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learning!workplace
learning!professional
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11 Adaptive workplace learning assistance

Abstract: Workplace learning has been part of our everyday reality since a long time, but at present, it has become more important than ever before. New technological opportunities can radically change not only formal, but also informal (unintentional) learning, typical for the workplace. Nowadays companies face a new challenge, which is the transition towards Industry 4.0. It is a complex process that concerns both executives and employees. Therefore, it is important to find solutions that make it easier for both sides. This change is accompanied by numerous re-qualification requirements, which demand a radical improvement of workplace learning and on-the-job training. Recent developments enable a more precise understanding of users' needs, which can lead to better personalization of learning experiences. The effectiveness and efficiency of training and work processes can be improved through wearable technologies and augmented reality. Information technology should support the whole spectrum of educational methodologies, including personalized guidance, collaborative learning, and training of practical skills, as well as meta-cognitive scaffolding. Here we provide a reflective view on the former progress of adaptive workplace learning assistance (especially in the European context) and then point out several prospective approaches that aim to address the current issues. These should lead to innovative context-sensitive and intelligent adaptive assistance systems that support learning and training at the workplace.

Keywords: professional learning, adaptive workplace assistance, personalized training, Industry 4.0, Internet of Things

1 Introduction

Workplace learning was defined [47] as "the integrated use of learning and other interventions for the purpose of improving human performance, and addressing individual and organizational needs. It uses a systematic process of analysing and responding to individual, group, and organizational performance issues. It creates positive, progressive change within organizations by balancing humanistic and ethical considerations." In this chapter we use also the term *professional learning* in this sense.

An extensive survey of requirements for professional learning [10] showed that "learning needs to be available in a suitable form *everywhere*, and at the workplace it should be *seamlessly integrated into the work processes*. Learning objectives should involve the whole spectrum from high-level *competencies and skills* to concrete pieces of *knowledge*. E-learning and blended learning are highly demanded by users, especially if taking into account various pedagogical strategies according to the particu-

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learning!professional
Industry 4.0

lar objectives and context. Finding a suitable business model for professional learning is a crucial issue, which impacts on the availability of learning resources, as well as the quality, accessibility, flexibility, re-usability, and interoperability of learning solutions. *Personalisation* and *adaptation* of learning is generally considered as highly important, because learning has to be individualised to become more effective and efficient. This is particularly true for (...) workplace learning."

In the past a roadmap survey [4] on *Technology-Enhanced Professional Learning* (TEPL) in 2015 indicated that TEPL should support knowledge workers, promoting motivation performance, collaboration, innovation, and commitment to lifelong learning. According to this vision TEPL would become an effective tool to enhance work performance and promote innovation, creativity, and entrepreneurship among employees. Learning would become a catalyst in increasing employability. The use of knowledge would be democratized to provide equal opportunities for high-quality learning for all. Everyone would be empowered to learn anything at any time at anyplace, and the TEPL market would be commoditized to achieve transparency. Moreover, the survey predicted that TEPL would be highly impacted by seamless learning and working environments, two-way interactive collaboration based on ubiquitous internet with high bandwidth, meta-data facilitating management of content objects, and online communities. Among unpredictable factors were development of standards and whether the social climate will be driven by trust or suspicion. In the meantime, many of these predictions came true and TEPL became more common.

Current intelligent tools can process Big Data and transform work processes, but the related consequences are difficult to predict [70]. In order to be successful, business executives have to consider complementarities of humans and computers. Upskilling of employees should focus on competences that cannot be replaced by machines. The competitive advantage in small and medium-sized enterprises (SMEs) depends on skilled labor and specialization. The trend of automation and data exchange in manufacturing technologies influences the organizational processes as well as the role of the employee. Companies need to fill their competence gaps efficiently. Employees may want to plan their lifelong professional development. And society should be interested in reducing the unemployment rate and letting people develop their talents.

The existing centrally and hierarchically organized structures in production enterprises will be more and more decentralized. The *Industry 4.0* paradigm shift [62] from resource-oriented planning to product-oriented planning is based on networking of intelligent machines and products, called *Cyber-Physical Production Systems* (CPPSs). With changing customer demands, the product will be able to request the necessary production resources autonomously. From the change management perspective, it is crucial to obtain the support of employees. The organizational and technical changes imply regularly updated and dynamic competence profiles of employees, requiring re-qualification through new learning formats directly at the workplace. This development demands increased communication skills and an increased degree of self-organization, as well as new abstraction and problem solving competences [56]. Co-

Industry 4.0
learning!adaptive
adaptation!strategies

operation with robots will be another important skill in the near future. Consequently, this requires novel education paradigms as well as development of new learning settings and measures for this purpose. There is a strong requirement for re-training and upskilling of the workforce, but the employees should be motivated for this change, possess necessary meta-cognitive competences for professional development, and understand the decisions provided by machines. This is closely related to the control of privacy by each individual.

In the following we first outline the history of professional and workplace learning in the last decades, recalling a selection of relevant European projects. Then we recall the important learning theories and related models in this field. These are supported by different types of learning technology, introduced afterwards. We conclude with a vision of the technological support in the Industry 4.0 era and some future prospects.

2 Historical overview

Although the development of *Technology-Enhanced Learning* progressed intensively already since the middle of the 1980s with the dawn of the personal computer and accelerated dramatically in the 1990s with the spread of the Internet and the web, the particular focus on workplace learning came a bit later. In the European context halfway through the 2000s, researchers and developers started to investigate more intensively how to integrate information technology into corporate and industrial settings, in order to support professional development and qualification. Perhaps it is worth recalling briefly this history from the perspective of selected projects in the research and development programs funded by the European Commission. As this progress was to a large extent driven by the available technology, in the global context the situation did not look very differently.

PROLEARN (2004–2007) was the Network of Excellence in Professional Learning that gave a strong impulse to the new wave. Among other achievements, it advanced personalized adaptive learning, investigating interoperability of systems and re-usability of learning resources, and later also social software and the Web 2.0 impact in this field. The researchers identified several issues, like missing harmonization of available learning standards and their restriction in the representation of adaptive methods, as well as uneasy authoring of adaptation strategies. An important challenge was represented by open corpus adaptive hypermedia systems. In its roadmap PROLEARN provided also the following vision: *every knowledge worker should be able to learn anything anytime and at anyplace*.

The next phase (2005–2010) aimed at the development of suitable adaptive solutions integrated in normal workplace environments, considering target competences as meaningful educational objectives and learning processes as a crucial means for their achievement. TENCompetence investigated creation and exchange of knowledge

Learning Management Systems (LMS)
European Qualification Framework (EQF)
learning!self-regulated
personal learning environments (PLE)

resources, learning activities, competence development programs, and network data for lifelong competence development in learning networks and communities of practice. Realizing that a method of professional development will only be efficient when it is as adaptive and personalized as possible [23], the consortium implemented an appropriate standards-based and open-source technical infrastructure, integrating and interconnecting the various levels of the conceptual model mentioned above. PROLIX developed an open service-oriented architecture for interlinking business process intelligence tools enabling competence management with flexible learning environments. APOSDLE further advanced process-oriented self-directed learning and supported informal learning activities via their seamless integration in the professional work. Their approach was impacted by the competence-based knowledge space theory and included adaptive systems with context-sensitive recommenders.

The next projects (2008–1012) addressed not only interoperability at the level of learning outcomes and adaptation in traditional *Learning Management Systems* (LMSs), but also knowledge maturing through social learning. ICOPER created a reference model for competence-driven learning, considering the *European Qualification Framework* (EQF) for harmonization of various national qualifications systems [11]. The focus was on an output-centered approach, i. e., on knowledge, skills, and competences. GRAPPLE aimed to support lifelong adaptive learning, taking into account personal preferences, prior knowledge, skills, and competences, learning goals, and the current personal and social context. The project delivered a generic technical infrastructure, integrated with five different LMSs. MATURE investigated knowledge maturing in organizations, supporting social learning in knowledge networks and facilitating efficient competence development. The knowledge can emerge from informal representations towards more formalized semantic structures and processes. The success of community-driven approaches in the spirit of Web 2.0 showed that the intrinsic motivation of employees is crucial for their engagement in collaborative learning activities.

Later on (2009–2014) also cultivation of meta-cognitive skills became an important objective, like *self-regulated learning* (SRL), in which reflection plays a crucial role. For this purpose, innovative *personal learning environments* (PLEs) as well as immersive simulated environments were developed. ROLE advanced psycho-pedagogical theories of adaptive education, especially SRL. It offered adaptivity and personalization not only in terms of content and navigation, but also of the entire learning environment and its functionalities. This novel concept of PLE was evaluated in various educational settings. In the business context it turned out that a pure PLE did not satisfy the requirements of personnel development and a hybrid solution was developed – *Personal Learning Management System* [64]. It aggregated selected learning resources and applications, facilitating the activities of workplace learners, like planning activities, searching for content and tools, training, and testing, as well as reflecting and evaluating the progress. ImREAL enhanced immersive simulated environments to align such learning experience with daily job practice. It showed

Industry 4.0
Industry 4.0
wearable technologies (WT)
augmented reality (AR)
learning analytics (LA)

the usefulness of affective meta-cognitive scaffolding in the context of experiential training simulators, having a positive impact on motivation, learning experience, and self-regulation [65]. MIRROR elaborated on reflective learning to facilitate learning-on-the-job and experience sharing. It showcased reflection as a means to empower employees and achieve organizational impact, leading to innovative business offerings [45].

The following endeavors (2012–2018) emphasized scalability and focused on particular target groups, taking into account also professional identities. Learning Layers supported workplace practices in SMEs, bridging the gap between scaling and adaptation to personal needs. Building on mobile, contextualized, and social learning achievements, the project developed a common light-weight, distributed infrastructure for fast and flexible deployment in highly distributed and dynamic settings. These technologies were applied in two sectors, i. e., (i) healthcare and (ii) building and construction. BOOST addressed the need to engage small and micro-enterprises in vocational training, helping them to identify their critical business needs and skill gaps and fulfill the critical demands. The project built on the results of ROLE, using its PLE technology to design a customized learning environment both for managers and employees. EmployID supported public employment services and their employees in adapting to the changes in their area by facilitating the development of professional identities. The developed solutions include tools for reflection, e-coaching, creativity, networked learning structuring, and measuring impact.

In parallel (2014–2018), several German projects developed assistance and knowledge services for the workplace, preparing for Industry 4.0. APPSist implemented a new generation of such context-sensitive and intelligent services as well as the underlying architecture for settings with cyber-physical systems in the digitally networked factory of the future (“smart production”). DigiLernPro developed a software tool which used various digital media to semi-automatically generate learning scenarios, enabling new forms of learning for Industry 4.0 requirements. ADAPTION also addresses the challenges related to Industry 4.0, focusing on a holistic approach, taking into account also the impact on the organization and the employees, providing them with access to relevant knowledge related to required new skills.

Several currently running projects (2015–2019) benefit from newly available technologies and data processing approaches. WEKIT enhances human abilities to acquire procedural knowledge by providing a smart system that directs attention to where it is most needed. New opportunities for skill training are enabled by *wearable technologies* (WTs) and *augmented reality* (AR). AFEL advanced informal and collective learning as it surfaces implicitly in online social environments. Relying on real data from a commercially available platform, the aim is to provide and validate the technological grounding and tools for exploiting *learning analytics* (LA) on such learning activities. MOVING enables users from all societal sectors to improve their information literacy by training how to use, choose, reflect, and evaluate data mining methods in

recommender systems
Artificial Intelligence (AI)
behaviorism
cognitivism
constructivism
learning!workplace
socialization
externalization
combination
internalization

connection with their daily research tasks and to become data-savvy information professionals.

This short review of the workplace learning history in the European context shows the shift of support from knowledge workers learning new knowledge to industrial employees training new skills, but also lifelong learners cultivating their meta-cognitive competences. The development was essentially driven by the progress in information technology – from static LMS to adaptive systems and flexible PLE, further to social software and Web 2.0, including Recommender Systems (RSs) and LA, later on benefiting from mobile devices and smart phones, and more recently also WT and AR, as well as data science and Artificial Intelligence (AI).

3 Learning theories and models

The aim of professional and workplace learning is to acquire new knowledge and skills, as well as the ability to apply these in real settings. The EQF was proposed to make qualifications more readable and understandable across different countries and systems, facilitating lifelong learning [11]. Its core deals with different reference levels describing what a learner knows, understands, and is able to do – *learning outcomes*. In EQF, the term *competence* means the proved ability to use knowledge and skills, as well as personal, social, and methodological abilities, in work or study situations during professional and personal development.

Three basic theories can be applied in learning, depending on the domain, objective, and target group. *Behaviorism* aims at a change in external behavior of learners achieved through reinforcement and repetition (e. g., language learning). *Cognitivism* seeks to explain the process of knowledge acquisition and the subsequent effects on the mental structures within the mind (e. g., concept mapping). *Constructivism* focuses on how humans make meaning in relation to the interaction between their experiences and their ideas (e. g., problem-based learning).

Workplace learning should be naturally integrated in the work process and is usually problem-based and often informal, i. e., without set learning objectives and learner's intention. *The SECI theory of organizational knowledge creation* [43] distinguishes two basic types of knowledge. *Explicit knowledge* can be formally and systematically transmitted across individuals. *Tacit knowledge* is not easily expressible, but rooted in an individual's actions. Knowledge is created when tacit and explicit knowledge cyclically interact with each other:

1. *socialization*: creating new tacit knowledge through shared experiences;
2. *externalization*: tacit knowledge is made explicit;
3. *combination*: restructuring explicit knowledge;
4. *internalization*: reflection and conversion of explicit knowledge into tacit knowledge.

Novel models of informal learning should facilitate the creation of knowledge during the learning process. Therefore, the SECI theory has been elaborated into a framework modeling the knowledge creating learning process as divided in four sub-processes [40]:
1. *learning needs analysis*: describing the knowledge gap;
2. *learning preparation and content development*: preparing learning offerings;
3. *learning process execution*: creating understanding;
4. *learning assessment and certification*: producing quality certificates.

This framework distinguishes between two types of learning processes. *Knowledge transmission* occurs when the knowledge exists prior to the execution of the learning process; this is typical for formal learning. But in informal learning the knowledge is often created during the execution of the learning process. While in the first case the learners are trying to figure out the right answers, in the second they are trying to figure out the right questions. The SECI process framework can apply the *knowledge creation* process, connecting it to psychological and social motivators for learning.

The traditional methods originating in knowledge transmission focused on guidance and adaptation. *Competence-based Knowledge Space Theory* (CBKST) is a theoretical framework mainly used for personalizing learning to individual learners' domain-specific competences [55]. The psychological research on CBKST was extended for adaptive informal technology-enhanced workplace learning [33]. The aim was to support work-integrated learning, closely connected with task performance. Even nowadays, theories of knowledge acquisition (transmission) are still dominant in workplace learning technology research [48]. Nevertheless, theories of participation and knowledge creation deserve more interest, especially *social constructivist learning theory* mediated by means of artifacts created by the community [35].

Another important aspect of lifelong learning in general are meta-cognitive skills, which belong to the key competences of a successful learner [15]. One of them is self-regulation, which includes monitoring and managing one's cognitive processes as well as the awareness of and control over one's emotions, motivations, behavior, and environment as related to learning [41]. Research has shown that the application of SRL increases the effectiveness of education, enhancing learning performance as well as the development of reflective and responsible professionalism. SRL was considered as a cyclic process of meta-cognitive activities consisting of the forethought phase (e. g., goal setting, planning), the performance phase (e. g., self-observation processes), and the self-reflection phase [69]. *Reflection* attracted special attention in the informal workplace learning context [45]. It means re-examining and re-assessing past experiences and drawing conclusions for further behavior. In this sense reflection was investigated as a means to empower employees and impact organizational success.

Each of these approaches has a different meaning and should be applied accordingly. *Guidance* can be very helpful in knowledge transmission for novice learners,

personalized!adaptive learning
cognitivism
constructivism
learning!self-regulated
behaviorism
personalized!adaptive learning
Intelligent Tutoring System (ITS)
Adaptive Hypermedia Application Model (AHAM)
adaptation!model
adaptation!process
adaptation!model

when the knowledge exists in advance. *Collaboration* can help to create new knowledge, which is crucial, especially for experts. *Self-regulation* operates on a meta-level, impacting the effectiveness and efficiency of learning processes. From this perspective we can consider these approaches as complementary. To scale informal learning in complex and dynamic domains a model was created [34] that provides an integrative view on three informal learning processes at work, i. e., (i) *task performance, reflection, and sense making*, (ii) *help seeking, guidance, and support*, and (iii) *emergence and maturing of collective knowledge*.

So we can distinguish three important areas of lifelong and workplace learning, which directly correspond with the abovementioned basic theories of learning. *Personalized adaptive learning* facilitates acquisition of well-structured knowledge by means of guidance, which relates to *cognitivism*. *Collaborative learning* supports cooperative construction of knowledge from own experiences, thus practicing *constructivism*. *Self-regulated learning* focuses on behavior changes at a meta-cognitive level, which is the aim of *behaviorism*. In reality a big challenge for learning designers is to take into account the particular objective and context, in order to find a suitable arrangement between guidance (adaptation of given knowledge structures) and emergence (collaborative creation of emerging knowledge structures), between freedom of the learner (stimulating motivation) and the system control (supporting efficiency of learning), as well as between direct adaptation of learning environments (that may cause confusion in some cases) and their responsiveness (e. g., by means of nudges and alerts, leaving the decision control to the learner).

3.1 Personalized adaptive learning

Personalized adaptive learning is usually a preferred choice for knowledge transmission in well-structured domains, when help seeking and guidance support are needed. The key assumption is that such knowledge can be formalized properly, in order to be suitably presented and acquired by the learner. An *Intelligent Tutoring System* (ITS) typically consists of four basic components [42], i. e., (i) *domain model*, (ii) *student model*, (iii) *tutoring model*, and (iv) *User Interface model*. They separately represent the knowledge about the subject domain, the learner, the pedagogical instructions, and the presentation opportunities. Similarly, the *Adaptive Hypermedia Application Model* (AHAM) distinguishes between the (i) *domain model*, (ii) *user model*, and (iii) *teaching model* [6]. Mobile technologies led to the additional recognition of the *context model* and consideration of alternative adaptation strategies to the *adaptation model*. The knowledge driving the adaptation process can be represented as five complementary models [1] – the *domain model* specifies *what* is to be adapted, the *user and context models* tell *according to what parameters* it can be adapted, and the *instruction* (*pedagogical*) and *adaptation models* express *how* the adaptation should be

adaptation!strategies
adaptation!strategies
learning!collaborative

performed, distinguishing selection of pedagogical methodologies for the current purpose (learning objective) and adaptation to the current context. The related development and authoring processes can be simplified if interoperability of system modules and re-usability of learning resources is achieved. The technological and conceptual differences between heterogeneous resources and services can be bridged either by means of standards or via approaches based on the Semantic Web (with data processable by machines, e. g., ontologies). As the existing standards cannot realize general interoperability in this area, the Semantic Web can be used as a mediator.

Ontologies can help us to achieve a certain kind of consensus and to contribute to the harmonization of the existing standards [24]. Two basic types of knowledge can be distinguished. *Declarative knowledge* is typical for the description of the subject domain (including learning materials – IMS Content Packaging, IMS Question and Test Interoperability; meta-data – IEEE Learning Object Meta-data; and domain ontologies), the user (IEEE Public and Private Information, IMS Learner Information Package), and the context knowledge. *Procedural knowledge* is important for designing learning activities from the pedagogical viewpoint (IMS Learning Design) as well as for defining adaptation strategies. There are various approaches to address these issues at different levels of formalization, from freely specified informal scripts, through procedural knowledge encoded directly in a software system, to re-usable elicited procedural knowledge, which ideally follows official standards or formalized re-usable ontologies. So, specification of learning activities and adaptation strategies by separating the content, declarative and procedural knowledge in adaptive courses seems to be quite natural. A suitable solution for the re-usability and adaptivity issues would be the representation of various types of knowledge driving the process of personalized adaptive learning, and their interaction when generating the concrete instances of adaptive learning design dynamically.

The CBKST iterative methodology [33] enables modeling and validating the domain model and the user model of an adaptive learning system that provides appropriate learning opportunities. This modeling methodology is based on a formal model of the relationships between tasks and needed competences (task–competence matrix). Creating the two models by starting from the tasks seems to be well suited for a work-integrated approach.

3.2 Collaborative learning

Informal learning, especially in ill-structured domains, requires knowledge creation support, facilitating continuous collaborative development and gradual formalization of new knowledge by a community of participants. This process includes sharing of knowledge and experience, exchange of opinions in discussions, as well as creation of new artifacts and their annotations. A critical point in developing an active learning community is the engagement of its members demonstrated by their participation

learning!self-regulated
learning!self-regulated

and contributions. According to *social exchange theory* individuals contribute more when there is an intrinsic or extrinsic motivation involved, such as anticipated reciprocity, personal reputation, social altruism, or tangible rewards [20]. Suitable incentive mechanisms can significantly increase both active and passive participation [16]. The issue of trust is related to the applied privacy and security policies.

People with a common interest can establish a *community of practice* (CoP), in order to develop personally and professionally through the process of sharing information and experiences with the group [63]. The structure of a CoP consists of norms and collaborative relationships, shared understanding, and communal resources. Learning is here considered as social participation. Similarly, a *learning network* is a self-organized community stimulating professional and career development through a better understanding of concepts and events [23]. A participant can specify personal learning goals in the context of competence profiles. After a (self-)assessment a gap analysis is performed, leading to a personal development plan, consisting of learning activities. Also here, sharing, communication, and collaboration are crucial.

3.3 Self-regulated learning

Studies have shown that the application of SRL increases the effectiveness of education. Self-regulation is crucial for the development of lifelong learning skills. According to educational psychologists, SRL is guided by meta-cognition, strategic action, and motivation to learn [67]. In this context students are proactive with respect to their learning [69]. Research shows that self-regulatory skills can be trained and can increase students' motivation and achievement [53].

Regarding learning performance, there is evidence that students with intrinsic motivation, initiative, and personal responsibility achieve more academic success [68]. Studies also indicate that in order to improve academic achievements, all three dimensions of SRL in students must be developed: the meta-cognitive, the motivational, and the behavioral ones [67]. Another interesting finding is that SRL can enable accelerated learning while maintaining long-term retention rates [37]. In a meta-analysis of 800 studies [15], it has been shown that applying meta-cognitive learning strategies significantly contributes to learning success. These results provide clear evidence that meta-cognitive skills and in particular SRL abilities belong to the key competences of a successful learner, especially in the context of lifelong learning.

Components of SRL are cognition, meta-cognition, motivation, affect, and volition [18]. Six key processes that are essential for self-regulated learning are listed by Dabbagh and Kitsantas [5]. These are *goal setting*, *self-monitoring*, *self-evaluation*, *task strategies*, *help seeking*, and *time management*. A cyclic approach to model SRL has been given by Zimmerman [69], where SRL is seen as a process of meta-cognitive activities consisting of three phases, namely, the *forethought phase* (e. g., goal setting

ICOPER Reference Model (IRM)
Internet of Things (IoT)

or planning), the *performance phase* (e. g., self-observation processes), and the *self-reflection phase*. According to this model, learning performance and behavior consist of both cognitive activities and meta-cognitive activities for controlling the learning process. A study investigating SRL in Massive Open Online Courses found that goal setting and strategic planning predicted attainment of personal course goals [19]. Moreover, individual characteristics like demographics and motivation predicted learners' SRL skills.

4 Learning technology

Available learning technologies usually support formal learning in well-structured domains. Nevertheless, various methods and techniques were used to develop workplace learning solutions, facilitating rapid prototyping and re-use of software components [10]. For virtual workplaces an appropriate choice incorporated a *distributed architecture*, with educational servers providing learning materials and pedagogical agents enabling communication between clients and servers. These agents could use various *web services* communicating with each other and providing the requested functionality at different levels of the learning process, including representation of the relevant models, as well as required functionality. The various types of knowledge could be encoded in software components, represented by meta-data, or elicited in formal specifications.

The *ICOPER Reference Model* (IRM) provided a common frame of reference for stakeholders who wish to contribute to the design and development of outcome-oriented teaching and content for re-use [54]. The IRM was designed to improve interoperability of educational systems and applications both at the process level and at the technical level (i. e., data and services).

Learning and training services are typically based on information about the user status and the current context. Nowadays, the *Internet of Things* (IoT) consists of identifiable objects that can communicate and interact [39], using sensors to collect information about their environment and actors to trigger actions. Although not all technical challenges of IoT have been already solved, the technology enables further research. In the area of education, the early work with IoT focused on recognizing an object, presenting its information or activities [2], as well as social interaction on objects [66]. So there is still a lot of unexploited potential of IoT in this field, especially beyond the technological perspective.

But there are also research fields that consider the pedagogical point of view in a more advanced way. *Educational Data Mining* deals with automatic extraction of meaning from large learning data repositories. This can be used for guidance (in planning and learning phases) and reflection.

Guidance is often facilitated by means of nudges based on RSs. But learning recommendations are highly context-dependent [38], which relates to the characteris-

learning!adaptive
adaptation!strategies

tics of the physical and virtual environment, the learning objective, as well as the learner and his or her current task at the workplace. In TEL, user preferences are not the most prominent factor and may not necessarily be in line with learning goals and other stakeholders' interests. Moreover, recommendation goals are complex and require well-conceived recommendation strategies, which need to be adapted to the specifics of a domain [22]. Thus, the learning environments with a very small number of users should either draw on a thorough description of the learner and learning content (ontology-based approach) or support the annotation of the relevant learning content (tag recommendation algorithm).

Supporting reflection on the learning process in a flexible way can be facilitated by suitable LA tools, visualizing both long-term and short-term behavior of participants. Nevertheless, various degrees of privacy and data security should allow different levels of integration, depending on special preferences of individuals and companies [27]. It is crucial to take into account relevant pedagogical approaches for learning at the workplace, like the one that orchestrates adaptive, social, and semantic technologies that will play a key role in allowing professionals to draw on collective knowledge and to scaffold learning in a networked workplace context [34]. An analysis of LA for professional and workplace learning [48] found that this field is in an early stage of development, with a relatively low occurrence of knowledge creation approaches, but with a big potential in multimodal LA that can help to overcome the problems of scarce data.

4.1 Adaptive learning technology

IMS Learning Design was created as a standard allowing to capture procedural knowledge about learning processes, enabling also adaptation through conditional constrained branching of the control flow in a learning activity, with conditions based on user characteristics [3]. When developing personalized and adaptive learning solutions, a key challenge was how to simplify the authoring process, considering collaboration of multiple persons. The previously mentioned survey [10] concluded that specification of adaptation strategies by separating the content, declarative, and procedural knowledge would be very helpful from the authoring point of view. This, of course, necessitates suitable orchestration of various representations.

In order to develop new competences in the industrial workforce quickly and efficiently, suitable paradigms for continuous training of employees are needed. Various approaches have been investigated. Traditional LMSs were enhanced with adaptive functionality in the GRAPPLE project. More flexibility into learning environment design was enabled by modular PLEs. The ROLE project experimented with a hybrid solution in the form of Personal LMS and developed an approach based on the responsive and open learning environments [44], which was later customized for SMEs [28]. The Learning Layers project addressed the issues of scalability of informal workplace

open learner models (OLM)
social software
Learning Network Services (LNS)

learning also with adaptive video trials based on semantic annotations [29]. Affordances of augmented reality and wearable technology for capturing the expert's performance in order to support its re-enactment and expertise development have been investigated in the WEKIT project [36].

Personalization of learning experiences deals with such issues like detection and management of context and personal data of the learner, considering also their emotions [50]. A better understanding of the person's needs can be achieved by including information from various resources (e. g., physiological and context sensors) and related Big Data. Learners' preferences change dynamically; therefore, available sensors can help significantly in their recognition. Collected sensor data can help to infer contextual preferences directly from the individual's behavior [61].

Meta-cognitive skills, like SRL, are crucial for the effectiveness of lifelong learning. Therefore, the employed technologies need to cultivate them, providing an appropriate balance between the learner's freedom and guidance. This should stimulate not only motivation, but also the effectiveness and efficiency of the learning experience [44]. Effective support for SRL includes integration of nudges and reflection facilities in a suitable way [26]. Awareness and reflection services can provide valuable feedback, if they interpret and visualize the collected data meaningfully and in an understandable form. Here knowledge from various fields has to be considered, including psychology, pedagogy, neuroscience, and informatics [30]. *Open learner models* (OLMs) show the learner model to users to assist their SRL by helping prompt reflection, facilitating planning and supporting navigation [13].

The usage of adaptation and recommendation services in learning is limited, if they are not understandable and scrutable, which is often the case when AI techniques like Deep Learning are employed [7]. Machine-made decisions should be explainable by rules or evidence, to raise the trust of users. These need also clear and manageable privacy policies, in order for users to feel they are in control [12].

4.2 Social software

The emergence of Web 2.0 opened quite new opportunities for active participation of users, e. g., by means of blogs or wikis. Consequently, the role of *social software* attracted a lot of attention, defined as tools and environments that support activities in digital social networks [20].

Learning Network Services (LNSs) are web services designed to facilitate the members of the network to exchange knowledge and experience in an effective way, to stimulate active and secure participation within the network, to develop and assess the competences of the members, to find relevant peers and experts to support you with certain problems, and to facilitate ubiquitous and mobile access to the learning network [23]. LNSs can stimulate social interaction, recommend navigation, assess competence levels, and provide personalization of learning events.

Industry 4.0
Industry 4.0

In the past, there were various approaches to professional learning. Building a technical and organizational infrastructure for lifelong competence development was the aim of the TENCompetence project. Their demand-driven approach [25] was based on the qualification matrix, mapping the relevant tasks on the required competence profiles and allowing to use such a competence map by the staff for self-assessment. An analysis of the resulting competence gap enabled to prioritize competence development needs. Expert facilitators were identified and competence networks were established for the required competences. This methodology was supported by the *Personal Competence Manager* [21], which at the individual level enabled goal setting (specification of the target competence profiles), self-assessment (to identify the knowledge gap), activity advice (selection of personal development plans), and progress monitoring (to support awareness and reflection).

Development of mobile technology enabled the Learning Layers project to aim at the scalability issue, using mobile devices with collaboratively created and shared multimedia artifacts. Their integrative approach orchestrates adaptive, social, and semantic technologies, in order to allow professionals to draw on collective knowledge and to scaffold learning in a networked workplace context [34].

4.3 Industry 4.0

The insufficient qualifications of employees were identified as a major problem for the transition to Industry 4.0 and several dozens of important competences were identified as required [52]. Crucial for Industry 4.0 are combinations of professional and IT competences with social and personal skills. A big challenge is to develop novel ways of individualized and informal learning integrated in various settings (including workplace) and also to cultivate meta-cognitive skills (like motivation and self-regulation).

Assistance and knowledge services have been defined as software components that provide specific types of support: assistance services help in solving current issues, while knowledge services support the transfer of knowledge to achieve individual qualification aims [59]. Currently service architectures provide functionalities resulting from the interplay of a number of services, each implementing a specific functionality and making it available for other services. A good example is the architecture implemented in the APPsist project, with intelligent assistance and knowledge services at the shop floor [60].

4.4 Vision

From the technological point of view, we can distinguish four layers of relevant services (Table 11.1). At the bottom we find the *Data* layer, where a fusion of data from

learning!adaptive
user!modeling
user!modeling
adaptation!strategies

Table 11.1: Four layers of services.

User Interface
Personalized and adaptive learning / training with WT and AR
Smart Services
Intelligent multimodal assistance and knowledge services
Basic Services
Data analysis
Data
IoT multisensory fusion

IoT sensors takes place. Then the *Basic Services* layer, where the data analysis is being performed. Next we find the *Smart Services* layer, with multimodal assistance and knowledge services. On the top the *User Interface* layer offers personalized and adaptive learning and training experience with wearable technologies and augmented reality.

The *Data* layer incorporates IoT, which is decentralized, providing privacy and security. Here the blockchain technology [57] plays a crucial role, allowing devices to autonomously execute digital contracts and function in a self-maintaining, self-servicing way. This new paradigm delegates the trust at the object level, enabling animation and personalization of the physical world. It will provide novel refined facilities for users to control their privacy and protect their data. Blockchain can disrupt education, replacing the broadcast model with preparation for lifelong learning, cultivating relevant competences, like critical thinking, problem solving, collaboration, and communication [58].

At the *Basic Services* layer there is support for user modeling to harness and manage personal data gathered from IoT [32], which will help IoT application developers to achieve light-weight, flexible, powerful, reactive user modeling that is accountable, transparent, and scrutable [17]. Related approaches address for instance elicitation of human cognitive styles [46] and affective states [51], as well as modeling psychomotor activities [49].

The *Smart Services* layer provides relevant awareness and reflection indicators [30] as well as guidance like nudges [9]. New useful services will be created, like meta-adaptation providing adaptation strategies according to learning objectives [29]. Assistance and knowledge services will incorporate various levels of interaction. Based on the user behavior and its analysis they can simply provide feedback in the forms of hints, nudges, and recommendations, letting the user decide which of them to consider and accept. On the other hand, they can conduct an intelligent dialogue with the user, responding to their questions and input.

user!modeling
personalized!adaptive learning
learning!collaborative
cognitivism
constructivism
behaviorism
Industry 4.0

The *User Interface* layer offers new chances for immersive procedural training, like capturing and re-enactment of expert performance, enabling immersive, in-situ, and intuitive learning [14]. Motor skill learning is another area where wearable technology and user modeling can be synergistically combined [8].

5 Conclusion and future prospects

We have observed that in recent decades alternative approaches have been investigated in the area of workplace learning. Transmission and acquisition of well-structured knowledge by means of guidance was a typical objective of *personalized adaptive learning* systems. Later on, *collaborative learning* could be facilitated by Web 2.0 and social software, supporting the creation of new knowledge. Moreover, a lot of attention has been given to the cultivation of meta-cognitive skills, like motivation, planning, and reflection, which are part of SRL. These efforts can benefit from the rapid progress in educational data mining, RSs, and LA. The three different types of learning correspond to the basic educational theories of cognitivism, constructivism, and behaviorism. In practice it is crucial to find a suitable orchestration and balance among them, depending on the concrete objectives and circumstances.

Industry 4.0 changes the manufacturing world dramatically and especially SMEs need and deserve special support in order to be able to benefit from the new conditions [31]. Such a transition is a complex process, which is very difficult to control. It includes change management at the technical, organizational, as well as personal level. A crucial part of these changes represents the human factor with upskilling of the workforce and development of required competences, which calls for a radical improvement of informal learning and training at the workplace, based on novel models that support creation of knowledge in the learning process. Nevertheless, it is important to search for solutions that can make this move easier for both parties involved – the companies themselves and their employees. Each of them needs a good motivation and a clear benefit when new tools and services are to be successfully adopted.

To summarize, learning and training offers should take into account not only individual preferences of users, but also the effectiveness and efficiency of the learning experience, including also the current context, with learner's emotional status and attention. Ubiquitous sensors and IoT open more opportunities for processing of the big educational data, which leads to a better recognition of learners' objectives, preferences and context, and consequently to a more precise personalization and adaptation of learning experiences. Their effectiveness and efficiency can be improved by wearable technologies and augmented reality, which open new horizons for innovative training methods, cultivating required competences. Transparency and understandability of machine decisions as well as clear and manageable privacy rules are crucial to gain the trust of the user. These requirements can be facilitated by blockchain technology, which has the potential to be disruptive.

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