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Abstract

Lifelong learning is essential as the industrial skill requirements are ever-increasing. However, traditional upskilling activities for industrial workers have shown less-than-optimal transfer of the learning content from education to practice. Hence, new approaches are needed, and Learning Factory-concepts are showing great potential. This paper investigates how Learning Factories (LF) under the Manufacturing Academy of Denmark (MADE) apply LF concepts in lifelong learning. The MADE initiative comprises three LFs operated by university colleges which develop and evaluate the learning activities in collaboration with university researchers. The LFs focus on 3D-printing, simulation and Operations Management, respectively. We analyse the MADE LFs' concepts and develop hypotheses to be tested in future work.

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Keywords: Learning Factory: concept; performance; advanced manufacturing; lifelong learning

1. Introduction

The quest for lifelong learning is as relevant as ever because industrial skill requirements change along with new technologies, business models and customer demand [1]. Within manufacturing, workers need new core technical competencies and contextual competencies that may catalyze a given effort's success [2]. However, when workers enroll in lifelong learning, authentic educational activities is important for transfer and motivation [3]. This is essential to obtain behavioral change and ensure the return of investment for worker, enterprise, and society [4]. Traditional industrial upskilling have shown low transfer of the learning content from education to practice [5] . However, with the emergence of problem-based learning approaches [6] and communities of practice and apprenticeship [7], educational practice is changing towards a more suitable path. One such path involves LF concepts offering a high degree of authenticity as a problem-based, multi-stage, and dimensional approach [8]. However, the use of LF for lifelong learning is still a greenfield. This paper describes the MADE LF initiative developed for lifelong learning within advanced manufacturing [9].
The study relies on an understanding of a LF defined by Abele et al. [8]: it can be product-oriented, physical and on-site, but also: Service-oriented, remote or virtual. At the same time, the purpose, operational model, and didactics described by Enke are vital for understanding the LFs' maturity level [10].
The understanding of didactics in this paper is rooted in the authentic, community-based learning approach that is often linked with Scandinavian education [11]. By engaging in authentic tasks that resemble actual industrial tasks, the knowledge, skills, and competencies obtained through the course are easily transferable into the learner's practice. For these competencies to be obtained first, it is also essential that the learner's prior knowledge is activated and linked to a demonstration of the new knowledge, technique, or topic [6]. After the demonstration, the learner can start applying the learning towards simple and later more complex and

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complicated problems. Lastly, the learning can transfer into the praxis of the learner [12]. Reflection enables transfer as new knowledge is chunked with existing ideas [13], which is a central part of the didactics of LFs [14]. However, learning needs to come before transfer. Dale's cone of experience describes how some activities are more likely to produce lasting learning than others. While Dale did not mean this as an absolute model, it is widely acknowledged that more activating activities has a higher learning outcome than passive activities [15]. Dale's model is often associated with percentages of knowledge retention, yet this is not corroborated with empirical evidence and is not part of Dale's work [16]. A learning experiment performed by Winther et al. indeed found that video training performed better than virtual reality training [17]. To meet their goal, the LFs must be successful on all of the four Kirkpatrick evaluation levels; reactions, learning, behavior, and results [4]. The learning is also a result of the planning, especially the didactics. However, behavioral change after the learning factory activity is a knowledge absorbance problem [18]; non-absorbed knowledge is waste.

2. Methodology

This study is designed as Information System Design Research [19]. It was initiated when the three MADE LFs were being established in October 2020 and is thus a simultaneous process of acting and doing research.
Each of the three LFs is operated by a university college and employs a researcher from a university. MADE funds the research and development performed by the LFs from October 2020 to December 2023.
Data for this paper is collected from the LFs' pilots. A MADE LF pilot consists of four phases. In the first phase, the LF reaches out to stakeholders who can contribute to developing a new, digitally-assisted course, e.g., manufacturing firms, suppliers of learning technology, GTS institutes and labour unions. The LF facilitates a collaborative and creative process among different stakeholders where knowledge, experience, and ideas are shared openly and subsequently analysed by the LF. The second phase involves building an innovative course based on the analysed input from stakeholders. Once the LF has built the course it will be tested. Participation is free of charge as the course is still being developed at this stage. During the third phase, the LF evaluates the course and modifies it based on the evaluation. Lastly, the LF invites paying participants to sign up and complete the course in the fourth phase and implements the course as an educational offer at the university college which is independent of external funding from MADE.

3. Analysis

Governance carried out by MADE to facilitate the LFs include a monthly meeting with sharing of ideas and external inputs, a steering committee meeting every six months, a resource repository and international contacts to test courses developed in MADE LFs abroad. MADE administers the external funding, ensures a project charter for each LF, and helps to scope, evaluate, and disseminate the pilots.
LF A builds a digital library with interactive course modules in 3D printing. In the developing phase soft tooling anchor all relevant modules. Polymer moulds are fabricated via additive manufacturing technologies for subsequent injection molding in this process chain. The students will learn operation and quality assurance methods through digital teaching (80%) and physical instruction (20%). Participants are students from a 4-week-course enrolled at the university college operating LF A and selected employees from two industrial companies. The students will participate in the entire training program, while the industrial partners will complete relevant modules. All modules will be open to all participants. In the evaluation, the participants will print a mould using additive manufacturing; the quality should be evaluated and analyzed using the instruments and theories taught. Report from the participants will be scored to evaluate the teaching method. An index will be developed to measure the learning. The obtained feedback and experience will be implemented in the next pilot project. Teaching materials for other additive manufacturing techniques will also be developed as modules. Evaluation for teaching/ learning effect will be further optimized and a follow-up training program will be developed.
LF B started by designing two educational activities with industrial software as learning technologies to transfer knowledge about the value chain to skilled workers. The LF was organized as a virtually extended LF where simple or even analogue learning activities were aided by digital simulations. The digital activities include a virtual simulation of a digital model of a classic lean board game, where the students produce a number of products and experience issues such as bottle-necks. This digital model demonstrates several mechanisms within the exercise and quantifies them, so the learners know the size-effect of, e.g., introducing a product store or similar. Furthermore, a product configurator is used to show the waste amount for product variations and how these can be automated and controlled. These activities are the first out of four phases. The following phases will contain: 2) individual learning technologies and their application as single modules, 3) incorporation of the modules from phase 2 into new courseware for test, and 4) development of stand-alone modules.
LF C conducted semi-structed interviews to gain an understanding of digitalization and automation among the target group. The LF analysed the interviews and decided to develop a course in digitalization of peer-to-peer training as production firms heavily rely on this manual training method. As a next step, LF C held a workshop for three manufacturing companies and introduced them for ways to digitalize peer-to-peer training through e-

learning, training in Virtual Reality (VR) and Augmented Reality (AR). In the demonstration phase, LF C built a course that exposes course participants to four ways of digitally replacing peer-to-peer training. In the evaluation phase, LF C facilitates a discussion among the course participants on pros and cons of specific learning technologies in relation to specific peer-to-peer training scenarios. Lastly, the companies develop an action plan for how to digitalize peer-to-peer training in their own company.

4. Concluding remarks

The operating model, purpose and didactic of the MADE LFs correspond to maturity level 3 in its current state. This is due to the fact that the organizational work processes are defined and described in detail, the target group is determined as employees in manufacturing, and reflection is enabled through feedback collection which is analysed and applied to optimize the final courses. To reach level 4, the LFs will have to implement the pilots as formal courses at their institution and continuously adjust the courses according to ongoing reflection processes. The MADE LFs measure the quality of learning by analyzing the course participants' completion of concrete tasks and by analyzing the course participants' replies to pre-, on- and offboarding surveys. This data is currently being collected and will be analyzed in the Fall of 2022. We hypothesize that:**H1**: the LFs' factory-like learning environment and their course content closely related to the course participants' reality as well as the use of digital learning technologies will ensure a high quality of learning, measured by reactions, learning, behavior, and results. This enhances the transfer from learning to behavior.
Considering Dale's (1969) cone of experience, we hypothesize that the educational activities performed by the MADE LFs will yield the highest learning output. **H2**: The general, expected order is: 1) Interactive learning material with a high degree of authenticity in expression, 2) interactive material in general, 3) one-way communication with a high degree of authenticity, and 4) one-way communication in general.
The MADE LFs assesses the value to the target group of both enterprises and employees by looking at which skills the employees' transfer to their everyday praxis. This data will be collected 1-3 months after the activities, so the employees can try out some elements but still have the course in recent memory.
The transfer from the learning situation (the learning factory setting) and the later reality of the learner (job), is enhanced by authentic tasks and activation of prior knowledge within the learning activity. Then, the learning factory can serve as a high-quality backdrop for reflection among the learners, leading to a higher degree of coupling between the learned content and the praxis of the learner [14].
The paper developed hypotheses regarding transfer and quality of learning based on the analysis which we are now testing in the MADE LFs.

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