Design Paradigms for Workplace-Integrated Learning in the Smart Factory

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***Abstract*—The vision of smart factories as a modern self-organizing production plant redefines the role of production workers. Knowledge, know-how, experience and competencies of production workers become ever more important, making knowledge management and knowledge transfer key objectives for production companies. In this paper we present five different use cases from five different companies, motivating a set of design paradigms for the creation of technical systems for workplace-integrated learning in the smart factory. These design paradigms seek to generalize the solution design for each of the five use cases. We find them to be in line with literature and previous research findings, and valuable guidelines for the design and implementation of said systems.**

I. Introduction

The use of educational technology in corporate contexts originated from distance education, where cost reduction and efficient delivery of educational content was a main driver [1]. Detached from educational technology research, knowledge management has evolved as its own research discipline in the early 1990s [2]. The independent origins of these two fields can still be observed through the way many companies have implemented their respective solutions. E-learning is used to distribute course material that is either centrally produced or even produced by external training companies, while work related documents are stored on share point servers or similar solutions to manage company knowledge. As part of a project funded by the Austrian Research Promotion Agency as part of the Digital Pro Bootcamps program, we explored the situations in 6 different companies, 5 of which we will present in this paper. We found that the traditional e-learning paradigms implemented in most companies struggle to deliver procedural knowledge efficiently, capture tacit knowledge within the company and accomplish ongoing knowledge transfer. We argue that it is necessary to embed learning and knowledge management into daily work. Based upon this argument we follow a design science approach as described by [3], [4] and apply the research process guidelines by [5]. In this paper we describe the initial situation, the involved design artifacts, the five specific use cases that informed our design and the formalized design paradigms that we infer for technological solutions for workplace-integrated learning in the smart factory.

II. Background

The vision of smart factories as a modern self-organizing production plant redefines the role of production workers. Knowledge, know-how, experience and competencies of production workers become ever more important, making knowledge management and knowledge transfer key objectives for production companies. Our work draws from three main observations that require a novel approach to information systems for workplace learning:

1) the increasingly important role of knowledge and competencies as production factor,
2) the problems of knowledge management approaches in practice,
3) and the shortage of skilled workers in production processes.

A. The role of knowledge and competencies in modern production

Labor, resources and capital are the classic production factors of industrial production. Against the backdrop of increasing globalization, the progress of digitization and a massive increase in the complexity of products and production, however, knowledge, know-how and competence have now taken on at least as important a role. As the new fourth production factor, intellectual capital for the efficient and high-quality execution of processes in many cases represents the unique selling proposition and a high proportion of the total value added of companies, with an upward trend. Intellectual capital is not just data or information in files and databases. It comprises all useful knowledge in whatever form in the organization. Therefore, it is critically important that intellectual assets be well understood and properly managed if organizations are to compete successfully in today's world economy [6].

B. Knowledge management in companies

The goal of knowledge management is “to achieve specific goals with the help of knowledge resources” [7]. This means the goal-oriented collection, organization and use of existing knowledge in the company. It is no longer just a matter of using technical systems to “store knowledge”, but of holistically improving or innovating knowledge-intensive value creation processes [8]. In the area of training expertise, the goal is to document the know-how and competence of individual employees and to make it scalable, i.e., efficiently transferable. For the operational organization, an internal structure is required. This involves the infrastructures and rules with the help of which knowledge can be identified, represented, communicated and transferred. This includes, in particular, information and communication technologies, such as traditional workflow systems or intranets, as well as micro-learning technologies.

C. Training and continuing education as a tool against the shortage of skilled workers

The results of an Austria-wide survey of more than 4,400 companies commissioned by the Austrian Federal Economic Chamber show that large parts of the Austrian economy continue to be severely affected by the shortage of skilled workers in September 2020 despite the Corona crisis: 35% of companies are suffering from a very severe, another 28% from a rather severe shortage of skilled labour (Skilled Labour Radar [9]). Especially against the background of the existing shortage of skilled workers, modern, efficient measures for the training and further education of employees are playing an increasingly central role. It is no longer just a matter of “recruiting high potentials” for selected key functions, but rather the lack or loss of qualified employees gnaws away at the entire knowledge and know-how foundation of companies and thus threatens their economic basis in the medium term.

III. ALeS Platform

The digital bootcamp program of the Austrian Research Promoting Agency FFG was realized in the ALeS project (“Arbeitsplatzintegriertes Lernen in der Smart Factory”—Workplace-Integrated Learning in the Smart Factory). The ALeS project’s goal is to provide the corporate participants with the toolkit to realize learning scenarios for workers in their own workplace setting. In the bootcamp, the participants are provided with the theoretical, didactical, and also practical tools to achieve this.

Augmented reality has become increasingly established over the years in key applications such as teaching and specialist training. Augmented reality refers to a virtual interface that enhances (or augments) what we see by overlaying additional information (digital content) onto the real world. Immersion in the virtual world is not total, because we can always see the real world around us [10]. AR provides numerous educational benefits. For students, these benefits can be summarized as: courses’ being fun, reducing cognitive load, increase in motivation and interest towards the course, increased opportunity to ask questions, increase in interaction between students, new opportunities for individual learning, concretizing abstract concepts, rise of success. As for teachers, these benefits consist of contribution to the development of creativity in students, ensuring effective participation of students to the course, students’ being able to carry out the course with their own pace [11].

In order to provide the bootcamp participants with practical tools, an AR learning solution was developed, consisting in terms of software of two Android smartphone apps, and in terms of hardware of a Samsung S1e smartphone and an optical see-through head-mounted display (HMD), as shown in figure 1. While some participants are equipped with their own AR hardware, such as Microsoft Hololens 2 devices[1], and are encouraged to integrate such equipment into their use cases, the ALeS platform constitutes a baseline AR solution available to all participants.

Fig. 1. Optical see-through head-mounted display. The smartphone slot can be seen at the front of the HMD.

The HMD allows for the smartphone to be slotted in, and uses a sequence of mirrors to project the content of the smartphone display onto the wearer’s field of view. The first app, the ALeS Creator, allows the user to generate learning items – units of text and/or images that constitute a localized item of learning content (see fig. 2). Each learning item is assigned a QR code (which can be readily printed through the app), which then serve as anchors, denoting the location of the learning item in the physical world. The second app, the ALeS Visualizer, serves as the AR visualization module, detecting the QR codes in the smartphone’s camera view via the ZXing library[2] and displaying the learning item as an AR overlay in Unity (see fig. 3). The Visualizer app uses the IMMERSE XR[3] rendering module that has been developed in-house specifically to allow for accurate, drift-free stereoscopic rendering of AR content.

IV. Smart Factory Use Cases

Within the funded ALeS project, we work with 6 companies to design workplace-integrated learning. Five of these companies provided a production oriented use case. We describe these use cases hereinafter and use them to motivate the design paradigms presented in the subsequent section that we derived from working on the use cases with these companies and prior scientific knowledge (cf. relevance-cycle and rigor cycle [3]).

[1]https://www.microsoft.com/de-de/hololens/hardware
[2]https://github.com/zxing/zxing
[3]https://assetstore.unity.com/packages/add-ons/immerse-xr-179805

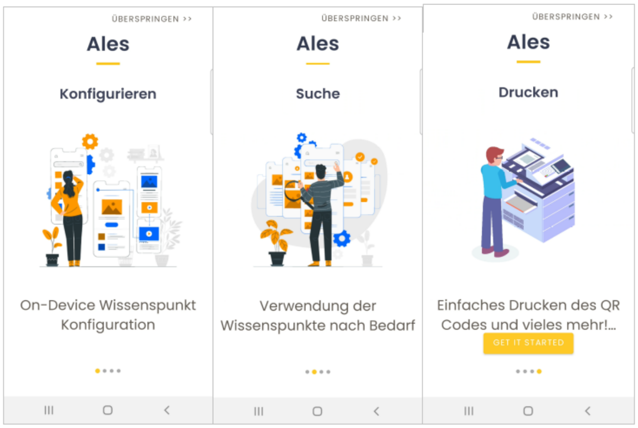

Fig. 2. ALeS Creator App with menus for configuration (left), learning item search (middle), and QR code printing (right).

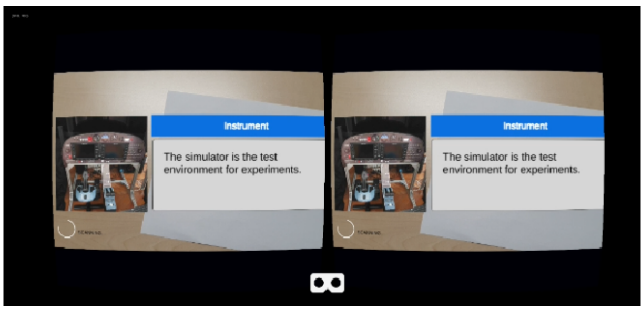

Fig. 3. ALeS Visualizer App showing the stereoscopic rendering output to be projected through the HMD.

A. Use Case 1: Medical Product Manufacturing

The first use case is an on-the-job training of production workers, who are assigned to a new production line, and novice production workers. More specifically the example use case focuses on the process of *line clearance*, which has to be executed after the production of an order is completed and before equipping the production line for the next order. The example product line is the injector pen assembling and packaging line for a gut-selective, humanized monoclonal antibody (biopharmaceutical). Production processes in the pharmaceutical industry are highly standardized and well documented due to regulatory requirements and zero-defect policies. The process of line clearance is documented in a standard operating procedure (SOP). For workers with no prior experience with a particular production line, these written SOPs are hard to follow and assistance of experience workers is needed to physically locate described facilities and properly execute process steps. The company uses Microsoft Hololens 2 in combination with a tailor-made knowledge management platform for SOPs to create a workplace-integrated solution. The planned implementation consist of employing the AR application to physically place instructions for process steps that are defined in the SOPs at the production line to support novice workers to find the correct location and execute the respective tasks correctly. The company also acknowledged that experience workers posses tacit knowledge about the production line that is not yet reflected in the SOP and tailored their SOP knowledge management software accordingly. The mixed-reality implementation should therefore provide means to annotate and comment existing learning material in the application. This learner generated content is subsequently incorporated into new revisions of the SOP after quality assurance.

B. Use Case 2: Metal Machining Product Manufacturing

The second use case aims to support the manufacturing process of metal machining products. Despite a high degree of standardization of most products manufactured at the company, a substantial amount of complex manual assembly work has to be performed. The assembly steps are dependent on the assembly stage and the underlying fully digitized construction plan. The current process requires workers to visit shared work stations to open and review these construction plans to identify the next required tasks before returning to the product under construction. For rapid prototyping and exploration the ALeS platform is used, but a final technology decision will be made in a later design cycle, when the needs of the production workers are better understood through experiments with the prototypes. As of now, the planned implementation shall provide context aware assistance in an AR application by tracking the assembly stage for each product and visualizing relevant parts of the construction plans. A head-mounted solution allows the workers to carry out tasks while being able to consult the construction plans by looking at visual markers placed at the product under development.

C. Use Case 3: Tamping Machine Operation Training

Fig. 4. Plasser & Theurer 09-16 CSM Tamper / Liner[12].

The aim of this use case is to instruct novice workers in the usage of highly-specialized track tamping machines. These tampers, usually of comparable size to a train engine (see fig. 4), are self-propelled machines designed to compress the track ballast under railway tracks, making the tracks level and more durable. Teaching novice workers the usage of such devices generally proves a difficult task due to the tampers' high degree of complexity and expansive size. The planned implementation consists of employing the AR application to teach key concepts about tamper operation at the appropriate time and place: a typical start-up process, for instance, requires machine input not only in the cockpit, but also on machine parts outside the tamper. Similarly, troubleshooting upon problems during operation might require the operator to check a range of critical elements inside and around the tamper. The hands-free AR system would allow for guidance to be displayed to the novice at all times, guiding them around the tamper as they perform the necessary work steps in the correct order. Furthermore, the use case is also intended to display information about the tampers to interested laypeople, such as in the context of exhibitions. Here, the AR system could display technical information or trivia at relevant locations of a tamper display model.

D. Use Case 4: Locking System Manufacturing

The fourth use case instructs production employees of key and lock cylinder systems in the assembly and documentation of the lock coding. A lock cylinder is the part of the cylinder lock that can be operated by means of a key and usually consists of a housing and a rotating cylinder core. Each key has a specific code. This locking code or key code refers to the arrangement and combination of holes or teeth (serrations) on the key bit. This allows the key to be assigned to one or more identical cylinders that correspond to this coding. Whereas coding used to be calculated manually by specialists, this is now done by a computer on the basis of customer requirements. In production, a lock consisting of up to 300 individual parts is then assembled on the basis of the desired coding. This is a complex and delicate task that is quite demanding to learn, which can be supported by an AR prototype. Therefore, a prototype is to be implemented in this use case, which supports the workers during assembly. With the help of head-mounted AR technology, it is possible to work with both hands and simultaneously have a view of the respective activity in order to make as few mistakes as possible.

E. Use Case 5: Makerspace/Prototyping Environment

In this use case, an AR training app is to be developed for the operation of selected production machines (e.g. laser cutters). The target group works on the creation of physical prototypes for trade show installations and art visualizations. These prototypes will be made in a makerspace, a collloborative workspace equipped with various equipment like 3D printers, laser cutters, cnc machines, soldering irons and even sewing machines. The Makerspace is open to a wide range of people, such as students, teachers, children, companies or even private individuals. While simpler machines and tools such as a hammer, oscilloscope or drilling machine are available to everyone, more complex machines such as a CNC machine or Öa require their own training. This is mainly due to the fact that, on the one hand, the extent of damage in the event of incorrect operation is considerably greater and, on the other hand, the insurance also requires this. For example, certain machines may currently only be put into operation by means of an electronic key card if it is noted in the database behind it that the respective person has acquired the authorization to use the machine and has also renewed it after its expiration, if necessary. In this use case, an AR training app is developed to obtain the authorization to use a machine. The special requirements are to have the hands free for the operation through head-mounted systems and to fade in step by step the right information in the learning process at the right place of the machine.

V. Design Paradigms for Workplace-Integrated Learning in the Smart Factory

To subsume and systematize the principles that informed the individual solution design for these real world use cases we defined a set of design paradigms. In the following subsections we describe these paradigms and how they relate to literature and use cases.

A. Design for Spatial Context

Smart factories are increasingly moving into more advanced stages of digitization – in the context of Industry 4.0, innovative technologies such as Internet of Things, cloud technology, and AR/VR methods become more and more integrated into how manufacturing work is done[14]. Consequently, workplace training also increasingly relies on such technologies, which increases the range and possibilities of educational content that is being displayed to learners in the workplace. A key aspect of this is how information can be conveyed in a spatially relevant way, i.e. not abstractly in a classroom or virtual space, but exactly where the information is needed. The spatial dimension has been recognized as one of the four essential dimensions of workplace learning[15], [16], and constitutes an important aspect in how information is presented to learners in the workplace.

Various technologies exist that allow for learning content to be displayed at relevant locations. AR glasses or heads-up displays (HUDs) display information in the user's field of vision, allowing for the spatial localization of educational content under the condition that the AR or HUD system recognizes the user's location. User localization can be achieved in a rough way via GPS, or more precisely by marker-based methods, where computer vision algorithms recognize markers such as QR codes in the AR device's field of view. At the cutting edge of technology, absolute localization in 3D spaces can also be achieved via image-based feature matching in pre-mapped environments[17], [18].

The spatial design paradigm was realized in the ALeS platform by using marker-based location recognition, due to its ease of use and general applicability. The ALeS App allows for the generation of QR codes that are linked to the content to be displayed, including textual and image information. The QR codes are then placed at appropriate locations, allowing

Guidance	⟷	Emergence
Learning as adaptation to knowledge and practices	**Key Learning Principles**	Learning as collaborative creation of new knowledge and practices
Teacher agency	**Agency**	Learner agency
Scaffolding, Cognitive Apprenticeship	**Theoretical approaches**	Knowledge creation and maturation
Given	**Knowledge structures**	Emerging
Ontologies, Adaptive Learning Technology	**Technological Choices**	Folksonomies, Collaborative Learning Technology

Fig. 5. The guidance–emergence continuum and possible trade-offs when designing learning technology for workplace learning (from [13])

the AR system to visualize the relevant information at the location where it is needed.

B. Design for Social Context

The social context of professional production workers can be described using Communities of Practice theory [19], [20]. Accordingly, production workers are mutually engaged in a joint enterprise (e.g. assembling something) and have a shared repertoire (e.g. terminology that is specific to the product, company or profession). This also implies that learning is situated and happens informally [21]. Within such a social configuration, different processes of learning take place. Ley describes them as a continuum from strong guidance to free emergence of new knowledge [13]. With the shift of the role of production workers, and the increased importance of their know-how, competencies and experience for the essential business processes, emergence of knowledge and consequently collaborative learning technology becomes increasingly important (see fig. 5).

While novices need guidance, which is often provided by more knowledgeable peers, experts continuously create new knowledge through interacting with their work environment and creating new artifacts and processes [22]. Community Information Systems, Software and Tools need to support these inherently social processes. Use Case 1 (Medical Product Manufacturing) provides a good example for such a design. The planned solution allows experts and advanced production workers to enhance the on-the-job-training of novice workers. Thus, they can respond to mistakes or inaccuracies they notice when novices run through the training process, being rewarded by a more frictionless onboarding. The benefit within their immediate social context (physically co-located colleague) creates more motivation to contribute than a knowledge base entry with an unclear, abstract future audience.

C. Design for Pervasiveness

The concept of pervasiveness, specifically in pervasive computing, refers to the ability of a computing system to understand its context, and to react based on it. ‘Context’ here refers to relevant surrounding aspects of the device, such as its absolute location, its user’s relative location, and its user’s attentive state. Pervasive, or ubiquitous, computing began in the 80s and 90s with the works of Mark Weiser[23], where a key quality of computing systems began to be seen as their unobtrusiveness. This means that a computing system should only interact with its user when needed and relevant, for which context understanding is a crucial prerequisite[24], [25]. Furthermore, ubiquitous systems should integrate themselves into the background environments of their users[26], which in combination frees up the users’ mental and physical resources.

Pervasiveness in the context of workplace learning means that the teaching system itself should not unduly take up the learner’s resources. The requirements of relevance and unobtrusiveness in the use cases considered here translates to only immediately relevant learning content being delivered, and delivered in an way that doesn’t impede the workflow meant to be taught. These requirements are fulfilled by the ALeS platform in the sense that the micro-learning content can be precisely tuned to the location where it is to be displayed, and that the AR HMD allows the user to remain hands-free throughout the teaching unit.

D. Design for Workplace Integration

Workplace-integrated learning tries to embed learning processes into daily routines of a worker. Learning activities that are integrated into everyday working routines are more sustainable. For example the *Lernschoner* described in [27], [28] was a screensaver application that prompted self-evaluation questions (question prompt, show answer button, I was correct/incorrect buttons). It was perceived as an unobtrusive e-learning application that integrated well into work routines of office workers. Depending on the work process different types of learning resources or performance support are required. For Ley et al. information about the work process is one of the pillars for their model of work-integrated learning [29]. In his aforementioned recent work Ley emphasizes the continuum from guidance to emergence, corresponding with the level of competence of the target audience [13]. Consequently, the level of expertise of the target audience is focal to design for an integrated and accepted solution. Use case 1 (Medical

Product Manufacturing) illustrates this continuum and targets production workers on both ends of the scale:

1) novice workers are trained on the basis of SOPs that are encoded into a mixed reality application that provides strong guidance;
2) expert workers can create annotations and comments on existing SOPs, allowing the emergence of new knowledge within the company.

The application usage is tied to a recurring event (mandatory on-the-job training of novices) and an essential business process (line clearance), ensuring its sustainability.

VI. Outlook

This paper presents our preliminary insights of the ongoing ALeS project. The ALeS platform that allows exploring the design space for AR applications in production environments has been finished. It consists of an affordable hardware setup and smartphone apps to create design artifacts for a first relevancy cycle for each use case. These first cycles have led us to to a set of design paradigms that we found to reoccurringly inform the design of the workplace-integrated learning solutions. We find our design paradigms in line with previous research findings.

For the near future the participating companies implement and evaluate the solutions for their individual use case, and we plan to scientifically accompany these processes to provide in-depth insights into the impact of our design paradigms on learner motivation (solution attractiveness) and learning outcome (solution effectiveness).

Acknowledgement

This work was supported by the project ALeS (FFG, Contract No. 884909).

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