INTRODUCING HYBRID LEARNING TO LEARNING FACTORIES

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Abstract: *The ongoing digital transformation of the manufacturing industry needs to be met with new forms of education and training to maintain a highly skilled workforce. New professional education concepts need to provide effective learning content that is industry-relevant, of high quality, and easily accessible. To tackle these challenges, the paper presents a methodology for developing a course founded on a combination of didactic approaches including blended and hybrid learning, active learning, and flipped classroom. According to industry needs in South-East Europe, the course design is then applied to selected topics around a smart assembly workstation, i.e., human-robot collaboration, enhanced quality control, and lean manufacturing 4.0. The trainings will be offered online, via E-learning and through the partners' Learning Factories, i.e., hands-on. Examples of different concepts are presented in each Learning Factory.*

Keywords: Learning Factory, hybrid learning, professional education, Industry 4.0.

1. INTRODUCTION

The concepts of hybrid learning and Learning Factories (LF) have recently become increasingly popular means of education (Abele et al., 2019; Raes et al., 2020). In the sector of manufacturing, new, emerging technologies and digital transformation create increasing demands on upskilling and education of the existing workforce to stay competitive (Tvenge & Martinsen, 2018). To keep up with these needs, optimized training concepts need to be explored that can provide enhanced flexibility, availability, and efficiency to the industry. To do so, this paper presents a methodology for development of hybrid training courses centered around LFs. In addition, several use cases of a pilot course on the topic of Industry 4.0 are provided.

1.1 Hybrid, blended and flipped learnin

Hybrid learning is often used synonymously with the term blended learning, both describing education that combines face-to-face learning with online learning (Hrastinski, 2019). Even combining different instructional methods, pedagogical approaches, and technologies can be considered blended learning (Sharma, 2010). While the term hybrid learning seems to be more widely adopted in practice, blended learning is more commonly used in research. The lack of clear and universally agreed-upon definitions leads to inconsistencies in the literature on the subject. Consequently, Hrastinski recommends researchers and practitioners to carefully define their understanding and perception of the terminology (Hrastinski, 2019).
In the context of this paper, hybrid learning is considered a combination of in-person and remote (online) learning, both carried out synchronously (at the same, specific time). Blended learning refers to a combination of asynchronous online learning (on the learner's own schedule) and synchronous in-person learning, as depicted in Figure 1.
Another related concept is flipped classroom, which is an instructional method that reverses the traditional sequence of classroom activities and homework (Tucker, 2012). Learners consume instructional content

(e.g., via pre-recorded videos) at home before attending class, where they engage in group discussion, problem-solving, and teacher-guided activities (Tucker, 2012).

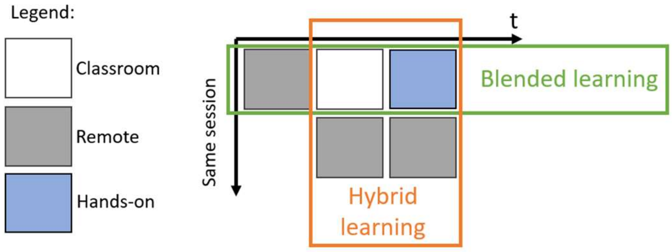

Figure 1: Example course structure with the distinction of hybrid and blended learning

For example, significant increases in student performance have been shown in the case of hybrid learning (Joyce et al., 2014), for blended learning (Cavanagh, 2011), and for flipped classroom (Baepler et al., 2014). Among the reported advantages compared with traditional teaching approaches are flexibility in terms of location (synchronous online activities in hybrid learning) and time (asynchronous learning activities in blended learning) for the learners, making education more inclusive and accessible (Saichaie, 2020), Figure 1. Furthermore, flipped classroom has shown to provide more frequent opportunities for students to interact with peers and instructors, affecting the in-class learning experience positively (Lage et al., 2000). Moreover, diverse instructional methods and interactive multimedia content can be incorporated into the learning to serve different learning styles (Kolb & Kolb, 2013).

1.2 Learning Factory (LF)

LFs are facilities that resemble a manufacturing environment by providing simplified representations of processes and multiple workstations. In that way, real value chains, including organizational aspects, are simulated and can be used for training purposes. In fact, LFs have gained considerable popularity as effective platforms for learners to acquire practical skills required in real-world manufacturing environments through hands-on learning via e.g., problem-solving, and experiential learning.

The growing interest in LFs is also evident in the formation of national and international scientific communities, the increasing number of publications on the subject and the engagement of manufacturing sectors (Nixdorf et al., 2022).

The educational approach used by LFs is founded on a combination of didactic concepts of active and experiential learning, which emphasizes the learner's engagement and participation in the learning process and its reflection. It includes activities such as problem-solving, discussions, group work, and hands-on experiences (i.e. "learning by doing") (Abele et al., 2019).

Even though LFs have proven to be an effective means of preparing learners for careers in the manufacturing industry (Abele et al., 2017), several limitations and drawbacks have been reported. These include their resource-intensive operation, limited flexibility and scope of individual facilities, and limited accessibility, i.e., they are only regionally available (Abele et al., 2017).

2. HYBRID COURSE DESIGN

2.1 Didactic approach

The proposed course design combines various didactic approaches (see Table 1). Its focus is on hybrid and blended learning, flipped classroom, and constructive alignment. By centering it around LFs, valuable hands-on learning experiences are provided (e.g. problem-solving or experiential learning).

Constructive alignment (Biggs, 2014) is integrated to formulate clear and measurable learning outcomes in line with Bloom's taxonomy (Krathwohl, 2002. Generally, learning outcomes of lower levels of Bloom's taxonomy (e.g., remember) are most suitable for pre-class (online) learning segments while in-class or hands-on training sessions are intended to tackle higher-level learning outcomes (e.g., apply, evaluate).

The course is also utilizing the benefits of hybrid learning and blended learning via the flipped classroom approach. Blended learning concepts with online learning are the core of pre-class learning activities. The goal of pre-class learning is to lay the knowledge-foundation for the second aspect of blended learning, the in-class hands-on training sessions at the learning factories. Learning before meeting in-person will help utilize the time and resources at the learning factories effectively making space for active learning activities such as problem-solving. The online pre-class segment also enables learners to adapt learning to their schedule which brings significant advantages for working professionals.

Hybrid learning elements are incorporated by including synchronous online sessions during which interaction and knowledge sharing between learners and teachers of different LFs is promoted.
The proposed course is designed to be carried out as a joint effort by several LFs allowing for sharing resources and expertise and widening the training scope. Video conferencing tools enable interaction between learners and instructors present on-site at the various participating learning factories.

Table 1: Components of the theoretical basis of proposed course design with main features listed

Learning factory	Hybrid & blended learning	Flipped classroom	Constructive alignment
• Active learning • Problem-based learning • Experiential learning • Project-based learning	• Blend of in-person & online learning in sequence • Learn at own schedule • Hybrid synchronous learning • Personalized/tailored learning	• Student-centered • Reversal of traditional teaching • Pre-class learning • In-class activities • Flexible learning environment	• Outcome-based • Intended learning outcomes (ILOs) • Alignment ILOs & learning activities • Assessment & feedback

2.2 Course design

Based on the principles laid out in subsection 2.1, a course containing hybrid learning paths was designed. This course features three LFs with distinct infrastructures (LF 1, LF 2, and LF 3). As summarized in Figure 2a, the course contains a combination of online learning (synchronous and asynchronous) and in-person attendance. It is built around a common manufacturing-related challenge which is addressed during the hands-on sessions at the different LFs.
During the asynchronous pre-class learning segment, learners engage with assigned online material before the first synchronous event. During this introduction event, instructors from the participating LFs will introduce the manufacturing challenge and furthermore address questions that may have arisen during the prior online-learning segment. This session is held hybrid, i.e., in presence and online at the same time to increase accessibility.
The subsequent synchronous event comprises the hands-on training where learners meet at the respective regional LF where they will tackle the common challenge by applying one of the topics/methods they have gained theoretical knowledge about during the pre-class segment. The topic/method and associated hands-on activity are developed in accordance with the available equipment and expertise at the respective LF. Active learning aspects associated with LFs (see Table 1) like group work enables to include non-technical learning outcomes, such as collaboration, communication, and leadership skills.
The group work segment extends beyond the hands-on training. Groups are asked to summarize their experiences and outcomes from the hands-on training and present it to other groups who were active in another LF. This is done in an online debriefing session, scheduled at least a week later to give sufficient time and flexibility for team members to prepare (e.g., arrange meetings among them). In the debriefing session, conducted online, learners and instructors from all LFs participate and each group presents their hands-on experience to other trainees, thereby practicing their communication and presentation skills and providing space for discussions.
The possible paths an individual learner can take within the proposed course design are illustrated in Figure 2b. The main variation for the different learning paths is due to the hands-on training. Whether a learner takes path (I), (II), or (III) depends on which LF the learner has access to (i.e., usually a domestic LF). Completion of the course will require a learner to successfully take part in all course elements along the specific learning path.
Assessment can be conducted at multiple stages of the learning path. Asynchronous online learning can be assessed on a learning management system (e.g., quiz questions). During the hands-on training instructors assess individual and group performance according to the intended learning outcomes. The final assessment can be performed during the debriefing session, e.g. with the help of peer-review.
In previous studies, LFs have been enriched by either blended (Andersen et al., 2019) or hybrid learning (e.g. via virtual reality) (Riemann et al., 2021). In contrast, the present course design provides an advantageous combination of both concepts providing flexibility and accessibility for learners, a wider scope of the training, and shared resources (e.g. learning content creation) and instructor-expertise.

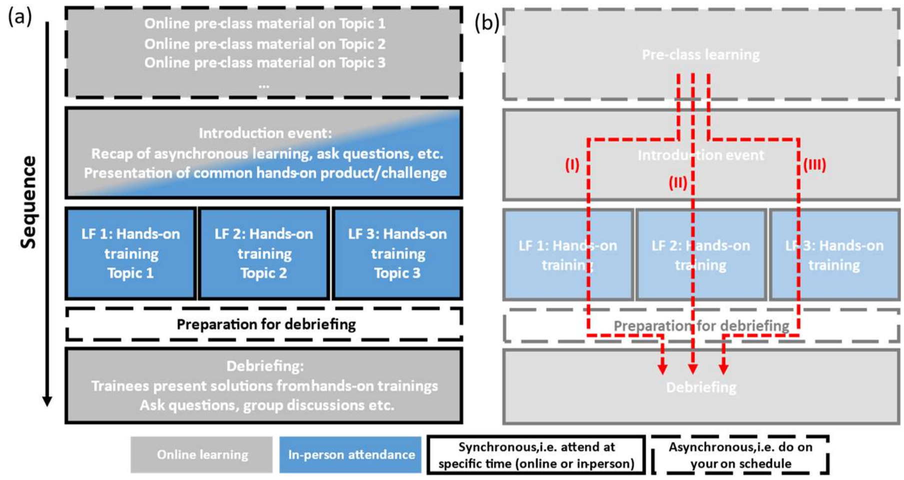

Figure 2: (a) Course design with three participating Learning Factories. (b) Individual learner's possible paths in course.

Possible challenges include the reliance on technology necessary for the hybrid format leading to additional costs and risks due to technical problems. An increase in planning workload to synchronize all activities is also expected.

3. MORPHOLOGY FOR HYBRID LEARNING

Based on the different concepts described in the previous sections, a morphology is proposed for hybrid learning, Figure 3. It is based on the three categories of hybridization:

- Trainer – what is the location of the trainer?
- Trainee – what is the location of the trainee during the session?
- Equipment – what is the location of the equipment?

All these options were "overlapped" with all ideas that were generated how to deliver the training in practical situations. That is how three different streams were generated:

I. E-Learning, through online learning platforms (e.g., EIT Manufacturing's Skills.move). This option does not require hardware equipment, the trainer has already uploaded the material on the online platform and no interaction is needed. The trainee can access the training from anywhere, using a computer or even mobile devices, i.e., entirely self-paced.

II. Hands-on learning. This training is in the heart of the LF and it is the crucial part in delivering the training because the equipment is enabling the opportunity to gather own experiences. Further, it is the competitive advantage of a LF compared to other training providers.

III. Hybrid learning: This is the most flexible option because it can be tailored to the needs of the training and the capabilities/capacities of the trainer, however, it may also be the hardest to realize due to required supportive IT technologies that not only enable remote attendance but possibly also control Remote trainer or remote assistant can lead the training and the trainees can be remote or in a remote LF with a suitable equipment.

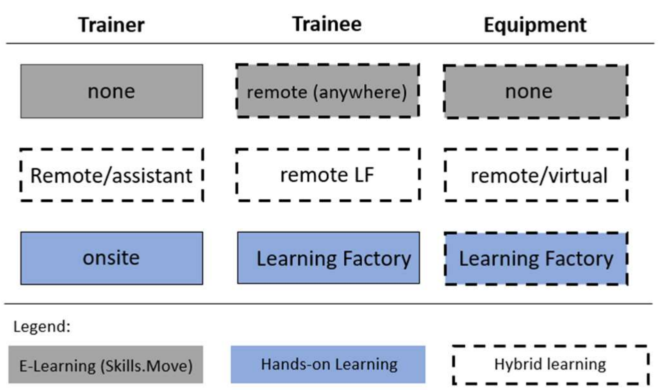

Figure 3: Morphology design for Hybrid Learning in the Learning Factories.

4. USE CASES IN THE LEARNING FACTORIES

In this section, several examples of hands-on trainings are outlined. These are meant to be embedded in a course designed according to Figure 2, i.e. learners will follow a learning path as exemplified in Figure 2b containing pre-learning segments, hybrid introduction event, and debriefing. The use cases are focused on the topic of a smart assembly station including Lean and Industry 4.0 concepts.

- Smart Learning Factory – Skopje, Skopje: The training covers a Smart Poka Yoke Station that is installed and will aid the process of assembly by an operator. The on-site trainer will be responsible to guide the trainees in making the assembly process as efficient as possible. The trainees will acquire skills for analyzing an assembly instruction, develop a new one and program the Smart Poka Yoke Station by themselves. The training is primarily aimed for engineers and operators, but engineering students and production managers can take part as well. The remote trainees can aid the process of designing new assembly instruction.
- Faculty of Mechanical Engineering and Naval Architecture, Zagreb: A training will be offered around Enhanced Quality Control (EQC) to reskill and upskill individuals in quality control and its enhancement through machine vision through hands-on workshop. They will discuss with the trainer and other participants to identify potential quality issues, such as errors in assembly sequence, missing components, or damaged parts. Once identified, participants will choose one relevant issue to address. They will design and implement a machine vision system using existing components, select suitable algorithms, optimize performance through hardware and software enhancements, and critically evaluate the effectiveness of their solution. The EQC training equips learners with competencies in artificial intelligence, digital transformation, problem-solving, and critical thinking, which are essential skills for Industry 4.0 and 5.0.
- University of Tartu, Tartu: The training provided in this LF focuses on learning technical skills for integrating and programming a collaborative robot manipulator (cobot) to complete a vision-guided assembly task. The practical task is intended to showcase collaborative flexible manufacturing where the workspace may change but the robot is able to adjust due to the adaptive nature of the task completion algorithm. The learners are expected to programmatically control the manipulator and implement a reactive control algorithm that takes a video stream of the work area as input. To ensure that the acquired skills are applicable for a wide range of tasks with different robot manipulators and vision systems, the training leverages ROS2 (Robot Operating System) as the main development tool.
- FabLab, Sarajevo: The training features advanced cobot vision integration, Enhanced Quality Control (EQC), and the mini Poka Yoke Station. Participants gain hands-on experience in programming cobots for vision-guided assembly tasks using UR. They also learn EQC skills, identifying quality issues, designing machine vision systems, and optimizing performance. Additionally, they enhance assembly efficiency using a mini Poka Yoke Station. FabLab Sarajevo offers a comprehensive learning environment, equipping learners with practical skills for Industry 4.0.
- TU Wien Pilot Factory Industry 4.0, Vienna: The training focuses on industrial maintenance, e.g., for operators to get accustomed to the technology of cobots via E-learning (Mayrhofer et al., 2021), then carry out maintenance tasks with a cobot hands-on (Nixdorf et al., 2022). In this way, this use case can be leveraged to localize the fault, diagnose the fault and disassemble the product after a failed inspection. To connect E-learning with hands-on learning and debrief trainees after the course, a hybrid approach can be realized. However, at this stage hybridization of hands-on activities is not planned. It is suggested that cognitive subtasks, such as visual inspection, can be carried out remotely, while the manual subtasks require presence.

5. CONCLUSIONS

This paper proposes how new industry-driven topics will be delivered through innovative hybrid learning pathways. The authors employ a blended and partly hybrid approach for the proposed trainings. In line with previous work on leveraging LF networks (Nixdorf et al., 2023), accessibility of LFs is an increasingly demanded topic, especially for South-East Europe. The official trainings will be conducted in the last quarter of 2023 and the collected data from the feedback will be used to optimize the hybridization. It is emphasized that further research needs to be done on hybridization of hands-on trainings, e.g., by virtual environments or remote access to training equipment.

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