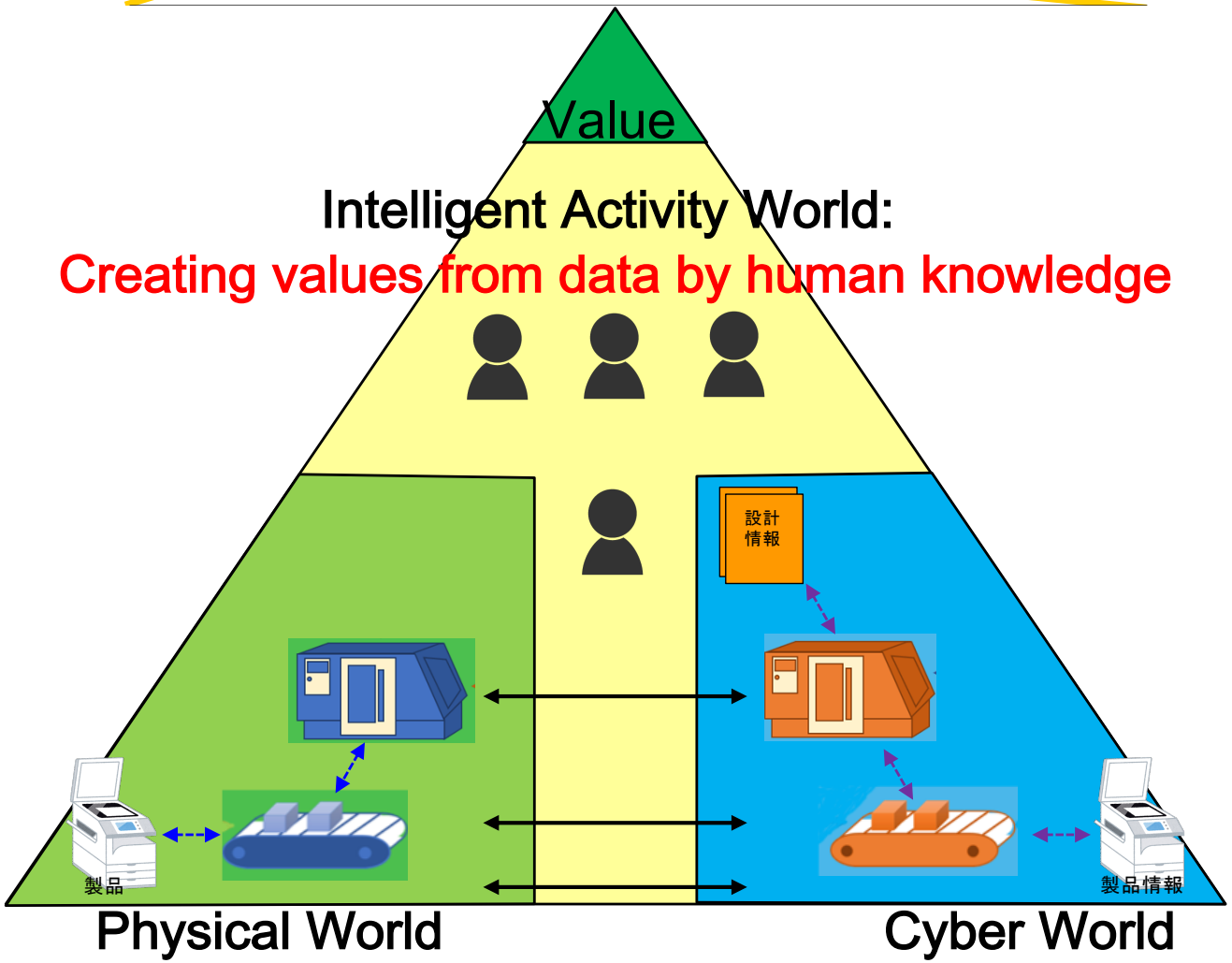
    ⇒ CPPS should also be kept improved by the manufacturing system engineers' initiatives
- Objective
  - Digital Triplet supports engineers to solve problems and to create various values throughout a product life cycle by encouraging these strengths

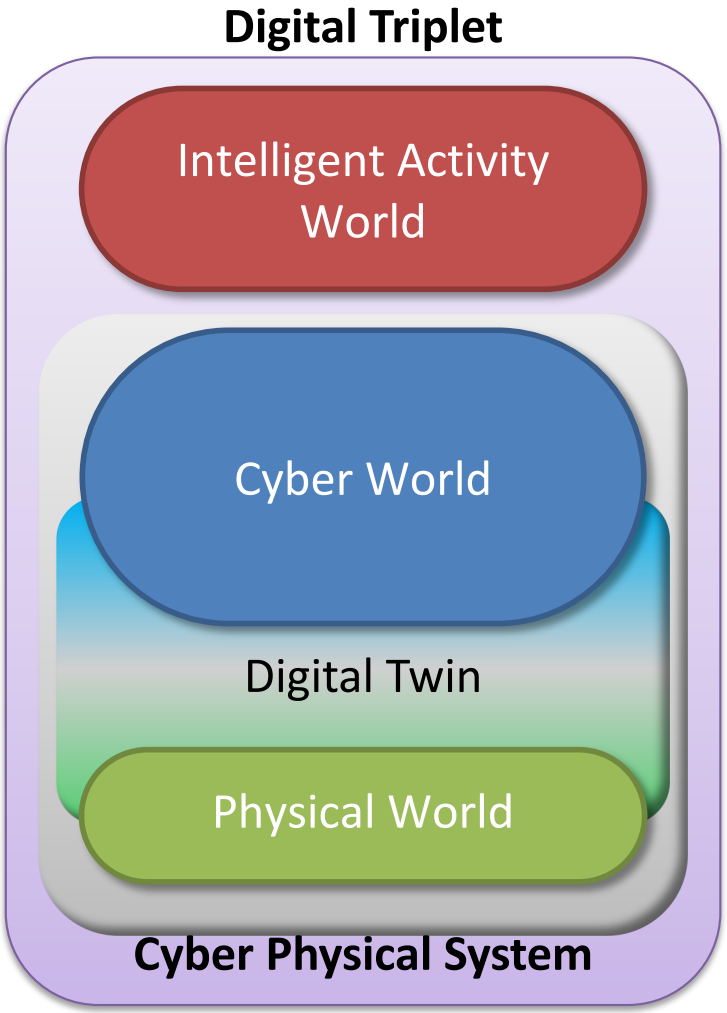
# The Image of Digital Triplet

Integrated support of engineering activities throughout a product life cycle

Design ⇔ Mfg ⇔ Use ⇔ Maint. ⇔ Reman. ⇔ Circulation

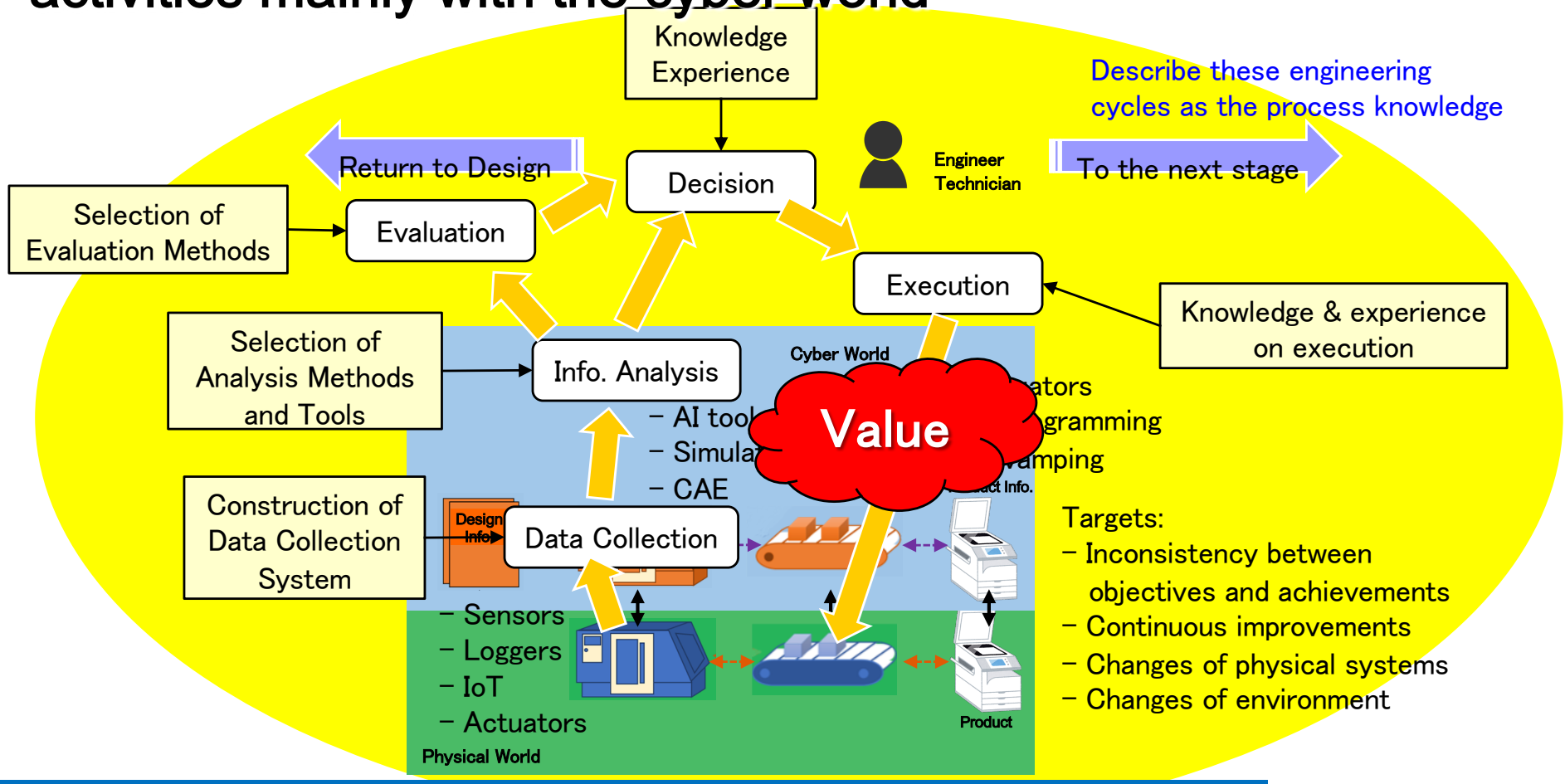
Taking mfg. stage as an example



# Acquiring Process Knowledge of Engineering Activities on Digital Triple

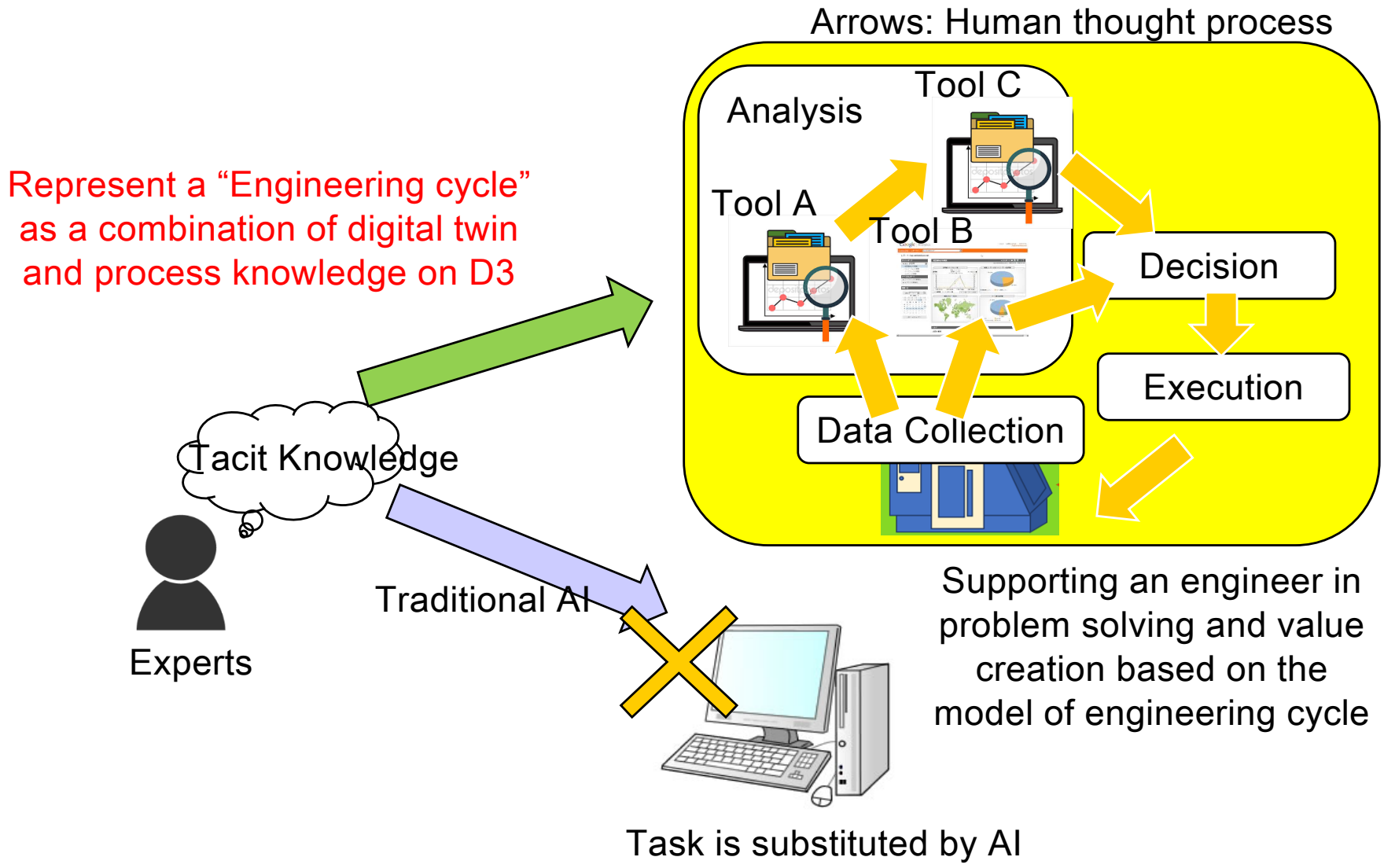
- From now: Engineers should execute engineering activities mainly with the cyber world



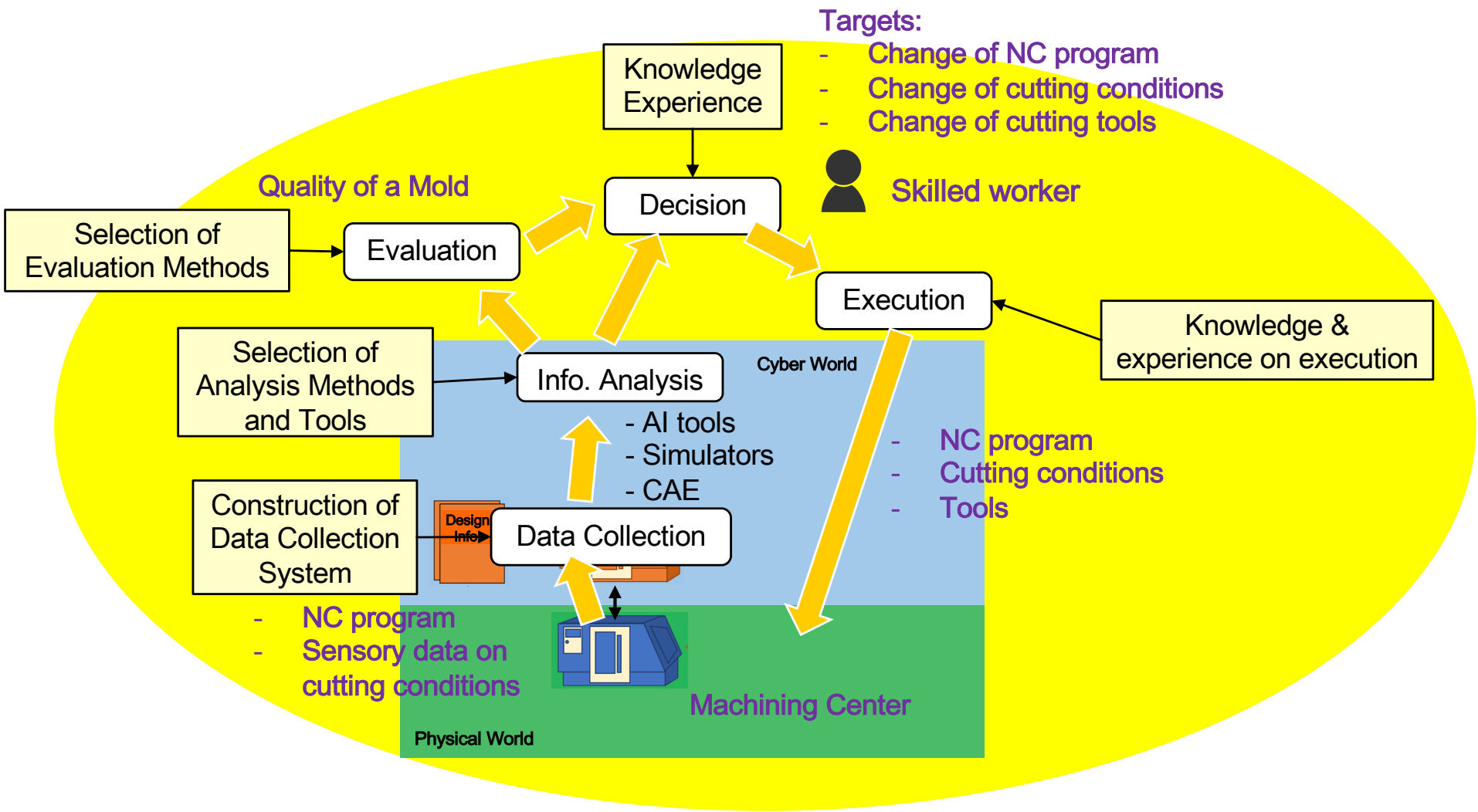

- Formalizing, collecting, and archiving the process knowledge
- Support human activities by reusing and deploying the knowledge
- Employing the knowledge to education

# Concept of Engineering Support by D3

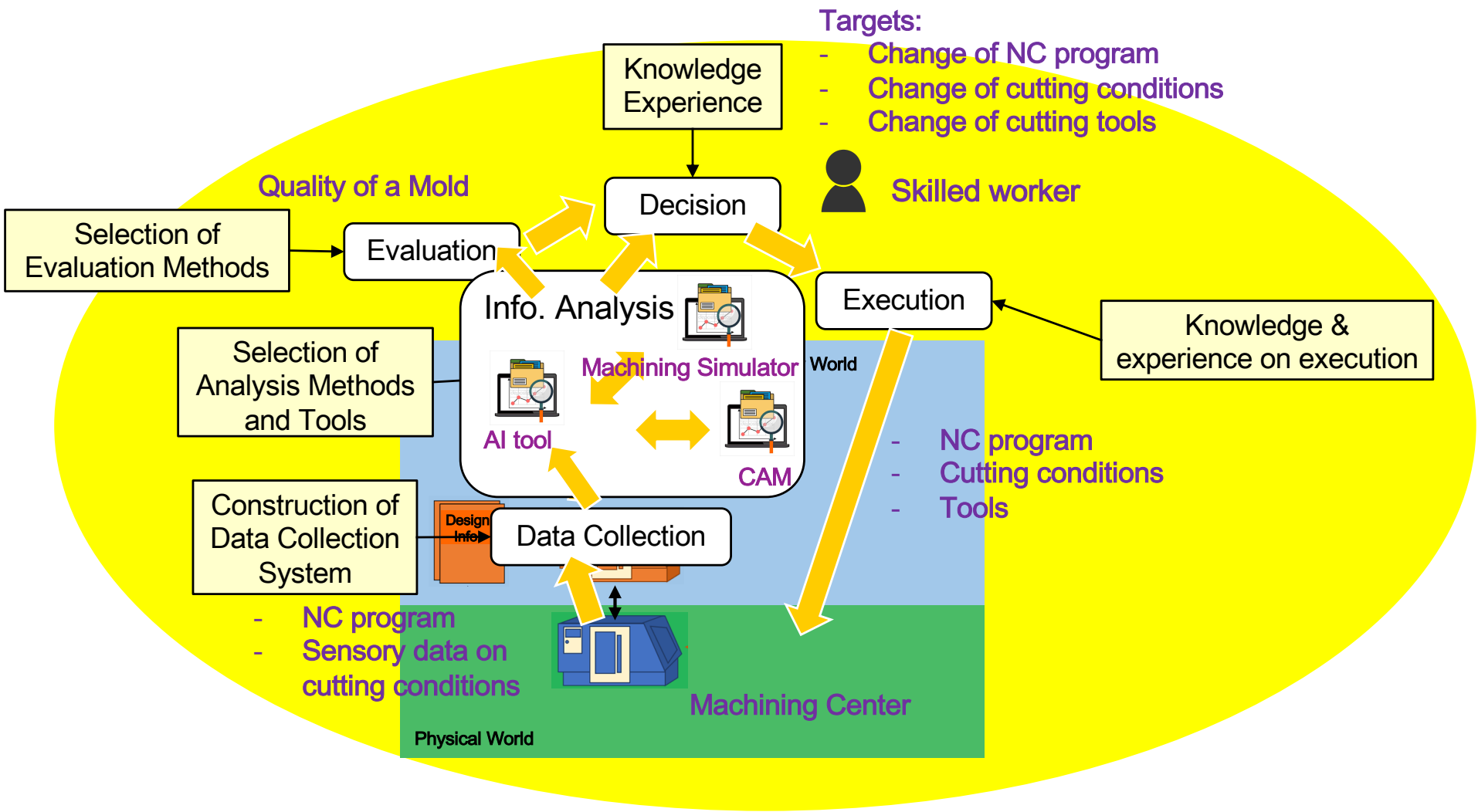
- We represent know-how and tacit knowledge in engineers



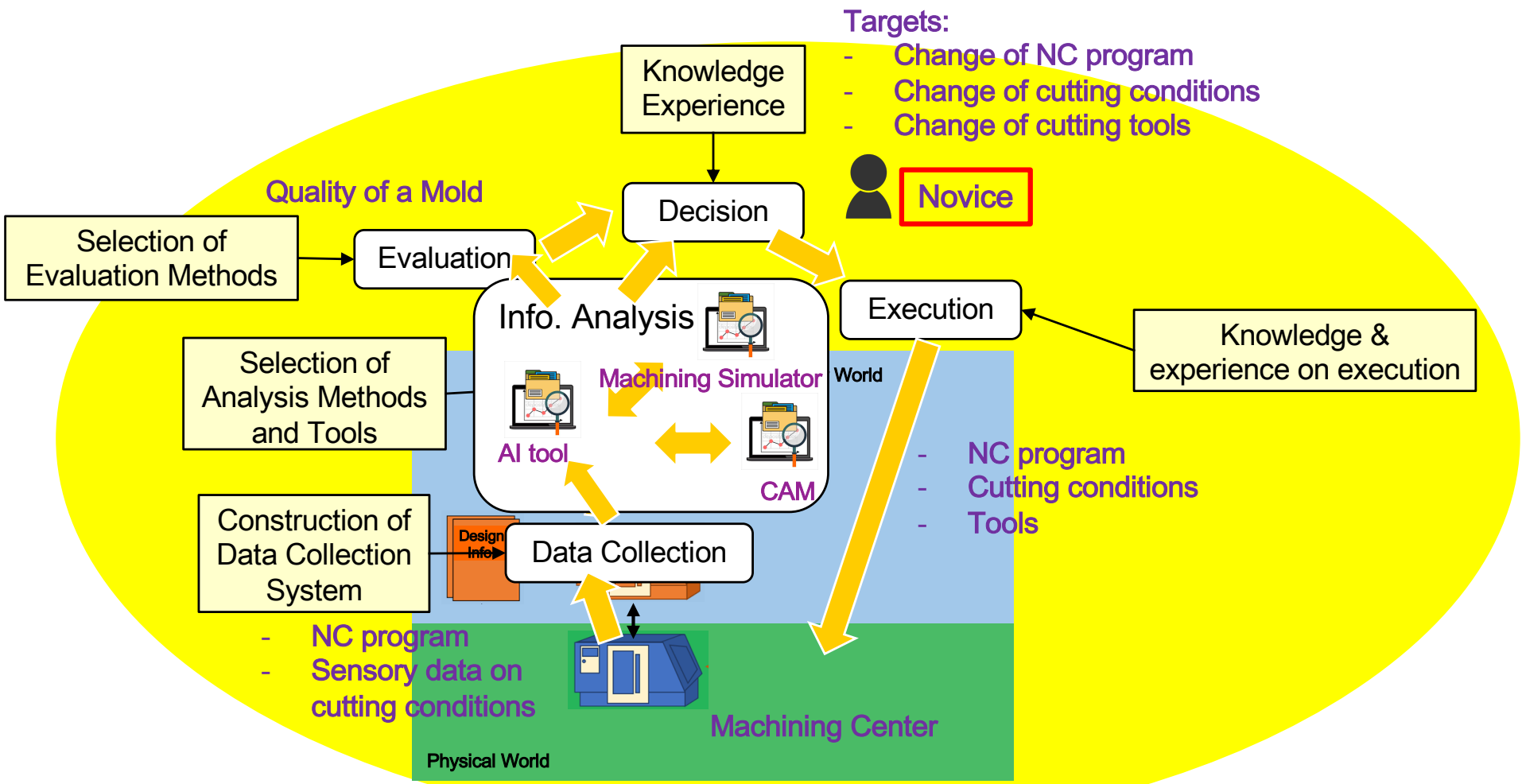
# Example: Machining Molds for Injection Molding Ver. 1



# Example: Machining Molds for Injection Molding Ver. 2

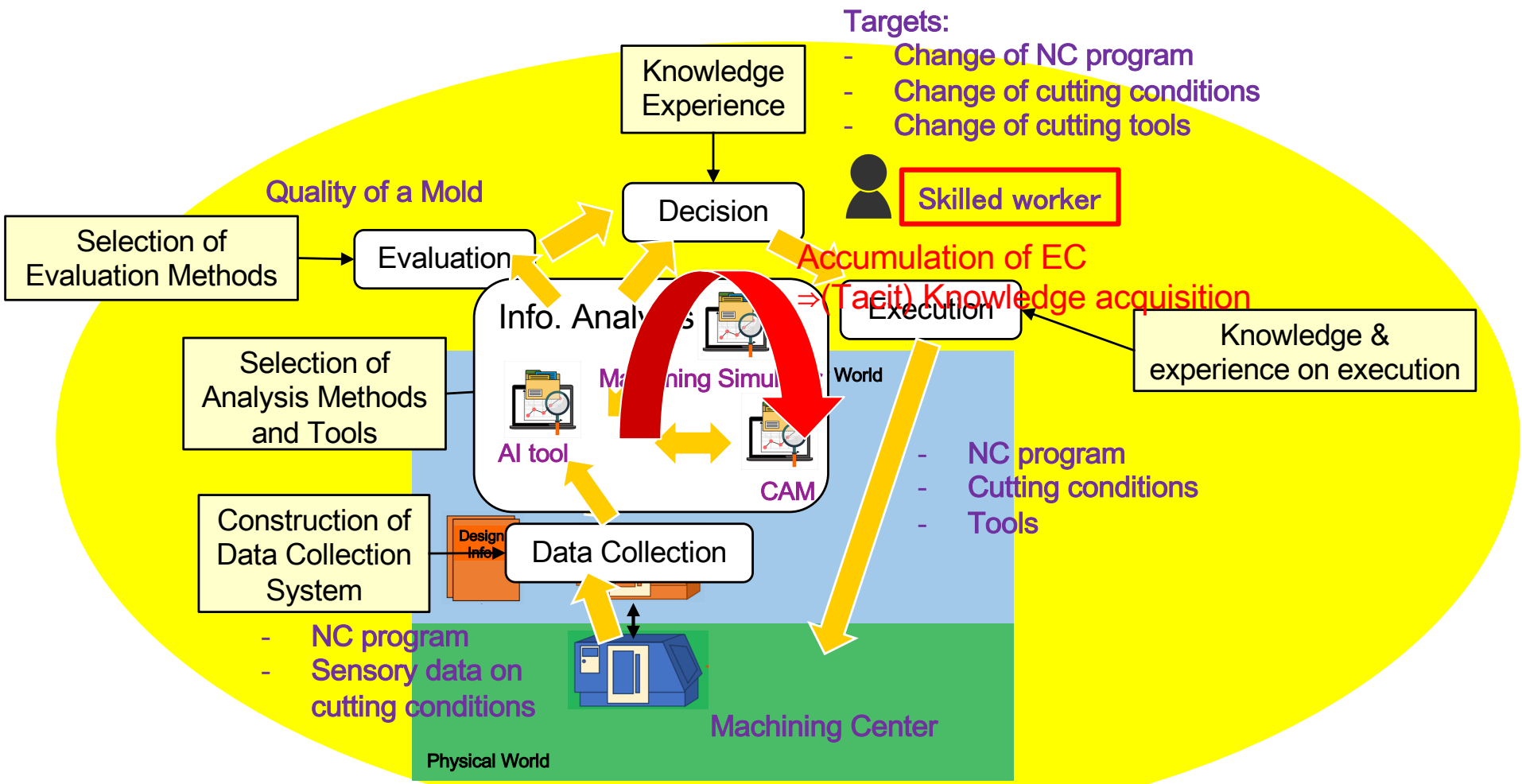


# Example: Machining Molds for Injection Molding Ver. 3a




- The novice can machine the molds with acceptable quality with the support of the constructed EC

# Example: Machining Molds for Injection Molding Ver. 3b




- Accumulation of EC performed by skilled workers and (tacit) Knowledge acquisition

⇒ Construction methodology of D3 type smart manufacturing system will be emerged through accumulating a lot of experiences for developing various D3 systems

# Digital Triplet as a CPPS

- Digital Triplet is a form of CPPS
  - Digital Triplet does not aim to automate manufacturing, rather to support human engineers
  - We dare to decompose the cyber space of CPPS into two worlds
    - » Digital Twin models the physical world
    - » Intelligent Activity World where human solves various problems by using the digital twin
- Human-centered CPPS: Theoretical approach for optimal interaction of human and CPPS
  - Digital Triple aims at providing an environment with supporting functions where engineers construct engineering circles on their own initiatives

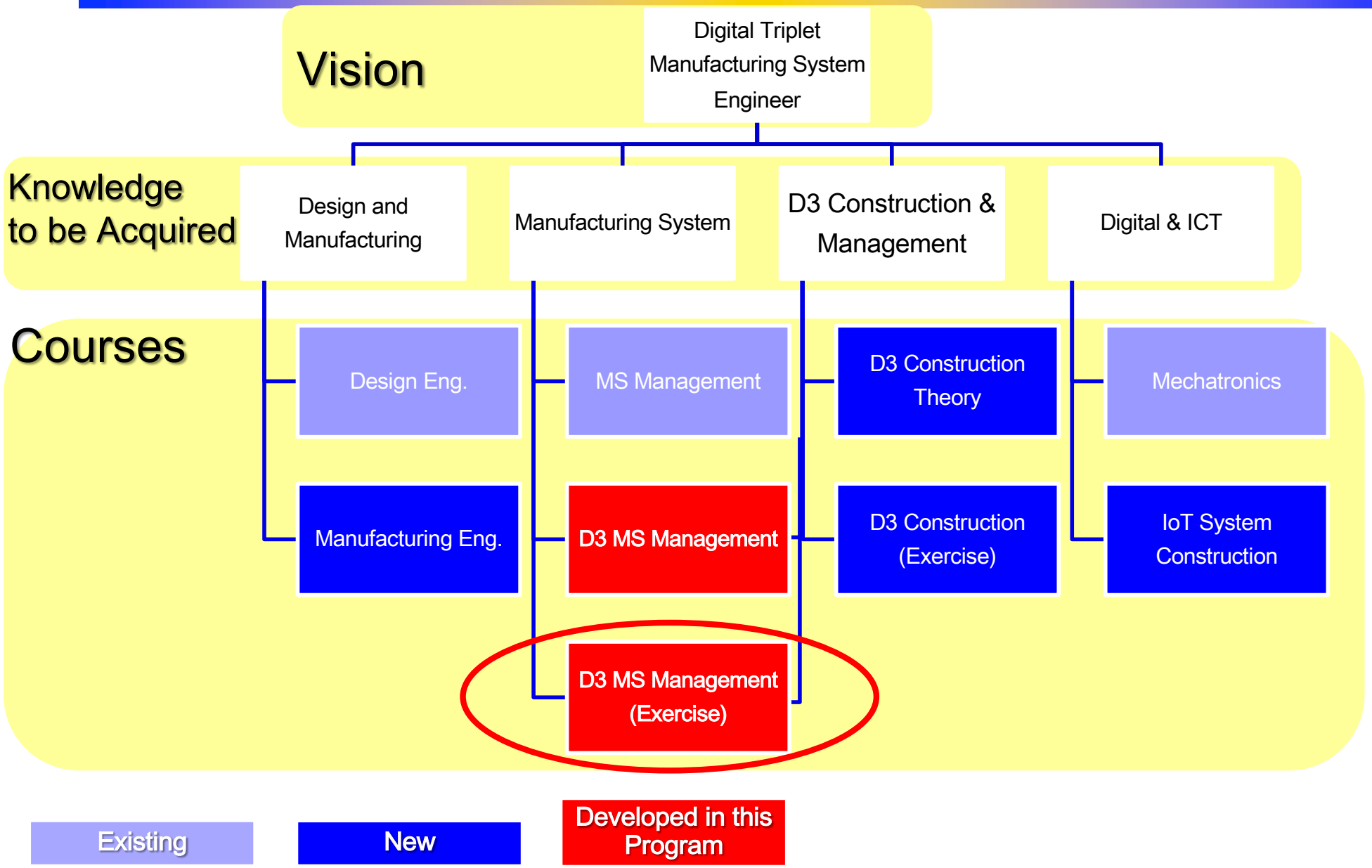
# Differences from (Human-centered) CPPS

- D3 does not focus on human-machine interface / human in the loop; human in the intelligent activity world holds the initiative to execute a task
- D3 focuses on the way of engineering using CPS, rather than system architecture of CPS
- While the digital twin represents cyber models of a physical system (e.g., production system), D3 tries to model problem solving processes done by human supported with CPS
- D3 aims to enable knowledge acquisition from the records of the problem solving processes
- We hope to embed strength of Japanese manufacturers into the intelligent activity world; including high quality engineers' diligence, persevering, etc.

# Digital Triplet as a Framework of Cyber Physical Learning Factories

1. Knowledge transfer
   - An expert engineer constructs an engineering cycle for a specific problem (e.g., to increase productivity of a manufacturing system) by himself/herself
   - Digital Triplet records this engineering cycle as a process record
   - By tracing this process recode, a novice engineer can study the way of thinking of the expert and how to solve this problem
2. Knowledge extraction
   - We are planning to apply some (deep) learning techniques or reasoning techniques to the repository of the process records in order to extract generalized patterns to solve various problems with the Digital Triplet
   - This will support an engineer to construct a new engineering cycle

# The Structure of the Curriculum (Tentative)



# Trial of D3 MS management (Exercise)

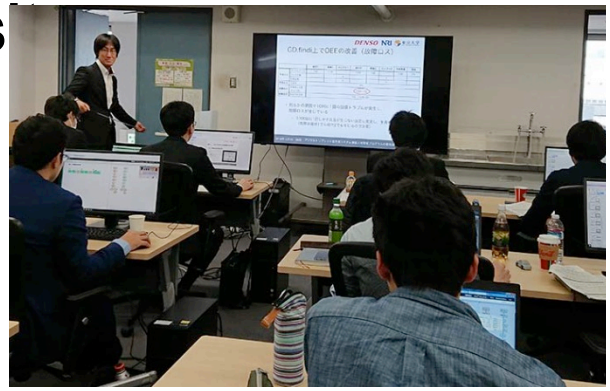
- 10 trainees from industry and the univers
- 2 days program

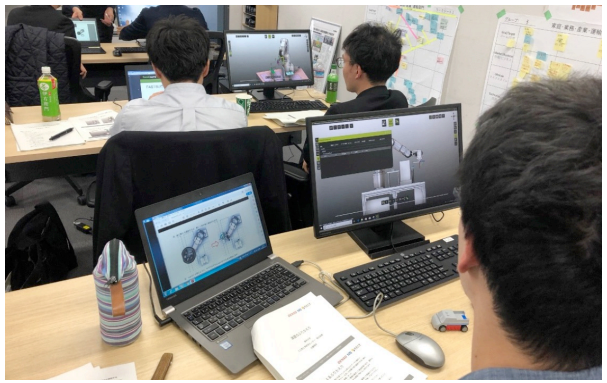
Day 1

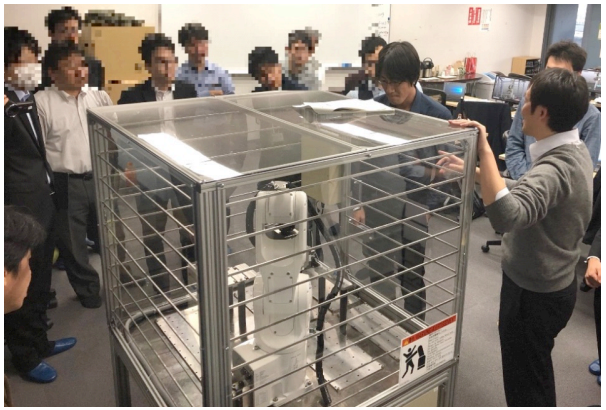
| | |
|---|---|
| 9:00 | 0. Introduction |
| 9:15 | 1. Lecture: Digital Triplet |
| 10:10 | 2. Lecture: Lean Automation and Learning Factory - LASI - |
| 11:10 | 3. Exercise (1):<br>- Recognition of the condition of the production line with the data from digital twin<br>- Practice of the pruction system simulator |
| 12:30 | Lunch |
| 13:30<br>18:00 | |

Day 2

| | |
|---|---|
| 9:00 | |
| 9:30 | - Presentation: Proposal of improvement of production line operation for improving OEE (Overall Equipment Effectiveness) |
| 11:00 | 4. Exercise (2):<br>- Planning of the robot path and trial with the real robot (a kind of tiny D3) |
| 12:30 | Lunch |
| 13:30 | |
| 14:30 | - Competition: Verification of the designed robot paths with the real robot |
| 16:30<br>18:00 | 5. Summary with KPT method |



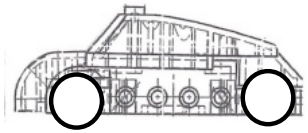




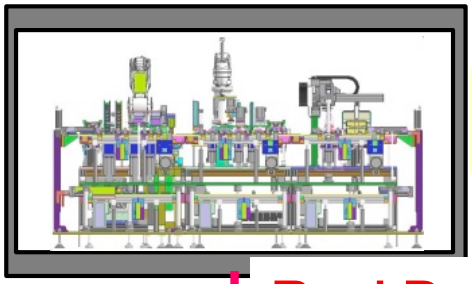
# D3 MS management (Exercise)

## Exercising to notice and to judge by using cyber world

MS Simulation with real data from LASI
→ Understanding the situation, problem solving, and improvement



Cyber

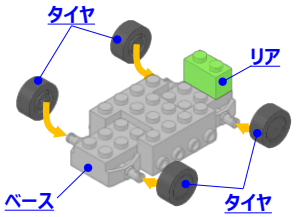


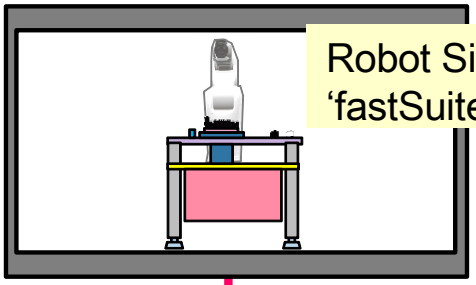
MS Sim.
'GD.findi'

Real Data

## Trial and error of improvement in the cyber world and implementation in the physical world

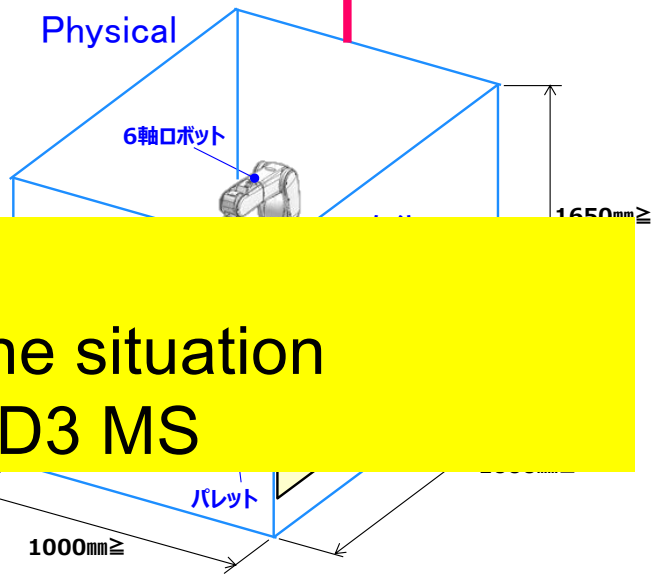
Cyber



Robot Sim.
'fastSuite'

Physical




Items to learn:
(1) Extracting information, (2) Understanding the situation
(3) Proposing improvements, (4) Constructing D3 MS

# Some Observations

- Inconsistency between Cyber World and Physical World
  - Inaccuracy etc.
- Models and simulators are too tiny: they can only represent some phenomena they can model
- It is difficult to extract meaningful data from huge amount of collected data
- It is crucial to choose appropriate data to collect and models and simulators to use for constructing engineering cycles
- The exercise needs a lot of efforts on preparing data and simulation models, setting the subjects and so on
- We have not developed D3 system and apply it to the education program. So far, the class room was a D3. We'd like to develop such a system

# Digital Triplet Projects

- Education Program (METTI, 2018)
- Development of Digital Triplet type Manufacturing Systems (NEDO)
  - Machining molds (2018-)
  - Automated assembly system (2019-)
- Theoretical development and knowledge and data transfer among different processes (e.g., from manufacturing to design) (JSPS, 2019-)

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Thank you very much for your attention!