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## Integration of digital learning in industry 4.0

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### Abstract

The emerging advances in sensor systems, automation and Information and Communication Technology (ICT) for manufacturing opens new possibilities for lifelong learning utilizing data from production. The data can be source for on-the-job practical learning as well as serve as cases for more formal learning situations. This paper proposes a model for company's implementation of learning, and discusses how this implies a closer integration with the learning activities to the cyber-physical manufacturing system as a seamless, integrated ICT learning and a hybrid human/machine intelligence model where data analysis, simulations and communication are sources for not only decision support, but also continuous learning and knowledge enhancement.

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### 1. Introduction

Future manufacturing systems are becoming intelligent, constantly learning and improving, with high adaptability to changing environments, increasing resource efficiency, and smart integrations of humans and technology. The emerging technological advances in sensor systems, automation and ICT for manufacturing plays a major role in this evolution. Some call this trend as the fourth industrial revolution, and “Industry 4.0” is a buzzword frequently used to describe this. The basis are technologies such as; Flexible Automation, Wireless Sensor Systems, Cyber-Physical Systems, Artificial Intelligence, (Big) Data Analysis and Internet of Things. Cyber Physical Manufacturing Systems (CPMS) will be a combination of computational elements, physical elements, software and humans. This trend implies

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changes in manufacturing workplaces towards less manual work and more “brain”-work. Future manufacturing workers need ability to analyse, abstract and innovate and the knowledge levels in general are rising.

### 1.1. A need for novel workplace learning paradigms in Industry 4.0

The increasing need for a competent workforce leads to an acceleration of the need for lifelong learning. On the other hand, are traditional social/practice based learning paradigms challenged by the current trends. The increasing digitalisation will change how we communicate and how we learn [1]. In traditional social learning systems in manufacturing, the individuals are working and learning together in teams or Apprentice-Systems. Lave and Wenger [2] described this as Communities of Practice (COP) which provides “*a sense of belonging, commitment, and shared identity*” [2]-[6] and a method for employees to learn from each other. In Industry 4.0, this way of learning seems to be challenged due to more specialized work and fewer employees doing the same type of work. Fewer people and more physical distance between each person results in new work organizations. This implies the need for novel learning systems i.e. in the form of supervision, guidance and collaborative learning; synchronous and/or asynchronous, mediated through ICT tools. ICT tools make it possible to develop new learning methodologies, throughout the spectrum from lifelong learning to campus students. The use of modern ICT opens new potentials for on-the-job, individual workplace learning, from more or less primitive e-learning schemes to advanced serious games [7].

### 1.2. ICT supported workplace learning

ICT has a natural place in Industry 4.0 education and knowledge creation, and there are versatile expectations to the effects on ICT supported lifelong learning [8] ;

- increased learning as an effect of access to more data and knowledge
- more efficient learning
- learner focused learning activities
- new learning environments with higher degree of collaboration/cooperation
- more opportunities for critical thinking and analytical approaches

Current implementations of ICT aided learning paradigms have, however not always been satisfactory for the involved participants [9]. One reason might be the gap between the formal ICT-supported learning and the practice based learning at the workplace. Formal learning plays currently only a minor part in workplace learning, a norm is that about 80% of workplace learning is informal [10]. Research shows that ICT supported learning will not make the teacher obsolete. ICT can boost more effective and efficient learning processes, but not without support. Learning activities as social interactions guided by a teacher, has had the greatest impact on learning outcome, significantly bigger than other methods [11].

More and more authors point to the fact that ICT-based learning has gone from being closed off and centred around the individuals to being social and where sharing is essential: The learner’s needs are at the centre, not the technology itself [12]. There is, however, still a need for social and practical training and technology is not a substitute for this, but a range of different tools that can enhance learning and increase students’ learning space [13]. The ability to collaborate is highly acknowledged and wanted by employers, therefore teamwork and communication must be facilitated in forthcoming work place learning paradigms. A growing number of social networks and other web 2.0 and web 3.0 services can be used for flexible and informal learning and provide access to experts and peers. This is also called semantic web and make it possible to share infinite amounts of multi-medial learning resources in future Industry 4.0 learning. Workers can set up their personal learning environments (PLEs) according to their interests, learning styles and ambitions. This is both an opportunity and a challenge for the individual learner. Large enterprises have the power to develop internal personal learning environments; SME’s have to utilize more or less ready-made solutions [14]. Open educational resources (OER) are freely accessible documents and media resources for teaching, learning, education, assessment and research purposes.

### 1.3. Industry 4.0 Learning factories

Learning Factories are physical learning spaces where social, practical and theoretical skills can meet and evolve [15] - [29]. The term dates back to the nineties and was born from the need to have more practical education of engineers, copying the model of nurses and medical doctors' education using university hospitals. Practical training in real factories has some limitations though, experiments and trial-and-error are costly and therefore not allowed. Since then the concept has evolved to include high-fidelity factory simulators where experiments, research and education can be combined. Such a Learning Factory emulates a real factory, contains real live processes, products and people. Abe et al. [18] has been working on a learning factory morphology, and the focus is on practice-oriented learning processes, but the effects on learning outcome and best didactical approaches are not well mapped yet, although there has been increased focus on this lately [30]-[32]. Another debate is whether learning factories are focusing too much on efficiency, as in reducing production costs, rather than human needs and demands in the manufacturing systems [21]. A physical learning factory would, however still imply a need for the learner/student to move away from the workplace to get to the learning factory. We claim that learning factories needs to be complemented with future workplace learning paradigm integrated in the Industry 4.0 work system.

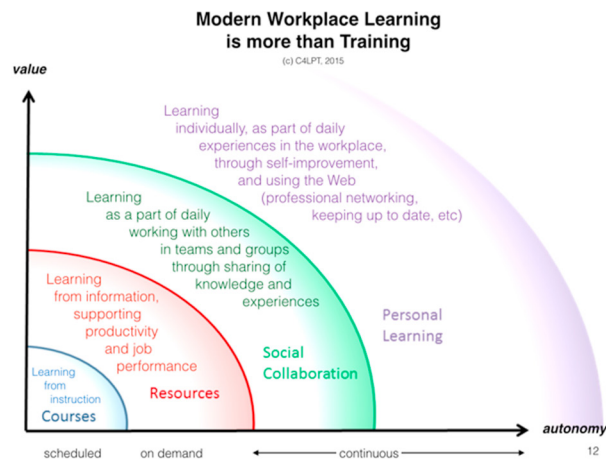


Fig. 1. The Modern Workplace Learning Framework [34].

## 2. Integration of learning in Industry 4.0

### 2.1. Workplace learning in Industry 4.0

Figure 1 shows a workplace learning framework developed by Jane Hart [33]-[36]. She emphasizes the importance of management support to personal learning rather than management control of learning activities. One conclusion from this work was that modern learning is different from traditional learning in many ways as it is: continuous, on demand, takes place in short bursts and on the go and in the flow of work. Furthermore, it is social, serendipitous, autonomous and personal performance-oriented.

With the increased automation, monitoring and control and autonomous systems, the future workplaces has less or no need for constant human interaction. Humans are monitoring the processes and are more involved in maintenance, improvements and innovations. The new Industry 4.0 work system creates “pockets of time” available for activities such as learning and training. These time pockets can be impossible to plan ahead, so it will be difficult to synchronize learning activities with other persons. This means the learning modules must be adaptable, short and possible to accomplished unsynchronised with teacher(s) and other students. Individual learning tasks such as e-learning or simulation/serious games are one possibility. However, as discussed earlier; social interactions, has a large impact on learning outcome [11], and should be promoted even within the asynchronous timeslots. The learning experience (for example when training of tacit skills) can be shared and discussed through the virtual classrooms/ learning management system, which should have social media functionality. The learning systems should be adaptable

to each individual student/learner needs and ambitions. Each learner/student and their leader(s) should have an active and continuous view to their career. Career management skills (CMS) are thus an important competence in future Industry 4.0 manufacturing systems [37]-[39]. The CMS will be used to guide the student on his/her individual path through series of possible learning modules. These modules should – as far as possible- be short and containing all necessary elements of learning- including description of expected learning outcome, learning material and final assessment/ examination. Figure 2 shows an illustration on this.

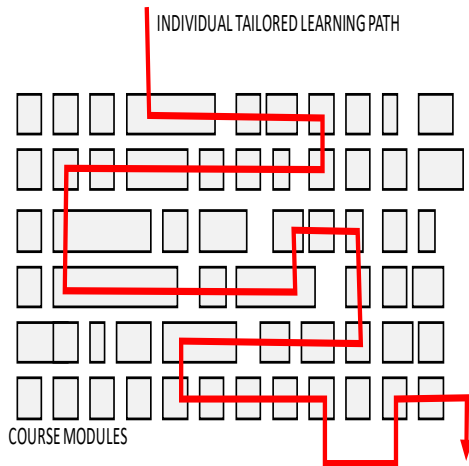


Fig. 2. Tailored learning path.

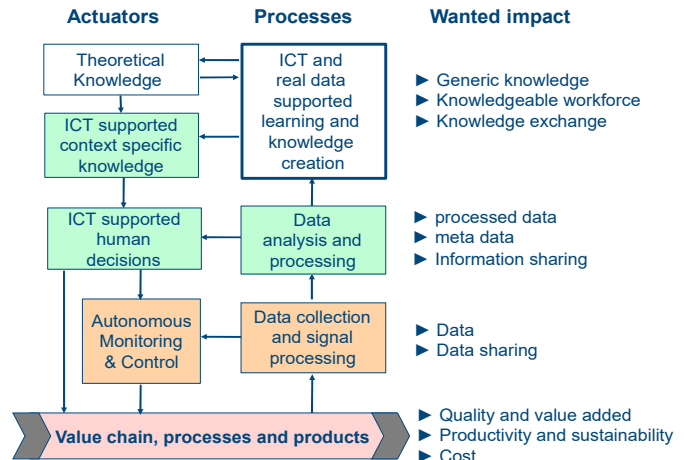


Fig. 3. Integration of learning in Industry 4.0.

## 2.2. Bridging formal and informal learning

The learning modules should, as far as possible utilise data, analysis, simulation and visualisation from the students actual manufacturing system. This is illustrated in figure 3. Data collection from sensors and measurement from the manufacturing processes, components and products along the value chain are used for autonomous or human control. This can be seen as a first and second control loop. Humans decisions are controlling, improving and innovation in the process itself as well as the first loop autonomous control system. The third loop is where the human learning occurs, and by analyse and systemize data from manufacturing, context specific knowledge about the processes will increase, and thus the ability to solve problems and innovate on the processes. The figure indicates how knowledge, human decision and autonomous control are “actuators”, while data collection, processing and the learning are “processes”. The wanted impact is not only increased productivity, quality and value added to lower cost, but also increased generic knowledge and a more knowledgeable workforce.

Generic theoretic knowledge is of course more or less used in this process. This is where we can bridge formal and informal workplace learning by involving the actual data, analysis and problems from the workplace into the virtual classrooms of the formal learning situations. In order to accomplish this, these elements need to be in place;

- The processed data must be fitted to the learning situation
- The learning methods must be fitted for “real life” input/ cases
- The teacher and classmates must be able to discuss and elaborate on the real-life input and connect theory and practice in the case

Figure 4 illustrates how an operator in a Cyber Physical Manufacturing System (CPMS) are affected by on one hand external (formal) learning through online courses or modules, secondly be the joint CMS planning with the HR department and his/her managers, third the knowledge sharing with other operators and forth by analysis of collected data from his/her manufacturing processes and components/products.

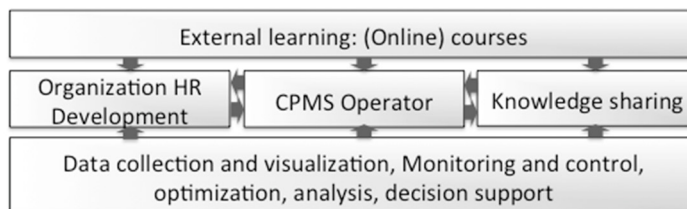


Fig. 4. Bridging formal and informal learning.

### 2.3. Combining workplace learning and learning factories

As mentioned are learning factories places where social, practical and theoretical skills can meet and evolve. Simulation and training of problem solving, maintenance, quality assurance etc. where humans and need to interact with each other and with the technology can be trained in the learning factories. The learning factory can be real-life social learning platforms acting as “physical twins” to digital twins/simulation models/serious games, or physical twins to actual manufacturing systems. Here as well, real data from the actual manufacturing can be utilised in the learning factory. The learning factories can be combined with unsynchronized workplace learning for pre-preparation and post-discussions and contemplation [40].

### 3. Conclusions and further work

This paper describes how learning activities can be an integrated part of future Industry 4.0 cyber-physical manufacturing systems. The approach can be summarized in the following bullet points;

- Virtual classrooms, opening for unsynchronized social learning
- Learning paradigms bridging formal and informal learning
- Systematic use of analysis and visualization of real data from the CPMS in both formal and informal learning
- Utilize asynchronous “pockets of time” for learning activates
- Adaptive learning and individually tailored learning path, pace and evaluation
- Active and continuous career planning and management by and for individuals
- Use of learning factories for synchronized social learning

In the further work, the authors will implement the suggested ideas in a novel Industry 4.0 learning factory, which will be a part of an investment in Norwegian national research infrastructure called MANULAB. There are plans to implement pilots in selected companies in the Centre for Research based Innovation (SFI) Manufacturing.

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