A Service-Oriented Distributed Learning Environment for Manufacturing Workplaces

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Abstract. Small and Medium Enterprises (SME) are key assets to Europe's economic future, providing millions of workers with access to technology, skills, and knowledge – often, however, missing a managed approach and appropriate tools for continuous learning and development.

This paper introduces a service-oriented platform – and associated building blocks – developed to implement an operational reference framework ("eMeMO"), tailored to learning and training needs of Blue Collar Workers in manufacturing environments, and built to increase their training and work performance directly at the workplace.

The experiences and results illustrated have been collected during the activities of the research project TELL ME [1], a EU-co-funded initiative held by industry, universities, research labs, technology firms and innovation companies from all over Europe.

Keywords: Service oriented architecture (SOA) · Technology enhanced learning (TEL) · Small medium enterprises · Manufacturing · Workplace · Augmented reality (AR) · Internet of things (IoT) · Mobile learning · Multimodal user interfaces (UI) · User experience

1 The Learning Process

The TELL ME project [1] was conceived to improve learning and training in small manufacturing environments by introducing advanced learning technologies and innovative training methods to SMEs.

To address this challenge, a new pedagogical framework was defined to be supported by state-of-the-art technologies and be tested during two piloting cycles in different application scenarios. This framework – a learning process meta-methodology – takes its name (eMeMO) from the steps it encompasses: enquire, mix, experience, match,

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and optimise [2–4]. It is tailored to the Blue Collar Workers' (BCW) needs in manufacturing environments, increasing their work performance rapidly, with training taking place directly at the workplace. eMeMO defines a process by which the correct learning/training method for each specific worker/activity/context is selected, applied and monitored: hence it is more correctly referenced to as a "meta-methodology" (Fig. 1).

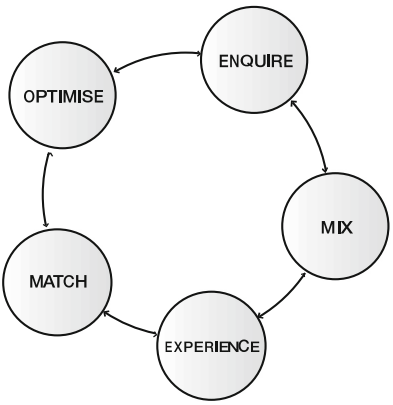

Fig. 1. The eMeMO meta-methodology cycle.

Step 1 (*Enquire*) provides tools to express a learning need, to retrieve training resources that could help BCWs in filling gaps on e.g. new manufacturing processes and associated skills. Enquiries can be generated by BCWs, Process Managers, or semi-automatically (e.g. IoT-based wrong behaviour detection).

Step 2 (*Mix*) helps in choosing an appropriate sub-set of the available training resources and blending those resources into learning mixes that suit specific training needs. Learning mixes conveyed to the worker can contain any type of contents so that existing material can be reused, minimizing costs. The learning mix is composed applying personalisation axes (eMeMo rule engine) modelled at configuration time.

Step 3 (*Experience*) provides the BCW with the actual training experience. Training resources are delivered on different complementary devices and can be contextualised on the fly according to the detected device, profile, environment, etc.

Step 4 (*Match*) uses engagement data from the training experiences to make predictions about trainee's state of competence, comparing learner behaviour with the reference models specified at design time.

Step 5 (*Optimise*) allows for experimentation with new parameters for steps 2-4, seeking an increase in engagement and driving up performance, while reducing time-to-competence.

eMeMO is particularly appropriate for BCWs accomplishing activities that require manual dexterity: their work typically involves a mix of physical and cognitive activity, with a blend of fast and slow steps, repeated in cycles within a time period ranging from seconds to hours. This scenario requires a mix of different types of learning methods for training-on-the-job according to the specific contexts. To support this approach, the eMeMO methodology provides suggestions at design time on how to organize the learning process and the associated contents, leading to a personalisation of the training solution.

2 The Service-Oriented Architecture

To support the five steps of the eMeMO methodology, the TELL ME project has implemented a distributed architecture (see Fig. 2), spanning three distinct layers: a presentation layer holding multimodal user interfaces, a middleware layer including the core business logic components (implementing the eMeMO-powered functionalities), and a repository layer including distributed repositories and legacy systems, including repositories for Open Educational Resources (OER).

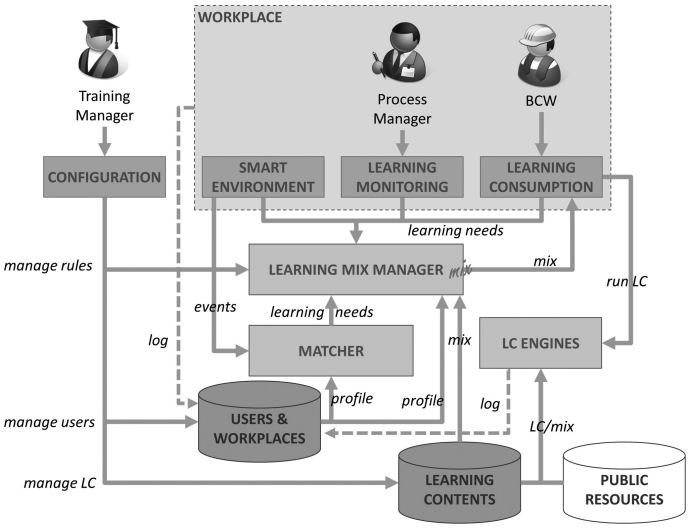

Fig. 2. Logical view of the architecture.

The approach allowed to develop a modular platform that can be customised easily and that scales out according to the needs of the applicable scenario, including customized components and tools in compliance with the technical and operational requirements defined by the working environment context.

2.1 Presentation Layer

The presentation layer includes tools for the Training Manager (in charge of the preparation of learning resources and of the planning of learning processes), the Process Manager (in charge of the scheduling and monitoring of working activities, for which specific training may be required), and the BCW, to support configuration and content preparation (upload, tagging, editing etc.), job/activity scheduling and monitoring, and learning content consumption while training-on-the-job.

Several tools allow the Training Manager to include available training resources in the assets managed by the TELL ME system, by uploading or referencing contents and tagging them with proper domain taxonomy tags for later indexing and retrieval.

A dedicated UI allows the Process Manager to assign jobs to BCWs: the system acts as a Decision Support System (DSS) suggesting the personalized training needed by the selected BCWs to accomplish the assigned task, according to the worker's previous experiences (in same or similar tasks) and on a set of personalisation criteria (e.g. the expertise in the specific sector). The system allows the manager to monitor the execution of learning and annotate the execution and the results of the work in order to align the user experience and optimise the learning ex-post.

The BCW accesses the system via the learning consumption user interface, where notifications on jobs to be done and associated learning mixes are available, thereby blending learning contents and manual activities to be executed in order to correctly accomplish the operations assigned. The UI includes a set of players to run the learning contents (which include e.g. video tutorials, interactive Computer Based Training contents, Precision Teaching lessons, extracts of manuals, electronic jobcards, etc.) plus tools to monitor the consumption and test results where applicable (e.g. in Precision Teaching modules).

2.2 Middleware Layer

The middleware layer provides two categories of functionalities to the TELL ME distributed architecture. Firstly, there are communication/integration functionalities, whose services are supported by components such as the Enterprise Service Bus (ESB), where services register in order to interact, or, to make another example, the Messaging Server that allows the communication between the TELL ME system and the IoT infrastructure. The second type of functionalities are those dealing with the business core, i.e., services that implement the eMeMO core functionality in order to provide the personalised and optimised learning mixes to the BCW, adapted according to context, previous expertise, identified existing knowledge and/or skills gaps (using, e.g., IoT-related Complex Event Processing, the eMeMO Rule Engine, and the Learning Content Indexing and Retrieval Engine).

2.3 Repository Layer

The repository layer includes repositories for data used by the platform components (e.g. Learning Contents and Learning Mixes, the associated meta-data, Domain Taxonomies, User Profiles) as well as the Repository Data Access functionality, providing a unified API for accessing the TELL ME data by means of services for retrieving local and distributed media and learning contents.

All training material is homogeneously described by using descriptive tags extracted from dedicated domain taxonomies modelling the workplace in terms of relationships associating categories such as Subject, Object, Mediator, Activities, plus technical information such as Format and contextual information such Rule (i.e. motivation for

a specific learning need) and Target (i.e. objective of training). In addition to such tag-based meta-description of learning contents, URLs can be added to directly retrieve contents from external public sources that are freely available on the web as well as from private, protected sources, typically given where storage resides in company databases and legacy repositories.

3 Technologies and Tools

3.1 Adaptive BCW User Interface

The adaptive web UI for BCWs includes a complete set of tools to allow trainees to consume learning contents on a web desktop environment, e.g. for briefing sessions before training-on-the-job activities.

The web UI is based on the Dojo Toolkit [5], improving modularity and reusability of modules and UI responsiveness. Tools and functionalities are 'widgetized', adhering to the principle of Progressive Enhancement (separation of concerns among presentation, structure and behaviour) and the graphical layout has been adapted from a fully adaptive dashboard template [6] based on Bootstrap [7].

Learning mixes can be inspected in a timeline view and experienced in a dedicated player, which allows rating and commenting the learning experience content by content. The information is later reused to optimise the proposed learning mixes.

Events (e.g. learning content consumption, search, browsing, rating) are logged to an instance of the Learning Locker [7], a Learning Record Store (LRS) implementing the Experience API (xAPI) [8], for tracking and analysing trainees' learning activity (ADL xAPI Vocabulary) and work behaviour (proprietary activity vocabulary).

3.2 Augmented Reality

Augmented Reality (AR) provides new possibilities to improve proficiency and safety on the workplace, while at the same time reducing training costs in particular in manufacturing industries. Among the applications developed to support workers on the shop floor, the possibility to perform training-on-the-job using an AR app for showing contextualised information is considered an innovative approach to experience learning contents, while carrying out manual tasks.

The TELL ME project developed an Augmented Reality system, called ARgh!, which utilises an activity model (managed as a special learning content to be consumed on tablets or smart glasses) to prompt contextual information such as safety signs and simple instructions, depending on environment recognised and actual objects detected. The tablet UI enables the presentation of both informative HTML5 contents and simple/contextualised AR contents (see Fig. 3).

The tablets are technically very suitable for AR: since the user looks at the environment through the live video produced by the tablet camera, the overlays can be placed accurately without the need of any offset correction. Being the AR layer added using this hand-held window, the user can simply put the AR layer aside, whenever it is not needed. Usability problems with tablets arise in cases where it is necessary to use

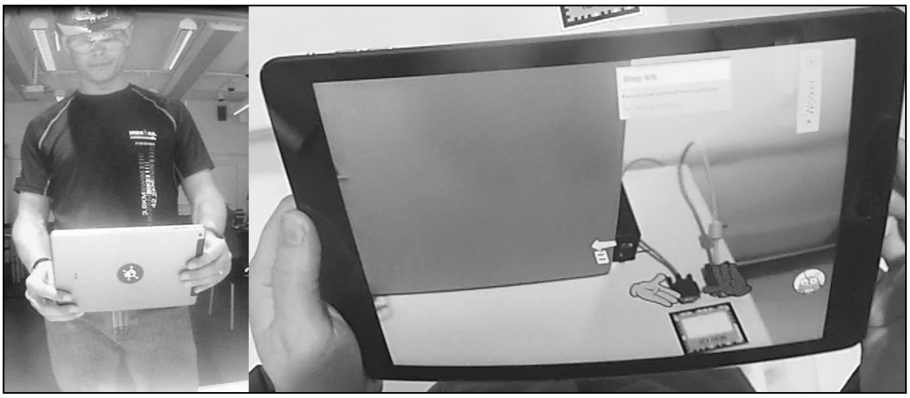

Fig. 3. ARgh! AR-systems tablet version: user performing a task (left), view of the graphical information overlay (right).

both hands for manual activities and get information through the AR layer as well. Since many on-the-job learning cases require hands-free operation, ARgh! running on tablets cannot be the only available option for training delivery, although the tablet might offer the most reliable AR experience: TELL ME provides such an alternative in terms of hands-free smartphone apps and smart glasses apps.

3.3 Multimodal JobCard App

An Android app was developed to allow multimodal consumption of training-on-the-job learning activities, modelled in form of electronic job cards. The app allows BCWs to download a particular training job card onto the mobile device and provides online and offline learning support for every included step. Multimodal interaction is powered by a hands-free interface with Speech Recognition and Text-to-Speech functionalities supported by a low-cost Bluetooth media headset: single clicks on the headset media button trigger the recognition of spoken commands, so that the trainee can follow instructions, immediately perform the illustrated manual activity and proceed further or, alternatively, ask for specific support, for example, on how to do a specific process, how to use a specific tool, or how to find specific parts. In the latter case, the app retrieves specific learning contents such as photos, instructions and tutorials (videos) enriching the on-the-job training experience.

3.4 Experience API (XAPI) and Learning Locker LRS

An instance of the Learning Locker [8] Learning Recording Store (LRS) has been included in the TELL ME SOA to support collecting, querying and reporting learning activities. Learning Locker is a LAMP-based [10] project using MongoDB, PHP, and AngularJS, designed to collect learning activity statements generated by xAPI-compliant components and generate reports from such data. A REST WS API

interface to the LRS is available to any TELL ME component to submit and retrieve xAPI statements. Use cases thus include the tracking of learning activity (e.g. expertise diary), constraint/check validation (e.g. for AR application, to enable triggering specific information according to the detected expertise and proficiency), optimisation for creating learning mixes (e.g. on the basis of training contents previously consumed, on average ratings/comments), and the logging of combinations of learning and work activities by means of dedicated vocabulary extensions (additional activities and verbs).

3.5 Video Segmentation and Adaptive Bitrate Streaming

The content delivery system in the TELL ME SOA includes also HTTP Adaptive Bitrate Streaming (ABS) capabilities, providing both server-side (transcoding, packaging and deployment) and client-side (delivery) tools for video management. This technology delivers videos at the highest-possible quality playback, independently of the workplace characteristics, by automatically detecting in real-time network and playback conditions. In this way, the videos (e.g. on-demand tutorials) are available without lags, allowing the workers to consume video tutorials and successfully conclude the assigned tasks in the expected time.

ABS works by dynamically monitoring CPU and memory capacity and then making corresponding adjustments to video quality. To accomplish this, the original learning video is encoded according to multiple qualities (bitrates). Then each of the different bitrate streams is segmented into small parts and uploaded to appropriate web server folders. The list of segments and bitrates is written into a manifest file, called Media Presentation Description (MPD). By parsing the MPD, the client learns about the video characteristics (media-content resolutions, minimum and maximum bandwidths, locations on the network, etc.). When the user plays the video, the user's device fetches the segments from the lowest bitrate stream (given in the manifest file), by using HTTP GET requests. After appropriate buffering to allow for network throughput variations, the player continues fetching the subsequent segments and also monitors the network bandwidth changes. If the video player detects that the download speed exceeds the bitrate of the initial segment, it will request the next higher bitrate segment. This process will continue until a close match is found between the current bitrate segment and the user's available bandwidth. The video will then play at that bitrate. Later, if user bandwidth changes, a different bitrate segment will be requested. The implemented components utilise the unified common standard MPEG-DASH [11] and open-source technologies, precisely x264 transcoder [12], the MP4BOX content packager [13], and video.js library for the player heuristics [14].

4 Conclusions

At the time of writing, the TELL ME project Consortium is carrying out a public campaign for the demonstration of results in several EU countries, involving dozens of companies (mainly SMEs) from the manufacturing sector and a large number of BCWs and Process Managers. Live demos will allow hands-on experience for all participants,

to show facts and best practices of TEL solutions adopted by the project and gather precious feedback on how to guide the industrialization process of the released prototypes, eventually supporting the exploitation phase.

During the final piloting, validation and evaluation phase, the proposed solutions will be further tested by end users in three different application scenarios: supplies and maintenance for the helicopter industry; fitting out luxury yachts (furniture making); and in the textile industry (quality inspection). The results of these activities will allow to fine tune the proposed tools and finally reduce the time-to-market for SME-tailored learning systems based on the proposed framework.

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