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A Learning Approach for Future Competencies in Manufacturing using a Learning Factory

Håkon Dahl[a], Nina Tvenge[b,*], Carla Susana A Assuad[b], Kristian Martinsen[a]

[a]*SINTEF Manufacturing, Enggata 40, 2830, Raufoss, Norway*
[b]*NTNU Department of Manufacturing and Cicil Eningeering, Teknologivn 21, 2815 Gjøvik, Norway*

* Corresponding author. Tel.: 0047 40636548. E-mail address: nina.tvenge@ntnu.no

Abstract

This paper describes a study on future competence needs in manufacturing and how a learning factory utilising a Connective Model for Didactic Design can be used in teaching and learning of these competencies. The paper briefly reports on a literature study, and a set of interviews in Norwegian manufacturing companies to get a better understanding on the expected future competence needs. This was used to design a learning process with four steps: 1: Exploration, 2: Product and process design, 3: Problem solving and 4: Debriefing. The method was tested in a case study where undergraduate students are learners following the 4-step method. The approach was evaluated through feedback from the learners. The case utilised a Festo CP-Factory learning factory at NTNU.

Keywords: Learning factory; Work related learning; Industry 4.0; Learning method; Manufacturing; Future work competencies

1. Introduction

Industry 4.0 technologies are changing how production is organized and what competencies a production operator must possess to perform satisfactorily at work. Increasing automation and use of AI and other advanced self-adaptable systems reduce the need for manual labour, and future operators will be “brain-workers” [1]

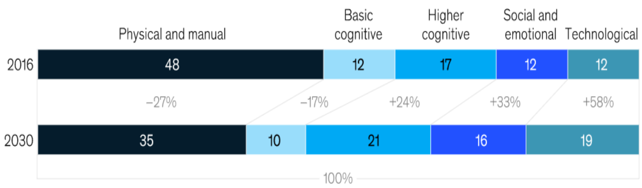

Fig. 1. Shift in US and W. Europe competency needs, % of time spent [2].

Fig. 1 shows results from an McKinsey analysis [2] indicating expected decrease of manual work and increased need in cognitive, soft (social and emotional), and technological competence. A similar study by Deloitte in 2018 shows expecting increase in technical competence, complex problem solving, cognitive and social competence to cope with Artificial Intelligence (AI), automations and robotics [3]. A more surprising aspect of the survey was that 49% of the respondents did not have a strategy on how to the needed competencies can be learned [ibid.].

The EC DG R&I white paper “Industry 5.0: Towards a sustainable, human-centric and resilient European industry” [4] point at “*One of the most important paradigmatic transitions characterising Industry 5.0 is the shift of focus from technology-driven progress to a thoroughly human-centric approach.*” The evolution of traditional training and teaching in manufacturing has, however, struggled to cope with the advances in manufacturing technology [5], and high-fidelity learning factories designed to offer (close to) industrial experience has been introduced as a novel learning tool [6, 7], creating knowledge, skills as well as competencies. The CIRP Collaborative Working Group on Learning Factories [8] have stated that learning factories contain authentic processes, multiple stations/value chain, technical as well as organizational aspects, manufacturing physical products, and with a didactical concept that comprises formal, informal and

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non-formal learning, enabled by own actions of the trainees in an on-site learning approach.

Abilities in system-thinking approach or the understanding of how complex systems work by studying real-life examples can help students see a variety of opportunities to alter the system. This will help them develop abilities to recognize solutions and improve the work [9, 10]. Four classes of competencies were defined by Erpenbeck and Rosenstiel [11] in [5, 12]: (i) Socio-communicative competencies, (ii) Technical and methodological competencies, (iii) Personal competencies (motivation, self-organisation and ability to adapt and reflect, as well as (iv) Activity and action competencies. A well-designed learning factory should preferably lead to learning outcome in all four classes.

1.1. Learning theories suitable for learning factories

There are many theories of learning, i.e.: behaviourism, cognitivism, constructivism, experiential learning and connectivism [13-15]. The different theories offer different perspectives on learning goals, learning performance, transfer of knowledge processes, motivational processes, the role of emotions, and the implications of the teaching methods [16]. Not all learning theories are suitable in every type of learning situation. Learning factories are work-based [17] allowing to do experiments, test different scenarios etc. often not possible in work-bound or on-the-job training [5], and in this research we focused on experiential learning which is stated by Abele et al. [ibid.] as the major benefit of learning factories. Learning factories have the potential to be used in cognitive, affective, and psychomotor learning [12].

1.2. Methodology

In the research described in this paper we have formulated two research questions:

RQ1: What competencies are essential for a manufacturing worker towards 2030?

RQ2: How can a manufacturing worker acquire needed future competencies using a Learning Factory?

To provide further insight in RQ1, we have performed a literature study as well as interviews of managers in selected Norwegian manufacturing companies. The results were used for the second RQ applied on a case study of a real learning situation with students at the NTNU. The interviewees were selected from businesses that show a strong ability to perform in a competitive market. All participants represent companies that are positioned in or in proximity of one of the biggest clusters of production companies in Norway, Raufoss Industrial Park. The interviews were so-called semi-structured with an initial list of questions, but with room for elaboration, follow-up- and open-ended questions, allowing discussions on the topic.

The case study followed the use of a learning factory at NTNU by one group of students throughout one semester. The learning factory is based on Festo Didactic CP-factory modules [18]. The case study evaluated the usage of learning factory in the learning situations, the usefulness of the learning factory in reaching the learning outcome goals as well as how the NTNU learning factory comply to generic learning factory literature and definitions.

2. Competencies for future manufacturing workers

To get more insight on expected future competence needs a literature study and semi-structured interviews were made. The literature studied where quite united in the expectation of future manufacturing workers will spend less time on manual labour and more on tasks needing higher cognitive, and technical competence [1-3, 9, 10, 19-23]. Furthermore, that there is to some extent a lack of strategy and insufficient learning methods to upskill workers to meet the future demands. The Future of Jobs Report 2018 [3] found that creativity, originality and initiative, analytical thinking and innovation, active learning and learning strategies, as well as technology design and programming are expected as emerging skills in Western Europe.

The interviews were made with managers in 5 different globally competitive Norwegian manufacturing companies. Two of the companies were SMEs, the other part of larger international groups. The persons interviewed had managing roles such as Chief Executive Officer (CEO), Chief Operation Officer (COO), Chief Learning Officer (CLO), chief human resources officer (CHRO) as well as Chief Quality Officer (CQO) [24]. The interviews confirmed the literature study, but also highlighted the need for a broad competence with technical understanding of the manufacturing processes and equipment/machines, as well as mathematical, digital and automation competence. The perception is that growing use of advanced AI-based adaptive and cognitive automation, will result in increasingly demands on the competence levels. In other words, according to the informants in this study, future workers are masters not slaves to the AI systems. The managers where quite united in the need for future workers to be autonomous; having a broad system-understanding. The table underneath summarize the results from the interviews:

Table 1. Expected competence and typical work for manufacturing work force in 2030.

Expected competence and typical work for manufacturing work force in 2030	
Knowledge and skills	**Typical work**
• Fundamental process knowledge • Broader systems understanding • Data management • Coding, mathematical knowledge • Collaboration and human interaction • Automation and robotisation	• Supervising process monitoring and control using AI • Human -machine collaboration • PLC and robot programming • Using digital tools for decision making and problem solving • Autonomous, empowered, flexible

3. Case study on NTNU Learning Factory

As Table 1 shows, the requirements on future workers are high. This study resulted in a proposed 4-stage learning approach or method where some of the knowledge needs are in focus: fundamental process knowledge, broader systems under-standing, data management, collaboration and human interaction, human-machine collaboration, and using digital tools for decision making and problem solving. The approach aims at covering all four competencies classes defined by Erpenbeck and Rosenstiel [11]. (A classic theoretical learning situation will normally not be able to cover all competencies). The case study comprises a proposed learning approach with a described learning scenario: a high-fidelity learning simulation setting and can as such give some insight in to the original research question (RQ2). Further study will focus on letting workers from manufacturing industry test the same framework as presented next.

3.1. Learning scenario framework

Because the framework of any given educational situation varies, i.e. the students, teachers, classrooms, politics and curriculum, among others, generating a common theoretical framework is very difficult according to the "Model of Relations between Didactical Categories" by Bjorndal and Lieberg [25]. Here, in this study, we have experimented with one way of dealing with this issue aiming to decrease the gap between practice and research, theory and application [26], making the learning setting as authentic as possible, a so-called high fidelity simulation [27]. The basic structure of the case study follows the "Connective Model for Didactic Design in Learning Factory", based on Riis [28] shown in Fig.2, which again is based on Bjorndal et al. [25]. The teacher(s) act as facilitators, i.e., taking a more observational role than a traditional teacher role. The learning factory, as described in 3.2, is the technological part of the framework, content and learning goals are described in 3.3, learners and time and in 3.4, the process as in "activities" in 3.5→ 3.8 and evaluation of the learning process in 3.8.

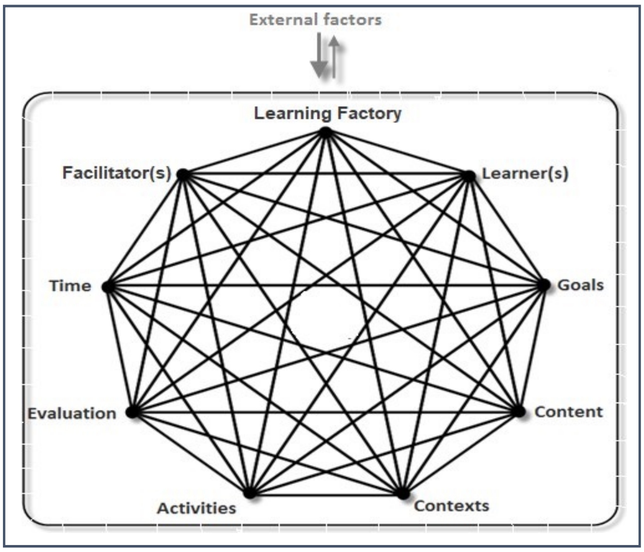

Fig. 2. *Connective Model for Didactic Design in Learning Factory* (based on Riis [28]).

3.2. NTNU Learning factory

The learning factory at NTNU consist of flexible Cyber Physical (CP) factory modules delivered by Festo Didactic AS, as well as number of desktop polymer Fused Filament Fabrication additive manufacturing machines. The Festo CP modules cover storage units, manual stations, automated assembly, 3-axis CNC milling, machine vision inspection, a heating station and a press. The products are transported on pallets on a conveyor-belt and an AGV. The modules are interchangeable, re-programable and ready for additional equipment.

A categorisation of the NTNU learning factory according to the learning factory morphology [7] can be: Academic institution ownership, operated by technical experts. Purpose is a mix of research and teaching, target groups university students and industry workers. A mix of processes; automated assembly, pressing and heating, CNC milling, Machine vision inspection. The learning factory offers physical production in a scale-down environment. It is possible to implement new technologies, especially on the application level. A Manufacturing Executing System (MES) is included. The standard product in the CP-factory is a Festo dummy mobile-phone consisting of 5 parts, but in this case study the student should propose other products. There are room for up to eight students/learners to attend simultaneously. A part of the learning factory is shown in Fig. 3.

Fig. 3. *Learning factory at NTNU.*

3.3. Case description

The learning goals in this scenario is to make the manufacturing workers understand an Industry 4.0 manufacturing system, the relations between the modules and problem solving in an Industry 4.0 factory. After the learning process, the learner is expected to describe what components make an Industry 4.0 system and how it is functioning, as well as analytical thinking are used to solve problems. The experiential learning theory sees learning as constructing knowledge and meaning from real-life experiences, and the learning factory functions as the platform or environment with Industry 4.0 technology.

The learners in this case where undergraduate students at the NTNU campus Gjøvik. They were divided into three groups, working together on each of the steps in the learning process. The total time spent for the learning was around 200 hours in total for each learner. The experiments follow the following stages: (i) Exploration stage, (ii) Product and process design phase, (iii) Problem solving stage, and finally (iv) Debriefing stage.

3.4. Exploration stage

After an introduction, the learners are given time to explore and investigate the learning factory with the guide of the facilitators. This segment of the learning process is driven by the curiosity of the learners, while the facilitators are not taking an active role, but provide their expertise if questions arise from the learners. From this stage the learners shall understand the basic principles of the learning factory, how the modules interact, and what are the capabilities of each single process as well as the Learning factory as a system.

3.5. Product and Process Design stage

The three groups have the task of designing a product and a process plan for production in the learning factory, preferably with potential market value. The learners must think not only on product design but also the process, i.e. design for manufacturing. The three products in this case study can be seen in Fig. 4, and was a set of toy gears, cutlery holders and Ganh-game boards, all made in polymer materials. The volume was expected to be medium to high (making it suitable for this learning factory). The toy gear and Ganh-game parts are CNC-milled, inspected by machine vision, and assembled. Glue is used at selected places for fixed assembly, cured by heat. The cutlery holder parts are also CNC-milled and inspected by machine vision, but assembly is done by the customer. The balls in the Ganh-game are delivered by subsupplier. All parts should fit the conveyor system with customized palettes, CNC fixtures and robot grippers. In this case, the products were not actually manufactured, due to lack of time. The learners got feedback om their products and feasibility on process plans though.

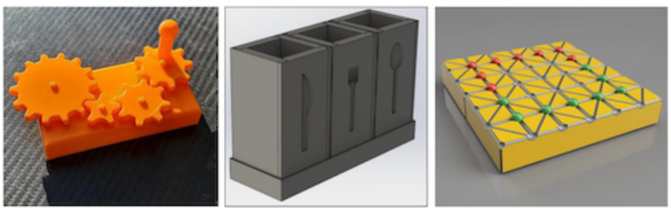

Fig. 4. Toy gears, cutlery holder, and Ganh-game. Student reports in [24].

3.6. Problem solving stage

In this stage the standard Festo-product is used, and the production process is altered in such a way that some of the parts are faulty. Some of the faulty workpiece can continue its way through the value chain without being stopped by the system. This means if a problem occurred in assembly, it does not have to be the root cause. The learners analyse data from the MES system and perform additional experiments/ testing in order to identify and define what the problem is, the root cause, and how to fix the problem.

3.7. Debriefing stage

In the debriefing stage [27], each group must reflect and discuss upon their learning process and outcome, both as a group and individually. All groups have given feedback to the research team through extensive written reports. Their feedback could be summarized like this:

- The exploration stage and the acceptance to let the students "play" with the learning factory equipment (with assistance from supervisors) gave the learners a good insight in "Industry 4.0" manufacturing equipment and how future manufacturing systems might look like.
- Combined focus of product and manufacturing process design with the limitations given by the learning factory, gave the learner a more realistic learning experience on the design stage of a product and the necessity of design for manufacturing.
- The problem-solving stage gave the learners experience in problem solving both practically as well as how to analyse data from a MES system to find the root cause.

A quote from one of the group reports: "*In order to develop a product that could be produced in the learning factory, the focus was all the way to design products and make changes in the learning factory adapted to each other, so that the learning outcome got as great as possible. Without this focus, it would have been possible to focus only on the product design, and thus miss out on a great deal of learning on the process-/production design part of product development. We found the project to be a successful test of the learning factory's opportunities and challenges. This has been a very good opportunity to learn both how a product can be adapted to a factory setting, but also how a factory can be adapted to a product.*"

4. Conclusion

The paper indicates future competence needs and showed how the use of work-based learning factories can be a promising approach to acquire these competencies. The paper suggests an approach rooted in learning theories, learning methods, didactic design, and the characteristics of the learning factory. The four-stage learning approach was designed with the aim to cover several of the needed competencies, and feedback form the learners was mainly positive. The learning approach can be used in other learning factories, it can easily be generalized as well as adapted to changing needs and contexts.

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