## 4th CONFERENCE ON LEARNING FACTORIES

**Increasing Resource Efficiency Through Education And Training**

27 - 28 May 2014, Stockholm, Sweden

# LEARNING FACTORIES for Manufacturing Systems

Keynote Paper By
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## Outline

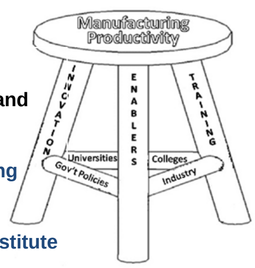
- Historical Development
- Definitions
- Classification of learning factories and modes of learning
- Examples of learning Factories (academic and Industry-based)
- Learning Factories for Manufacturing Systems
- Future Challenges
- Conclusions



## How can we compete in Manufacturing ... and Win?

**Essential Pillars:**

1. **Creativity and Innovation**
2. **Technological Productivity and Competitiveness Enablers**
3. **Education, Skills and Training**
   - **Universities, Colleges**
   - **Research Centres and Institute**
   - **Industry**

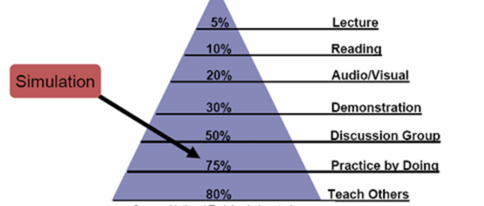



ElMaraghy, H., "Technologies and Future of Manufacturing, Report to Industry Canada, March 2013"



## Teaching and Learning

Research has shown that learning by doing drives greater retention than other learning methods.

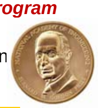



I hear and I forget. I see and I remember.
I do and I understand. Confucius



## The USA Learning Factory Project (1994 - )

- In 1994, NSF awarded three institutions (Penn State, University of Washington and University of Puerto Rico at Mayagüez) and a national laboratory (Sandia National Labs) a grant to develop a "Learning Factory".
- College-wide infrastructure and 6500 sq. ft facility to support industry-sponsored design projects
  - 700+ projects for 175+ companies since 1995
- Facility utilized by 10+ courses within the college
- Recognized nationally *as a model capstone design program*
  - 2006 National Academy of Engineering's Gordon Prize for Innovation in Engineering Education

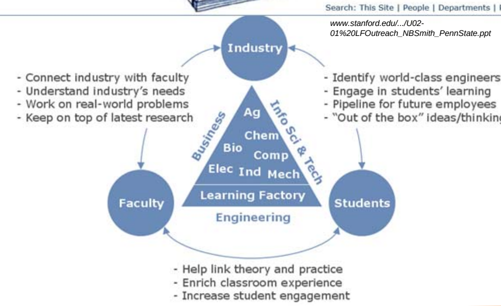


*The Learning Factory©*



PENNSTATE College of Engineering


www.stanford.edu/.../U02-01%20LFOutreach_NBSmith_PennState.ppt

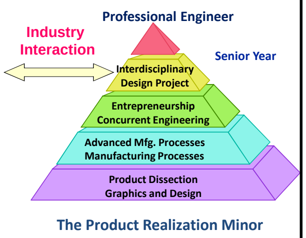


PENNSTATE College of Engineering


Modern design/manufacturing facilities

www.stanford.edu/.../U02-01%20LFOutreach_NBSmith_PennState.ppt

Hands-on curriculum






## The Windsor Experiment (1995 - )

In 1995, Chrysler Canada Ltd. Launched a series of benchmarking initiatives called the *"Windsor Experiment"* with the University of Windsor:

- To identify best practices in apprenticeship training programs and
- To explore joint research and development projects.
- In undertaking the Windsor Experiment, Chrysler Canada is facing up to the realities of youth unemployment and industry's need for highly skilled and flexible workers.



## The University of Windsor / Chrysler Canada Automotive R&D Centre, ARDC (1996 - )

- Set-up as a unique University / Industry Partnership in education and research





## Benefits and Challenges

- **Students:** practical research projects, acquire self-confidence, teamwork and lifelong learning skills, hands-on in-plant training, are steeped in the knowledge of industry.
- **Industry:** benefits from technology development and transfer of technology from academia to industry production floor.

**Industry Challenges:**

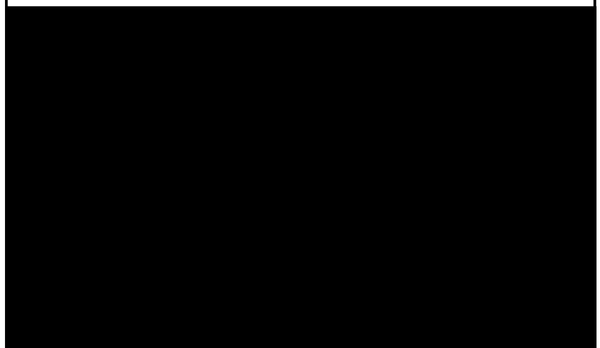
- Developing knowledge workers as tasks becomes more complex, with a broad-based education and a high degree of flexibility.
- To respond speedily to the challenges of technological change, and to the pressing need to fill vacancies created by an aging workforce.
- Colleges and Universities do not produce sufficient skilled graduates that can readily skilled knowledge workers.



## Chrysler World Class Manufacturing Academy WCMA (2012 - ) in Warren, MI




## WCMA





## Survey of Learning Factories

**Aim:**

- Investigate the state-of-the-art of learning factories
- Summarize their characteristics
- Classification of the systems
- Derivate future prospects for learning factories that fulfill the requirements of changeability

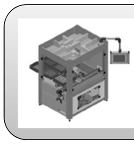
**Source and Scope:**

- A literature survey was conducted and in addition a questionnaire was sent to all members of CIRP
- More than 20 research and development organizations that have established learning factories were investigated

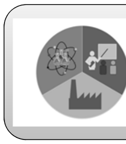
ElMaraghy, et al., 2012, The State-of-the-Art and Prospects of Learning Factories, 45th CIRP CMS Conf., Procedia CIRP 3(1) pp. 109 -114.



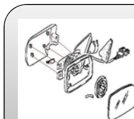
## Classification of Learning Factories



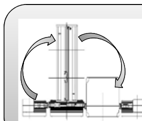
**Manufacturing System:**
•Equipment
•Manufacturer
•Year of installation
•Manufacturing and logistic processes



**Usage of Learning Factory:**
•Teaching (course topics, level, courses for industry, experience)
•Research (topics)
•Projects with industry (fields of application, contents)



**Product:**
•Description
•Variants
•Product structure
•Simplification of product for learning factory



**Characteristics of Changeability:**
•Universality
•Mobility
•Modularity
•Scalability
•Compatibility

ElMaraghy, et al., 2012, The State-of-the-Art and Prospects of Learning Factories, 45th CIRP CMS Conf., Procedia CIRP 3(1) pp. 109 -114.



## Classification of Learning Factories

**Matrix for Determining the Basic Classification of Learning Factories illustrated with some Examples**

| Features \ Learning Factories | Process Learning Factory (TU Darmstadt) | IFA Production Training & Competence Factory (Leibniz University Hanover) | Learning Factory New Technologies Berlin (RKW Deutschland GmbH) | Experimental and Digital Factory (TU Chemnitz) | The NKG Learning Factory (Verein Lernfabrik) | Laboratories for Discrete and Process technology (University Pelita Harapan) | Learning Factory for advanced Industrial Engineering (University of Stuttgart) |
|---|---|---|---|---|---|---|---|
| Factory-in-a-Lab (It is not used for selling products) | • | • | ○ | • | ○ | • | • |
| Used for Teaching/ Education | • | • | • | • | • | ○ | • |
| Comprises a physical learning environment (e.g. machining, assembly and logistics equipment) | • | • | • | • | ○ | • | • |

*Legend: • ...true ○ ...not true*

ElMaraghy, et al., 2012, The State-of-the-Art and Prospects of Learning Factories, 45th CIRP CMS Conf., Procedia CIRP 3(1) pp. 109 -114.



## TU Darmstadt – Lean Manufacturing

**1) Institute for Production Management, Technology and Machine Tools, TU Darmstadt, Prof. Dr.-Ing. Eberhard Abele**

**Use for Teaching:** Lean production (industry), advanced design (students)

**Use for Research:** Lean production, didactical concepts for education in manufacturing

**Projects with industry:** Analysis and optimization of production processes and production lines regarding the implementation of lean production

**Characteristics of Changeability:**

- Changes in production setups can be realized by several equipment modules
- System can be changed in about 30 minutes including substitution of equipment and gadgets

Source: http://www.prozesslernfabrik.de/

## Leibniz Univ. Hanover - Changeability

**2) Institute of Production Systems and Logistics, Leibniz University Hanover, Prof. Dr.-Ing. habil. Peter Nyhuis**

**Use for Teaching:** System is used for different purposes:
1. IFA Production Training for teaching lean production methods
2. Competence Factory to enable the human for change

**Use for Research:** None

**Projects with industry:** See Teaching (Heijunka, Kanban, CIP, synchron production, 6S)

**Characteristics of Changeability:**

- Modularity and scalability by Plug´n play elements of the mounting system
- System can be changed quickly and easily

Source: Questionnaire – Learning Factory Survey
Source: http://www.prozesslernfabrik.de/



## TU Chemnitz – Assembly & Energy

**3) Department of Factory Planning and Factory Management, TU Chemnitz, Prof. Dr.-Ing. Egon Müller**

**Use for Teaching:** Changeability with regard to product, process and resource, case study about factory planning

**Use for Research:** Changeability of manufacturing systems, energy efficient production, innovation laboratory for production and logistic

**Projects with industry:**

Testing environment for regional equipment manufacturers

**Characteristics of Changeability:**

- Mobile system modules and system layout variants
- Flexible area-wide media network (Plug´n play)
- Software - Hardware Integration
- .....

Source: http://www.youtube.com/watch?v=2W-fTAUaT0o



## University of Bremen - Logistics

**4) Institute for Production Systems and Logistics (BIBA), University of Bremen, Prof. Dr.-Ing. Bernd Scholz-Reiter**

**Use for Teaching:** Autonomous logistics, application of RFID, application of software agents

**Use for Research:** Autonomous logistics

**Projects with industry:** None

**Characteristics of Changeability:**

- RFID and mono rail system are built up on a modular basis (but no Plug'n play)
- Factory layout can be changed but substantial time and personnel effort are necessary
- Use of Ethernet to connect the elements

Source: http://www.biba.uni-bremen.de/panorama/



## University of Stuttgart – Systems & Logistics

**5) Institute for Industrial Manufacturing and Management, University of Stuttgart, Prof. Dr.-Ing. Prof.E.h. Dr.-Ing.E.h. Dr.h.c. mult Engelbert Westkämper**

**Use for Teaching:** Methods and tools for increasing changeability in companies, methods of industrial engineering and intra-logistics

**Use for Research:** Innovative sustainable and changeable production, optimization of dynamic work flows, integration of manufacturing steps into assembly etc.

**Projects with industry:** Sustainable powder coating integrated in changeable production

**Characteristics of Changeability:**

- Mobile system modules and system layout variants
- Standardized equipment components and Plug n play elements
- Software - Hardware Integration
- ...

Source: training brochure learning factory



## TU Dortmund - Assembly

**6) Chair of Industrial Engineering, TU Dortmund, Prof. Dr.-Ing. Jochen Deuse**

**Use for Teaching:** Work system design, industrial assembly, work and time study, work place design

**Use for Research:** Experimental environment for research on industrial engineering methods

**Projects with industry:** Workshops and simulation games for industry partners about assembly

**Characteristics of Changeability:**

- Mobile and standardized modules (movable with rollers)
- Unplugging power cords (hung down from ceiling)

Source: Questionnaire – Learning Factory Survey



## Ruhr-Univ. Bochum – Lean & Energy

**7) Chair of Production Systems, Ruhr-University Bochum, Prof. Dr.-Ing. Horst Meier**

**Use for Teaching:** Connected production systems, lean management and organization, awareness of energy waste

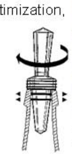
**Use for Research:** Industrial production systems, condition monitoring, modular model-based control systems for integrated manufacturing simulations

**Projects with industry:**

Seminars with focus on process optimization, lean and energy efficiency

**Characteristics of Changeability:**

- System can be moved by crane (expect CNC machines)
- Workstations are also moveable



Source: http://www.lps.rub.de/ausstattung/pilotfabrik/index.htm

## TU Kaiserslautern - Systems

**8) Technologie-Initiative SmartFactory KL e.V., Kaiserslautern, Prof. Dr.-Ing. Detlef Zühlke**

**Use for Teaching:** Students bachelor / master thesis based on topics concerning the advancement of factories

**Use for Research:** Wireless communication systems, location based services, mobile human-machine-interaction, novel software architectures in automation, cyber-physical-systems etc.

**Projects with industry:** Development of human-machine-interaction systems, RFID-based production control etc.

**Characteristics of Changeability:**

- Modular equipment structure, standardized web-based software-services (control) and standardized interfaces (UPC-UA)



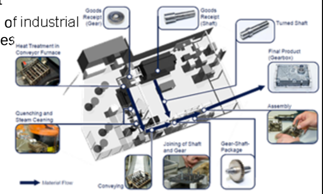
## TU Munich - Energy

**9.1) Institute for Machine Tools and Industrial Management, TU Münschen, Prof. Dr.-Ing. Gunther Reinhart:** ***1 Learning Factory for Energy Productivity***

**Use for Teaching:** Energy value stream, production planning and control, manufacturing processes like joining, cutting, compressed air supply, human behavior, organization, KPIs

**Use for Research:** Measures, tools and methodologies to reduce energy consumption in an existing production environment

**Projects with industry:** Improvement of industrial manufacturing sites, areas or machines regarding energy consumption



**Characteristics of Changeability:**

- Designed changeable to be able to implement optimization measures
- Nevertheless changeability is not in The focus of the factory, but energy productivity



## TU Munich – Lean Manufacturing

**9.2) Institute for Machine Tools and Industrial Management, TU Münschen, Prof. Dr.-Ing. Gunther Reinhart:** ***2 Learning Factory for Lean Production***

**Use for Teaching:** Principles and methodologies of lean production

**Use for Research:** None

**Projects with industry:** None

**Characteristics of Changeability:**

- Universal assembling tables and equipment
- The equipment is installed on rolls and modular exchangeable



## MTA SZTAKI - Systems

**10) MTA SZTAKI, Budapest, Hungary, Prof. László Monostori**
***(The system is not existing yet. It is at the planning stage!)***

**Use for Teaching:** Short, interactive course for industrials

**Use for Research:** The integration of the real, physical world with the Digital Factory software tools of the laboratory

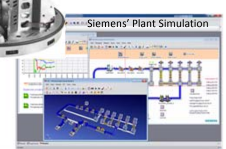
Robotino AGV

*Source: http://www.festo-didactic.com*

**Projects with industry:** TBD

**Characteristics of Changeability:**

- Flexible routes by AGVs
- Multiple control strategies



Siemens' Plant Simulation

*Source: http://www.plm.automation.siemens.com*



## Learning Factory-in-a-Lab at U Windsor, Canada

Plug & Produce modules that can be easily reconfigured to change the system "*layout and functionality*" using unique drive technology, control and interfaces (FESTO Automation, Siemens Control, RFIDs, Vision, Robots, ASRS,….).

iFactory is a Changeable Industrial Grade Manufacturing System - one of a kind in NA.

It demonstrates innovative physical and logical enablers of change such as variant - oriented re-configurable process and production plans and manufacturing systems

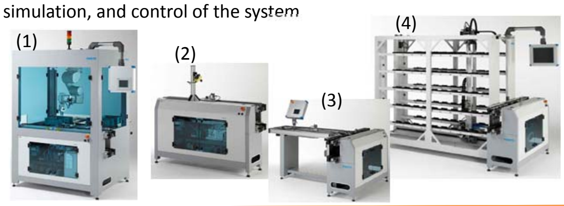


## Intelligent Manufacturing Systems Centre (IMSC)

- Established in July 1994
- 22 Researchers (PDFs, PhD, MSc) are engaged in projects funded Provincially and Federally as well as International collaborations.
- Graduated > 100 HQPs → working in industry/ academia.
- Housed in the Ed Lumley Centre for Engineering Innovation (CEI) - A "LEED" certified environmentally friendly and live building.

## The Changeable Learning Manufacturing System

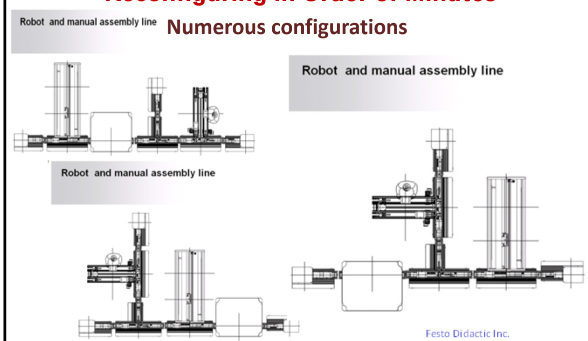
- Reconfigurable assembly system consisting of cells such as robot assembly (1), manual assembly (2), camera inspection (3), automated storage & retrieval (4)
- Mobile cells and system layout variants, standardized equipment components and Plug n play elements, Software-Hardware-Integration
- Computing environment for planning, modeling, visualization and simulation, and control of the system





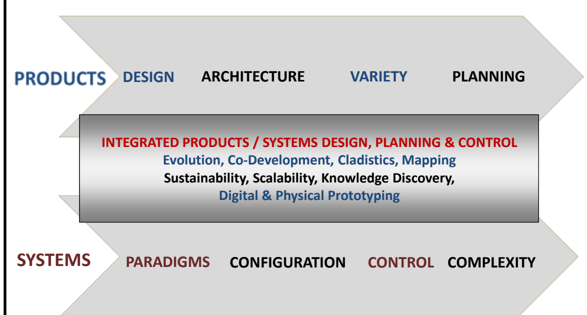

## Reconfiguring in Order of Minutes

Numerous configurations






## IMSC Current Research Thrusts





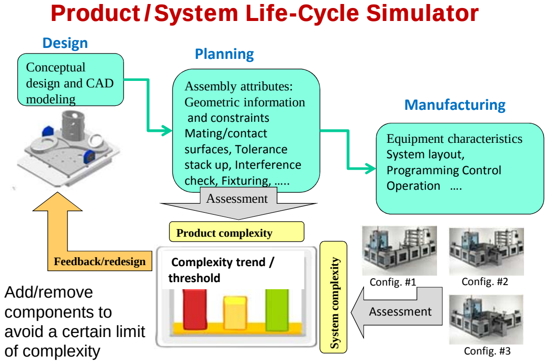

## Experiential Learning with *iFactory*

- **Courses**
  - Flexible Manufacturing Systems (Under Grad.)
  - Manufacturing Systems Paradigms (Grad.)
  - Capstone Projects
- **Research**
  - System Configuration design, *iDesign*,
  - *iPlan* (process & production planning), *iControl*
  - Variety management, Enablers of Change, *iOrder*, Logistics, ..
  - Co-Development of Products and Systems, Platforms Design
- **Training**
  - Industrial Short courses
- **Demonstrations and outreach**

ElMaraghy, H. and W. et al. , 2011, Change in Manufacturing - Research and Industrial Challenge. KN Paper, CARV2011 Conference, Montreal, pp 2-9.

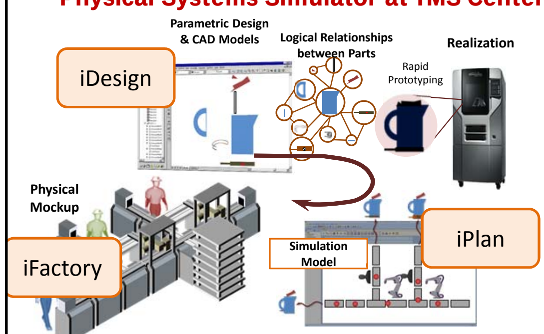


## Product / System Life-Cycle Simulator






## Physical Systems Simulator at IMS Center



## iDesign

- Design Collaboration
- Customer Negotiation
- Interactive Multi-touch Screens
- Immersive Design Environment
- Rapid Prototyping

Parts and Assemblies Visualizing

RP Machine
Dimension-1200es



## iPlan

Powerful computing environment for synthesis, configuration, modeling and analysis of products, processes and manufacturing systems

**Digital Manufacturing Software:**

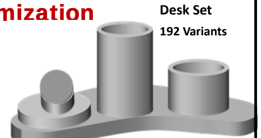
- PLM
- CAD/CAM
- System Simulation
- Operation Simulation
- Process & Production Planning
- Inspection Planning




## iOrder - Customization

- Online product configurator
- Automated data retrieval
- Automated scheduling
- Cost and completion time evaluation
- Preference menus and personalization
- Automated process and production planning

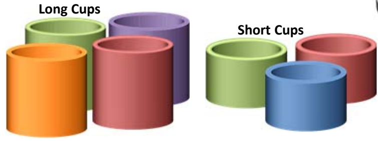
Desk Set
192 Variants



Gauges

Long Cups

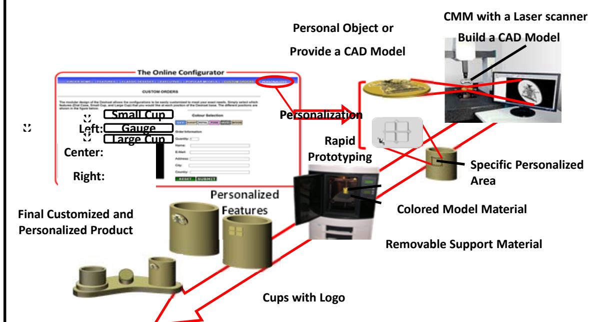
Short Cups





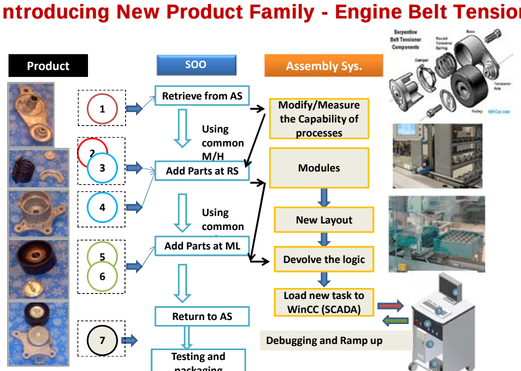
## iOrder - Personalization

Capturing Customer's Specifications





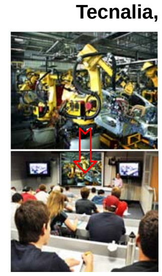

## Introducing New Product Family - Engine Belt Tensioner

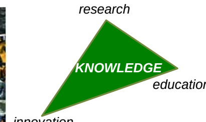





## Know-Fact Project

**(Patras U, Polytechnico di Milano, TU Darmstadt, Tecnalia, CASP S.A., Volvo and Festo)**






The **Teaching Factory** as a 2-ways "learning channel" communicating

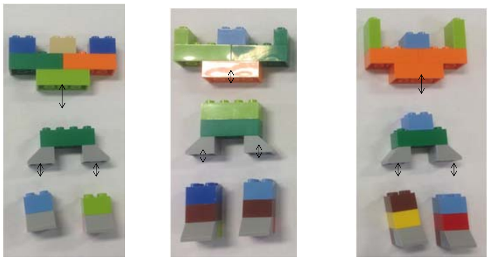
*industrial practices to the classroom*
*Factory-to-Lab*

*"new" knowledge to the factory*
*Lab-to-Factory*

http://www.lms.mech.upatras.gr/

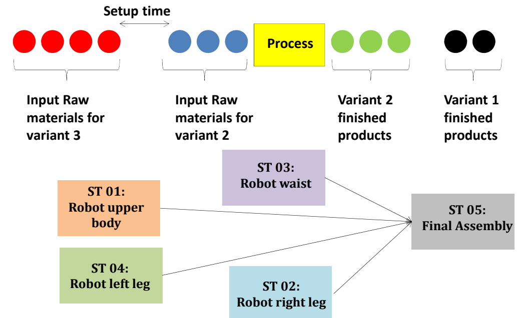
## Low Cost Manufacturing Games - U Windsor
**Product Variants Production Learning System ©**

| Variant 1 | Variant 2 | Variant 3 |
|---|---|---|
| **Short Robot** | **Tall Robot** | **Slender Robot** |



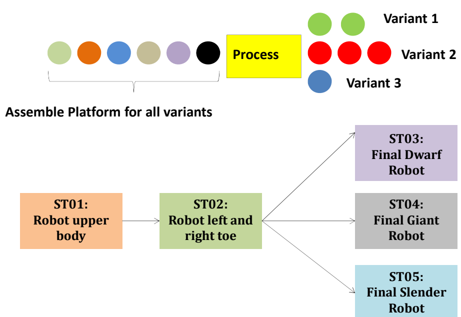


## Batch Production






## Delayed Differentiation / Mass Customization ©






## "Learning" "Factories" Definitions

- **Learning** (not teaching) > is enhanced by doing
  Experiential Learning / Hands-on Learning
- **Factory** > Collection of entities that produce something(s)

**Conceptual Learning Factory**
- Integrated curriculum with enhanced learning
  Modules, labs, simulations, projects, industrial
  Internships
- Produces well-trained students, employees, ..



## "Learning" "Factories" Definitions

**Physical Learning Factory**
- System of physical entities - stand alone or integrated Hardware and software components (e.g. machines, MHS, computers, software, and physical products) designed to provide rich learning experience and environment to trainees.
- Produces well-trained people (students, employees, ..)



## Learning Factories Classification

- **Scope:**
  - Teaching / research / Applications
- **Implementation:**
  - Physical / Virtual / Internships / Joint Projects
- **Size:**
  - Full Scale / Scaled (bench tops) /
- **Function:**
  - Operational / Static Physical Models
  - Technology training focus
- **Location:**
  - On-site (local) / off-site (remote) / In-plant

## Selecting / Designing Learning Factories & Products

*It is different – Not a production factory*

- **Objectives:** Target leaning area and topic (education curricula and research programs)
- **Demonstration** of intended concepts, e.g. variety and its management, assembly, manufacturing systems paradigms, Lean manufacturing, energy, etc.
- **Structure and architecture** (topology, modularity, scalability, changeability, layout re-configuration,..)
- **Physical limitations** (space, equipment and capabilities, work envelope, ..)
- **Financial constraints** ( virtual/real, on-site/distance, full-size/scale model, projects, ..)



## Learning Factories

- Provide engineers, students and researchers with a valuable learning and training experience in a realistic setting
- Integrate product design, manufacturing planning and the actual making of the product
- All involved steps can be demonstrated and learned
- Helps transfer research outcomes to industry



## Final Remarks

- Learning Factory is an Old Concept which has been receiving renewed interest the last 10 years.
- Several have been set up in academic institutions and in industry to serve many and different objectives.
- Learning factories enhance opportunities for experiential learning both for students and practitioners in the field.
- They involve practical hands-on experience with some fundamental concepts, technologies & systems paradigms
- Selection/design of sample products for demonstration using learning factories depends on their particular focus and characteristics. This is particularly challenging when dealing with systems-oriented learning factories.



## Conclusions

- There are many types of learning factories worldwide, only a few of them are geared towards developing the enablers of manufacturing systems changeability.
- The cost of learning factories can vary widely from ones that are low cost to others that require significant investment.
- Alternate forms of experiential learning involve gaining experience at Real Factories through Internships and Industrial Projects, Factory-in-a-Lab., Scale Models of Factories, Lego Manufacturing Games and Simulated Virtual Factories present many alternative for delivering experiential learning experience at different cost levels.
- Challenges include developing and delivering variety of innovative experiential learning experiences