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Tangible Industry 4.0: a scenario-based approach to learning for the future of production

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Abstract

Industry is currently undergoing a transformation towards full digitalization and intelligentization of manufacturing processes. Visionary but quite realistic concepts such as the Internet of Things, Industrial Internet, Cloud-based Manufacturing and Smart Manufacturing are drivers of the so called Fourth Industrial Revolution which is commonly referred to as Industry 4.0. Although a common agreement exists on the necessity for technological advancement of production technologies and business models in the sense of Industry 4.0, a major obstacle lies in the perceived complexity and abstractness which partly hinders its quick transformation into industrial practice. To overcome these burdens, we suggest a Scenario-based Industry 4.0 Learning Factory concept that we are currently planning to implement in Austria's first Industry 4.0 Pilot Factory. The concept is built upon a tentative competency model for Industry 4.0 and the use of scenarios for problem-oriented learning of future production engineering.

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1. Introduction

For the future of production both academics and practitioners envision significant efficiency gains mainly through consequent digital integration and intelligentization [1] of manufacturing processes [2]. Accordingly, integration needs to take place on the horizontal axis (across all participants in the entire value-chain) and on the vertical axis (across all organizational levels). Fully integrated and networked factories, machines and products then need to act in an intelligent and partly autonomous way that requires minimal manual interventions [3].

Recent concepts such as the Internet of Things, Industrial Internet, Cloud-based Manufacturing [4] and Smart Manufacturing address this vision of future digitally enabled production and are commonly subsumed by the visionary concept of a Fourth Industrial Revolution or Industry 4.0 [5]. All these concepts are related to recent technological developments where the internet and supporting technologies (e.g. embedded systems) serve as a backbone to integrate human and machine agents, materials, products, production lines and processes within and beyond organizational boundaries to form a new kind of intelligent, connected and agile value chain.

It is obvious that such a vision will lead to an increased technical and organizational complexity of manufacturing processes on the micro and macro level [6] which imposes substantial challenges especially to small- and medium-sized manufacturing companies. Challenges are not limited to the financial investment required for the acquisition of new technology but are also related to the availability of qualified staff on all organizational levels that is able to cope with the increasing complexity of future production systems.

Learning factories have proven to be an essential means for educating students and professionals regarding the practical application of production management principles. Lean management as a learning topic has clearly dominated the scene in the last decades. However, for future production scenarios in the sense of Industry 4.0 also other competencies need to be addressed that enable future managers and workers of a factory to deal with the challenges of an increasingly digitalized production system [7].

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In this paper we will first present a taxonomy of required skills and competencies with regard to the challenges of Industry 4.0 which is based on a small scale literature review (section 2). In section 3 we will introduce our newly initiated Industry 4.0 Pilot Factory at TU Wien and the scenario-based learning approach that we plan to implement there. In section 4 we will conclude with a reflection on the current state of our Industry 4.0 learning approach and the future activities planned.

2. Competencies for the future of production

The future of production as it is envisioned by Industry 4.0 is characterized by small decentralized and digitalized production networks which are acting autonomously and are therefore capable of efficiently controlling their operations in response to changes of the environment and strategic goals. The nodes of such a network are so called smart factories which are connected to a larger value-chain network that fulfils a certain customer demand. Machines and materials are the assets that are located at the bottom line of the whole automation pyramid but are all well integrated through standardized interfaces. Materials and products are uniquely identifiable and locatable at all times during the manufacturing process and as well along their entire life-cycle. These smart materials and products are customized to a large extent at the costs of mass production.

On an employee level, Industry 4.0 propagates the idea of workers that increasingly will focus on creative, innovative and communicative activities [2]. Routine activities which also include monitoring tasks are entirely or partly taken over by machines.

Based on this vision of future work we will examine required competencies in the next subsections. For this purpose, we conducted a literature review and systemically summarized the results. It is important to note that there is an ongoing debate on the concept of competency [8], [9] in the context of education which has led to different theories and models of competency, see for example [10]. However, for the purpose of identifying competencies required for Industry 4.0 we focus on an output oriented model of competency and refer to the individual as the object of analysis rather than organizations. Output oriented refers to a concept where competencies are always related to some type of task and the ability to fulfil this task. For our review of literature regarding required competencies for future production, we use the classification of competencies (Personal, Social, Action and Domain) according to Erpenbeck and Rosenstiel [11]. In addition, we distinguish between competencies needed on a worker level from those needed on an engineer and manager level.

2.1. Personal competencies

Personal competency can be understood as the ability of a person to act in a reflective and autonomous way. Personal competency also comprises the ability to learn (develop cognitive abilities), to develop an own attitude and ethic value system.

On a worker level Industry 4.0 will lead to an increased automation of routine tasks which implies that workers will have to face the fact that their present tasks will no longer exist in the future. Such a perspective on one's own job future requires the ability to see the bigger picture for society as a whole (the challenges, e.g. resource scarcity, and opportunities, e.g. wealth), the opportunities for one's own development and the commitment to lifelong learning as one's own responsibility [12]. However, rather than developing a naïve technology devoutness also a critical attitude towards technological developments will be a key asset for the future worker and organization. A general trust in technology [13] is vital but as well the ability to recognize the fine line between technology as a means for increasing productivity and technology as a means of total worker control.

Personal flexibility with regard to work time, work content and work place [12,14] is a mindset that is a prerequisite for an agile production that is able to respond quickly to market need and environmental conditions.

Naturally, the same applies for managers of future production systems. In addition, managers of the future will need the ability to transform their management style from power-driven to value-driven [14] as the teams of the future are diverse both in terms of culture, education and geographical location.

2.2. Social/Interpersonal competencies

Social competency refers to the fact that an individual embedded in a social context, e.g. an organization, requires the ability to communicate, cooperate and to establish social connections and structures with other individuals and groups.

The full digital integration and automation of whole manufacturing processes in the vertical and horizontal dimension implies as well an automation of communication and cooperation especially along standardized processes. Therefore, workers will be responsible for a broader process scope and will need the ability to understand relations between processes, the information flows, possible disruptions as well as potential solutions. Increasing scope and complexity require a mindset that is oriented towards building and maintaining networks of experts to be able to cooperate ad-hoc in finding appropriate solutions for particular problems. Human work will concentrate at the edges of such processes where human flexibility in problem solving and creativity is advantageous. Hence, creative activities will be performed in a distributed social setting, involve heterogeneous interdisciplinary and interorganizational teams [12] and require the ability to communicate complex problems [15] in different languages [15] as well.

Managers must be able to build or act as mediators that enable social processes (also cooperative decision processes) not only within traditional organizational boundaries but for the whole network [16]. Social media play a key role as a supporting technology. Managers, engineers and workers will have to show literacy with the different flavors of technical communication and cooperation systems [12].

2.3. Action-related competencies

Action-related competency of a person is the ability to take individual or socially constructed ideas to action. It is the ability of an individual to integrate concepts into the its own agenda,

to successfully transfer plans into reality, not only on the individual but also on an organizational level.

Digitalization of production inevitably will lead to high financial and technological efforts. The inherent risk of such efforts needs pragmatic thinkers and actors that bring down the "sky-high" vision of Industry 4.0 to the shop floor [15]. Strong analytical skills and an ability to find domain-specific and practicable "brown field" solutions without losing the overall goal are key competencies of future engineers. Managers must be able to break down complex concepts into realistic work packages, to find and to assign appropriate people and teams. As Industry 4.0 is not a straight forward methodology or technology managers are required to encourage taking new routes ("green field") but also to take into account risk of failure. For workers and managers alike a strong interdisciplinary "out-of-the-box" orientation is likely to facilitate solution finding in complex environments. Probably the most critical competency for acting in a future production is the ability to deal with the existence of parallel structures: structures that are actually outdated but vital for continuing operations and structures that are built in parallel for meeting new challenges.

2.4. Domain-related competencies

While the above outlined classes of competencies are largely independent of the environment or context an individual is embedded, domain-related competencies refer to the ability to access and use domain knowledge for a job or a specific task. Domain knowledge includes methodologies, languages, tools that are especially important for a problem or business domain and reaches beyond the trivial.

A core element of Industry 4.0 is the full digitalization of production and the exploitation of data to enable intelligent planning and control of production processes and networks. Production processes and networks (also those in the future) have domain peculiarities that require domain-specific competencies.

Digitalized and intelligently managed production processes require workers that are capable to understand the basics of network technologies and data processing [15]. In the future material and work flows will entirely be accompanied by respective information flows and related information processing equipment, e.g. sensors, RFID tags, embedded computers. All these technical components are strongly connected and have high interdependencies although each component is able to act in an autonomous way. Workers will need to evaluate whether the subsystems are functioning as expected and must be able to interact with such systems through appropriate interfaces. In case of disturbances workers and engineers must be able to analyze complex systems through specialized software.

For engineers a deep understanding of interrelations between the electrical, mechanical and computer components will be a vital ability [15, 12, 17] in order to develop innovative products and processes and to solve related problems in quality. Both products and processes will increasingly be engineered through so called virtual representations which requires an ability towards abstract thinking and modeling with support of specialized software, e.g. PLM software. Software and data are key elements for intelligent planning and control of machines and factories of the future. Therefore, engineers are required to acquire knowledge about state-of-the art software architectures, modeling and programming techniques [15]. In addition, statistical methods and data mining techniques are key abilities for future production engineers [13], [17]. Advances in material technology will require skills regarding new production processes [17], [14], e.g. 3D-printing. Lean principles [17] can be regarded as a basic competence that need to be transferred as well to the technical level.

Apart from the above outlined cross-domain competencies also industry, company and process specific competencies will be required, e.g. continuous versus discrete manufacturing.

3. Scenario-based learning factory approach

3.1. Scenario-based Learning

Engineering and management practice has to deal with uncertainty, with incomplete and contradicting information from an organization's environment. In addition, also continuous technological and organizational changes in the workplace impose challenges to the individual.

However, the prevailing mode of teaching is similar to that teaching practices of the 1950's, with large classes and single-discipline, lecture-based courses. Hence, recent developments show a slow change towards student-centered learning such as problem-based and project-based learning [18].

Scenario-based learning (SBL) is rooted in situated learning and cognition theory [19], [20]. Situated learning theory claims that learning is most effective when it takes place in its natural context where the acquired knowledge is going to be used. Thus, knowledge can be transformed to competencies of action [20]. Kolb similarly states that learning is effective when it constantly shifts between "thinking" – a process of abstract conceptualization, "feeling" – largely based on experiences, "watching" – a process of observation and reflection and "doing" – an active stage of experimentation [21].

Scenario-based learning (SBL) uses scenarios, structured descriptions of real-world problems and related instructions, to support active learning. Scenarios are therefore the starting point for students to immerse in a real-world problem and a subsequent solution finding process. During this process students must apply their individual knowledge and cognitive and social abilities to collaboratively solve problems in a safe environment. SBL is an iterative process and provides numerous opportunities for feedback and discussions.

3.2. Industry 4.0 Learning Factory at TU Wien

TU Vienna recently has decided to build the first Industry 4.0 Pilot Factory in Austria. The planned Industry 4.0 Pilot Factory (I40PF) will serve both as a research platform and a teaching and training platform with regard to future production. The teaching and training part of the factory will be based on the former "Learning and Innovation Factory for Integrative Production Education" (LIF) which has been built some years ago. LIF has served as a platform for cross-disciplinary and practical education in production. On the basis of LIF, the course "Integrative Product Engineering Process" (i-PEP) was

developed to enable students to learn along the whole production process in a practical "hands-on" way, starting with the customer request and ending with the delivery of the developed and manufactured products [22]. I40PF will extend this concept with regard to Industry 4.0 competencies as outlined in the previous sections and the target groups, e.g. managers, engineers and workers from industrial firms. The main objectives of I40PF are:

- Research in the environment of „Smart Production". Technology solution providers, IT-contractors and Software Designers develop new concepts, models, technologies and systems in cooperation with scientific partners and validate the results together with technology applying manufacturing companies in the experimental area of the pilot factory.
- Providing access to new technologies and ICT for companies, especially SMEs, that have predominantly no own research infrastructure. If necessary, academic experts from various research fields can support their research, development or testing activities.
- Contract manufacturing, for example as support for start-ups, which require special technology competencies and manufacturing or assembly capacities to produce their prototypes or small lot series.
- Higher education of students on the basis of acquired research results. Beyond that, the innovative infrastructure is used for arranging lectures practically relevant and application-oriented.
- Advanced education trough hands-on workshops and seminars for staff from industry. Especially the increasing field of digitalization, which implicates an enhanced degree of abstraction including complex coherencies, can be educated and demonstrated in a practice-oriented way.

Although the I40PF will be focused on discrete manufacturing it will be open for cooperation with various industries (machinery and equipment, automotive, …). In particular, for SMEs, which have a rather large share in Austria's economy, we plan to provide easy access to the Industry 4.0 through the Pilot Factory. SMEs face the challenge of adopting Industry 4.0 ideas with little financial and human resources. Therefore, new technologies require a high level of maturity to pay back within a reasonable time. New and sophisticated technology as propagated by Industry 4.0 need a future-orientated qualification of employees to generate product, production and process innovations and improvements.

The I40PF will be built upon the concept of a human centered cyber-physical production system for „high-mix and low-volume" (lot size 1). Therefore, we partnered with 20 leading industrial technology and solution suppliers that will support us to build a state-of-the-art factory and will provide their knowledge in developing a factory that goes beyond the current state-of-the-art towards Industry 4.0. In particular, we will implement a cyber-physical manufacturing system, a cyber-physical assembly system and a cyber-physical adaptive logistics system. In the following the latter two subsystems will be described in more detail which are under the supervision of our research group at TU Wien.

The cyber-physical assembly system (see figure 1) will be composed of several connected mobile assembly stations. Within the assembly line various products will be assembled with lot-size 1. We are currently planning to use a consumer class 3D-printer as a demo product for our assembly line. The production worker will be supported in terms of managing complex assembly tasks as well as in managing physical, cognitive and psychological stress situations. On the one hand, support will be provided through digital assistance systems, and on the other hand by intelligent assembly technologies and collaborative robotic systems.

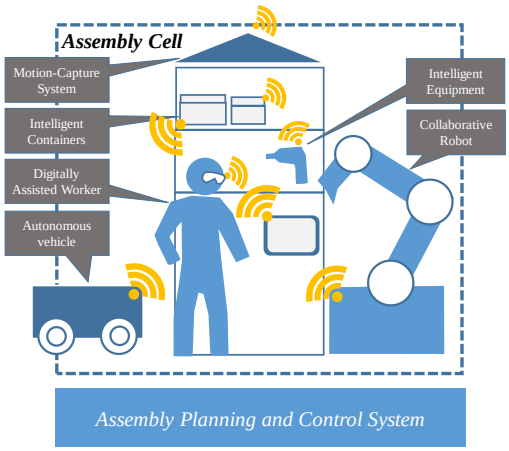

Figure 1: Assembly cell concept for the TU Wien Pilot Factory

The digital assistance system which is based on augmented reality technologies and a "wearable device" will display context-related work content information to the worker to enable the correct execution of an activity. In addition, the assembly process is monitored by ultrasound and different sensor systems. Handling errors of the worker are pointed out with adequate support information to correct the mistake. Here also ergonomic stress situations of the production worker are monitored in real time by a "Motion-Capture System". This information is used in order to identify and to analyze synergies between productivity and ergonomics quantitatively and to achieve a specific data flow to improve ergonomic stress situations continuously in the planning and control system of the work systems.

By sensitive and collaborative robotic systems, a context and situation sensitive support of the production worker is ensured. In this way, an ergonomic, age-appropriate and productive work execution is ensured next to the reconfigurable age-appropriated design of the assembly stations. All technical systems used in the assembly line – such as intelligent screwdrivers – will be connected to a quality assurance system which in combination with information systems will ensure an effective quality management.

The work piece itself is assembled on driverless transport systems (intelligent work piece carriers). The interaction of commissioning, autonomous transport vehicles as well as the transfer of goods between intra-logistics and production will be demonstrated in terms of highest possible adaptivity. Short time adaptability and scalability of interacting modules will be simulated in different use cases. Bilateral flow of information

between virtual planning and the physical manufacturing environment will continuously be further developed in research projects between research facilities and industrial partners. Another prospective research focus lies on indoor localization of goods, transport vehicles or products to gain the maximum of transparency. Other demonstrated innovative technologies are Auto-ID solutions like RFID for fully automated monitoring of goods as well as booking of goods. Apps will support the control of inventory and will lead to a higher transparency for operators.

The whole production system will be accompanied by a state-of-the-art information technology hardware infrastructure and software, e.g. a complete ERP and PLM Suite.

3.3. Towards Scenario-based Learning for Industry 4.0

For the purpose of making Industry 4.0 more tangible, in the sense that the basic problem area and solution area of Industry 4.0 can be more easily approached by practitioners and students

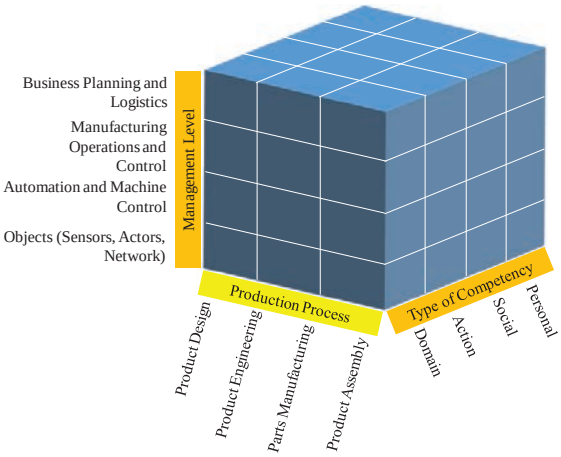

Figure 2: Problem area-competency cube

we combined a Learning Factory with a Scenario-based Learning approach. The learning concept is itself targeted at the competencies for Industry 4.0 as outlined in section 2.

In order to develop particular scenarios as a basis for learning different types of competencies regarding different problem areas, we developed a problem-competency framework which is illustrated as in the form of a cube (see figure 1) which implies a three-dimensional approach. The first dimension refers to the management levels of the enterprise as suggested by the ISA-95, IEC 62264 standards and most recently by RAMI4.0 [23] which is regarded as a reference architecture for Industry 4.0 production systems. The management levels in combination with the process areas (second dimension of cube) provide a complete map of the different problem areas of a manufacturing company reaching from product design to delivery. E.g. a typical problem area is the assembly process on the automation and machine level (see table 1).

For a targeted development of scenarios as a means for problem-oriented learning the third dimension – the types of competencies – serve as a point of reference. Based on these dimensions, different roles and related target groups for learning (e.g. manager, engineer, worker) and their required competencies can be modeled and addressed through appropriate scenarios.

In table 1 we have illustrated an exemplary scenario for the problem area assembly process on the automation and machine control level. The scenario is intended to address the different types of competencies required for the problem area "product assembly process" on the "manufacturing operations and control level". The *scenario description* allows a learner to understand the real world context and problem area. It serves as well as a trigger for solution development. Below the scenario description, several *tasks* are formulated in a way that stimulates imagination and critical thinking, thus provoking a collaborative and creative problem solving process. Learners engaging in completion of tasks are provided with *resources* that facilitate the solution finding process. Resources can be methodologies, tools, data sets, technologies and also human experts.

Table 1: Exemplary scenario description for assembly process

Scenario	It is March 2016. The Chief Operations Executive of M Corp. has announced that – due to increasing competition from the market – a substantial decrease in delivery time for low-volume customers must be achieved by the operations department. So far, the focus for reduction of delivery time will be on the assembly process of a particular product – the slot car. The results of the analysis and optimization concept will be transferred to other product lines in case they lead to significant improvements. For an initial analysis of the actual assembly process a data set is provided along with several interview data from workers about their daily work. …
Tasks	- Use the provided data to find out actual weaknesses of the assembly process. Ask yourself how an ideal manufacturing process in discrete manufacturing should look like regarding organization of work flow and material flow, takt-time and stock quantities, quality. - Given that you have identified the actual weaknesses of the process. What are adequate measures to improve the performance of the process? Which concepts (organizational, technological) exist that could lead to a significant improvement. Make a short list of concepts (organizational, technological) that is ranked regarding the potential impact on the performance of the process. - …
Competencies addressed	**Personal** - solution-oriented attitude - creativity, out-of-the-box thinking **Social** - team work ability - consensus finding ability, compromising - role taking, role making ability **Action** - Problem analysis and structuring, solution development - Data analysis and interpretation - Method, tool selection and use **Domain** - Application of Lean thinking and methods in manufacturing - Application conceptual modelling methods, e.g. data flow, material flow and process modelling - Application of Information and Communication Technology for material tracking and worker tracking
Resources	…

4. Conclusion

In this paper we shortly describe our endeavor to make the abstract vision of Industry 4.0 more tangible by means of a Learning Factory approach in combination with Scenario-based Learning.

Although still in the planning phase, the TU Wien Industry 4.0 Pilot Factory will serve as a basic infrastructure for the implementation of this concept.

The basic assumption of our approach is that human actors in a future production scenario will need specific competencies to cope with the new challenges regarding technological and organizational developments and business models. In order to frame the set of competencies required we developed a preliminary competency catalog where we distinguished competencies according to Rosenstiel und Erpenbecks competency framework and according to typical roles in production.

Based on the competency categories and typical problem areas of digital production systems as suggested for example by the RAMI4.0 architecture model, we created a "problem-competency cube" which serves as a reference for targeted development of problem-specific competencies and educational formats such as scenarios for problem-oriented and practical training towards Industry 4.0. We are still in the planning phase for our Learning Factory, therefore we will need to further detail our "problem-competency cube" and as well the scenarios that we are going to use for teaching.

There is a general need for rethinking competencies in the light of new technological developments which have significant impact on the way we design production systems of the future. Our theoretical approach together with the Industry 4.0 Pilot Factory is intended to be a first step towards a more tangible vision of Industry 4.0.

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