E-Learning with Hands-On Labs in Higher European Education

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***Abstract*—"Learning by doing" has incontestably the highest enduring and motivating effects in learning. It challenges the exploratory aptitude and curiosity of a person. In higher education in information technology, exploratory learning is hindered by technical situations that are not easy to reproduce and to verify. Technical skills are, however, mandatory for employees in this area. On the other side, theoretical concepts are often compromised by commercial implementations. The challenge is to contrast and reconcile theory with practise. In two European Union funded projects we designed, implemented, and evaluated a unique e-learning approach, which realises a modularised teaching concept that provides easily reproducible virtual hands-on labs. The novelty of the approach is to use software products of industrial relevance to compare with theory and to contrast different implementations. Pilot applications in several European countries demonstrated that the participants gained highly sustainable and profound understanding about the learning objects.**

***Keywords*-learning by doing, virtual laboratory, hands-on lab, e-learning concept.**

I. Introduction

Aristotle already promoted "learning by doing" in his eminent work on ethics, the Nicomachean Ethics [1]. The concept became known in pedagogy through the work of Comenius [2]. From the perspective of developmental biology learning by doing is known even from animals [3] and experimenting (the systematic learning by doing) is fundamental in the development of the *homo sapiens* [4][5].

Effective knowledge transfer at Higher Education (HE) institutions and Vocational Educational Training (VET) should be tailored to the needs of its clients. Employees are highly motivated to acquire new skills but are often hindered to follow a scheduled training programme. Students face a denser curriculum due to the Bologna process with a high degree of optional courses whose schedules and prerequisites are not aligned. Therefore it is essential to provide self study courses with small module sizes to enable the participants to learn in their spare time at an individual pace. In addition, in financially difficult times, knowledge transfer should be highly scalable in terms of costs. E-Learning offers this capability but has the difficulty to keep motivation high.

As consequence, e-learning has to solve a multidimensional problem: The learning content needs to be chunked into "digestible" portions while keeping the necessary context. Technological reality has to match with the theoretical underpinning. Technological aspects in Information and Communication Technology (ICT) are of particular importance to empower students and employees for a competitive labor market. This will stimulate the secondary motivation of the learners.

In our case we focus on one of the most important areas in ICT competency for information management professionals: *database systems*. Databases are now the underlying framework of information systems that have fundamentally changed the way organizations and individuals structure and handle information.

One crucial competence within the database domain is how to structure efficiently a database and how to correctly process the data. For example, in the case of a banking application the database has to process correctly and reliably the financial transaction under any circumstances.

This requires a sound understanding of the theory and practical skills of software products at the same time. Such a highly specialized knowledge cannot be only theoretically taught neither could it be trained only by examples like a cookbook. This is the scenario for our e-learning based concept with hands-on labs.

A. Structure of the Paper

With the following overview on related work in cognitive science the context for our learning theory will be settled. In Section II we point out the pedagogical requirements, the modularization constraints dictated by the learning object and the stress field between industry demands and long term knowledge for the students. This clarification is used in Section III as criterion for developing a unique reference model for the example learning object *database systems*.

Section IV describes the supporting technology, in particular, the environment for the hands-on labs. Our findings during pilot runs of the learning modules are presented and discussed in Section V. We end the paper with a conclusion.

B. Related Work

E-learning is a promising research subject and there is an abundance of publications on the foundation of on-line

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learning (e.g., [6][7][8][9][10]) as well as on problems. For instance, the decreasing motivation was described by Prenzel [11] and Paechter et al. [12]. It is also confirmed by our own experience with e-learning.

According to the constructionism [13] the learner generates knowledge by individual experience (radical constructivism [14]) or by social interaction within a cultural context (social constructivism [7]). As consequence, knowledge should be acquired by the learner in authentic situations that keep motivation high [15]. Connolly and Begg [16] report similar experiences and recommend teaching database analysis and design in a problem based environment.

Communication with fellow students and team work supports motivation, too [9]. This makes a communication and collaboration tool an indispensable ingredient of an e-learning system.

Multimedia support through E-learning systems is a an enabler for flexible and scalable HE and VET, but is no guaranty for a successful on-line course. Critical voices raised the issue of superficial and routine knowledge that may easily be transferred. This knowledge refers to the cognitive domains one (knowledge) and two (comprehension) of Bloom's taxonomy [8]. Bloom's knowledge taxonomy was chosen because it fits well into the evaluation of skills related learning. But, profound insights (analysis, synthesis, and evaluation in Bloom's categories) are difficult to convey with a computer based learning environment as the study conducted by Spannagel [17] reveals.

It seems difficult to ensure that theory and the necessary abstraction are drawn from an example. There are concepts that try to overcome these problems with the use of multimedia technology [10].

Blended learning, for example, tries to combine classroom learning with e-learning ([6], chap. 10 and 29). Classroom teaching can provide for theory and the e-learning session practise the knowledge in form of exercises or experiments. We apply this technique for our virtual laboratory workshops described in Subsection III-C. This hybrid learning does not ensure sustainable and deep understanding, but, a well thought concept may help to convey deep insights as Astleitner and Wiesner [9] point out.

Our concept aims further: It contrasts and reconciles theory with the reality of commercial software products. This is important because software professionals and experts need the competence to verify the real behavior of a database system for instance and compare it with the theory. As consequence real products are necessary as training tools and for assessment. No learning concept, so far, has tried to deal with the peculiarities of commercial software products.

II. Problem Description and Contribution

The goal is to provide a highly modularized e-learning environment for the specific theoretical and practical needs of HE and VET in the domain of ICT. For the proof of concept we have chosen the material produced during two EU funded projects: DBTech Pro (funded by the Leonardo da Vinci programme) and its successor DBTech EXT (funded by the EU Lifelong Learning Programme). The content focus was on in depth knowledge with hands-on labs for database design, transaction processing, and data mining. More information about both projects may be found at http://www.dbtechnet.org.

From the pedagogical view we identified the following requirements:

- self controlled learning
- authentic problem oriented learning
- most effective, cooperative learning
- self assessment
- feedback and evaluation

Self controlled learning is important because of the above mentioned time constraints and with regard to different precognitions of the learners. For high motivation it is necessary to pose authentic, real world problems to solve [16]. This requires state-of-the-art software used in industry.

Cooperative learning has two positive effects, one for the learner and one for the teacher: Communication among the students and working in groups keep motivation high and yield better learning results. From the teacher's view the communication provides feedback on the effectiveness of the teaching and exercise material. In addition, communication among students reduces teacher intervention.

Memorized knowledge may be assessed easily through multiple choice tests but constructive tasks and creative work are a challenge to assess in a automated way.

From the skills and competences demanded by employers the following requirements need to be taken into account:

- ability to solve real world tasks (problem solving)
- knowledge about state-of-the-art technology
- social skills, so called soft skills

Employees and students have increasing interest in learning skills that give a fast and easy to see return on their learning investment in form of directly applicable knowledge at their working place. This validates the first two qualification requirements. Problem solving and social skills are indispensable for highly demanding ICT jobs [18].

In addition to the above requirement, the teaching units (modules) need to comply with the taxonomy of that domain, which defines how to slice the content along the aspects:

- competence level
- subject area
- technology

Cutting the content along the competence level provides different degrees of detail in line with target competencies and work profile. Students of HE institutions prefer a different learning concept than in VET courses. The latter have a tighter time schedule with less time for reflection of theoretical issues than HE students.

So, apart from the challenging content we tried to address all of the above requirements by slicing the learning content so that it can be combined and composed in multiple ways.

A. *Contribution*

The contribution of this paper consists of an integrated learning concept for e-learning addressing the needs and constraints of HE and VET. For each learning unit the most appropriate learning concept was applied. Furthermore, the framework solves the problem of content modularization. Exemplary e-learning material that was used in multiple pilot runs proofed the usefulness and superior knowledge sustainability compared to traditional university teaching. The main advantage lies in the practical skills acquired using real DBMS products in the hands-on labs. The necessary lab environments are easy reproducible and provide full control of license restrictions.

III. The Reference Model

The reference model applies different learning concepts reflecting the different aspects and challenges presented in the previous Section. The interrelation of these requirements make it difficult to optimise the learning concept. For better understanding we treat the dimensions content, lab environment, and project work separately and discuss the global optimisation in Subsection III-E at the end of this section.

A. *Knowledge Taxonomy*

It is common to define a syllabus for the learning content. Structuring the syllabus results in a knowledge taxonomy of the teaching domain. From this structure we are able to deduct pre-requisites, identify learning elements, and designate learning outcomes. Structuring the teaching domain along the knowledge levels defined by Bloom [8] helped us to modularize the content according to knowledge depth and to provide teaching units for different target groups. As an example, Figure 1 shows an cutout of the DBTech database taxonomy [19] showing the comprehension levels. From this layering we were able to deduct pre-requisites for every learning unit. For instance the unit *data modeling* (see Silberschatz et al. [20]) requires knowledge about the *relational, hierarchical*, and *network model*.

B. *Virtual Laboratory*

The most important component of our e-learning model is the ”learning by doing”. The psychomotoric learning keeps motivation high and supports a high degree of practical skills needed by companies. Moreover, the endurance of knowledge is much better and profound than without hands-on labs. Small, practical exercises and experimenting prepares the way for problem based learning.

In the case of ICT we have to deal with sophisticated, interdependent software systems like database management systems, application servers, data warehousing, OLAP systems, or business intelligence suites. A student would need excessive time to install and set up the lab environment. This is unfeasible, considering only the risk that the system might be (unconsciously) misconfigured.

An other obstacle could be inhomogeneous hardware that might impede the installation of a certain product. The only technical solution that works without problems is the virtualization technology. It provides a lab environment independent of the physical computer, which can be copied across the Internet to computers of the learners. Even if a student accidentally damages the virtual system he can reset it to its original state. He is also able to save his results in a snapshot and continue later or at a different computer. There exist virtual image capturing and playing software that is freely available.

C. *Virtual Laboratory Workshops*

The technological complexity of the Virtual Laboratory makes it necessary to provide detailed, step-by-step tutorials for experimenting. In order to make the learning more effective, we decided to use blended learning techniques and gather students for live workshops using the virtual laboratory. One trainer for about 10 students was sufficient to answer questions or to provide help with the virtual lab environment.

Between workshop sessions and for remote participants Skype telephone and remote assistance via web conferencing tools have been available. This allowed interactive help directly with the laboratory environment.

The students had to submit their deliverables electronically via the e-learning platform for grading. The e-learning system was also heavily used as a discussion board and for feedback from students. The feedback was used for improvements.

D. *Project Work*

While teaching theory in a didactic way and practising or verifying the transferred knowledge in hands-on labs there is no guaranty that the students really acquire a problem solving competence. It is necessary to combine different knowledge pieces, then abstract and apply them as a whole. This systemic knowledge gap can be easily seen when students know about the ACID properties [21] of a transaction, but cannot relate a real world problem like the concurrent on-line reservation of flights with the concurrency issue. In the lab with real products it is possible to test the behavior of the used software also in case of concurrent clients.

Moreover, students might be skilled in technological aspects of application servers but do not realize the danger

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8	DBTech Pro Framework Reference courses and Topics	European Qualification Framework	IEEE/ACM CS2008	EUCIP initiative of CEPES	ACM AIS AITP IS 2002	BCS Professional Examination 2003	SweBOK
9							
10	**Principles of Database Systems** (Level: Introduction, - obligatory)	Knowledge Level	CS2:IM1, IM2	EUCIP core IM knowledge		BCS Diploma (D) - Database Systems	CS 5 IM
11	Database Principle	Level 5	IM2.1, IM2.2	3.2.2.3		D 5.2	
12	Concepts of Database Systems and Environments	Level 3		3.2.2.1 3.2.2.4		D 5.1	
13	User roles	Level 3		3.2.2.4			
14	Ansi/Sparc Architecture	Level 3					
15	Conceptual models: ER and UML	Level 3					
16	Data Modeling	Level 5	IM2	3.2.2.2			
17	- Relational Model (RM) - Hierarchical (for XML) - Network Model (for ODBMS)					D 5.4 (RM)	
18	Relational Theory	Level 3					
19	- Relational Algebra	Level 2		3.2.2.6		D 5.4	
20	*Normalization*	Level 4				D 5.4	
21	Object-oriented Model	Level 5					
22	ODMG Standard	Level 5					
23	SQL Basics	Level 5		3.2.2.7			
24	QBE	Level 5					
25	Security	Level 3					
26	Transaction Processing	Level 4					
27	*Transaction Principle*	Level 4				D 5.6	

Figure 1. Mapping of DBTech Database Taxonomy to other CS curricula (partial view) [19]

of compromised transaction due to technological tricks like pooled connections or disconnected components.

To ensure problem solving competences beyond technical issues students have to develop their ability to work in teams, manage tasks, organise releases and orchestrate different versions. All these knowledge can be learned from real world projects.

E. E-Learning Model

We believe it is best to decide from the learning content, which learning concept will be best suited for a specific content. The e-learning model we present integrates different learning concepts (see Issing [6]):

- Learning as behavioral modification for *practical skills* and verification of the theory
- Learning as active information processing using assimilation and accommodation processes to build a mental model of the *theory*
- Learning as construction of knowledge used for problem based learning as in *project work*

All these concepts are used in an integrative way in order to get the most effective results in terms of applicable knowledge and profound cognition that enable abstraction and problem solving to a large extent. The design of the e-learning model (see Figure 2) starts with structuring the learning area guided by a taxonomy. The area is sliced with a minimum of dependencies and each chunk of learning content is represented in a theory unit, with examples and demonstrations of the theory. Hands-on experiments help

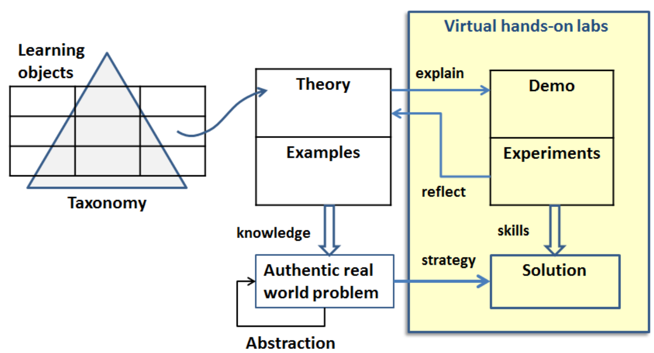

Figure 2. E-Learning Model Overview

to verify the theory. The global optimization task is to put together all aspects in balance with the target learning group.

Examples and demonstrations explain the theory, making it easier to understand. Hands-on experiments motivate and stimulate students to reflect the theory. Examples provide the students with analogous situations that could be applied and abstracted in the project work. The interrelation of all these elements provided in a virtual lab environment with the theory units and the examples are as shown in Figure 2.

The concrete real world problem forces the students to abstract from examples and construct a model of the problem world in order to find a solution.

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IV. Technical Framework and Infrastructure

The framework of technologies provides a central, web based repository for teaching material, lab environments, multimedia, communication and collaboration tools.

A. E-Learning Portal

We provide all e-learning material through a portal (see http://dbtech.uom.gr and [22]) using Moodle as software platform. It contains all theory units, mostly as reading material, video lectures, tests, assessments and experimental lab environments that will be described in the following subsection. Local versions, like translations or modifications that fit the curriculum constraints are hosted and maintained at the project partners sites (https://relax.reutlingen-university.de for Reutlingen University, or https://elearn.haaga-helia.fi/moodle/login/index.php for Haaga-Helia University for Applied Sciences).

B. Virtual Laboratory Infrastructure

The lab environments are available either through technologies like desktop virtualization or virtual machines running computer software images. The latter is used when the image only uses free software. In this case, there is no need to control the number of downloads or to provide licences. After downloading the image it can run off-line. Free player for the image are available, e.g., VirtualBox.

For commercial software products where licenses are needed, the use of a desktop virtualization is more appropriate as it let easily control the number of remote application accesses. Citrix XenDesktop or VMware View are examples that provide a Virtual Desktop Infrastructure (VDI) for different operating systems.

VDI provides remote access to a pool of virtual machines through a connection broker. If the license policy is for a number of concurrent users it is no problem to limit the concurrent users with this software. Access control may be enforced by LDAP or Active Directory. The virtual machines are automatically managed in terms of multiple and customized instances of computer systems, applications, and for every users. Independent virtual machines may be assigned to avoid any resource access conflicts. Access to different operating systems is possible and the assignment to a client's PC may be persistent or transient.

As infrastructure for accessing the virtual machines from a client machine a local or public area network is needed. Client computers only need a web browser with ActiveX or Java Applet technology support. Such a support is given by the most common web browsers.

DBTech EXT uses a VDI operated by the University of Málaga. The number of concurrently active virtual machines depend on the resources (processor cores, memory, and disc space) provided. In the case of DBTech EXT labs Málaga uses two VMware servers with two quad-core processors and 32 Gigabytes of RAM each [23]. This infrastructure

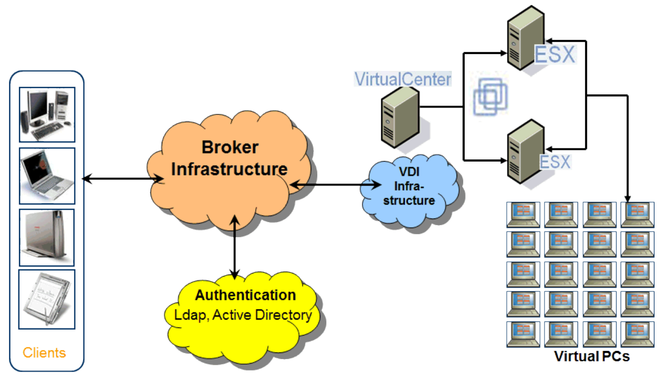

Figure 3. Virtual Desktop Infrastructure for virtual labs [23]

has enough power to run 96 concurrent virtual systems, each with 512 Megabytes of memory. The VDI architecture is presented in Figure 3 showing the VMware architecture consisting of a virtual center and two Hypervisor ESX servers that provide for multiple operating systems running on a single server. The broker is responsible for dispatching the connection requests from clients and to control the access with the help of an authentication service.

V. Experiences

The experiences mainly stem from two EU funded projects that were carried out during the years 2002-2005 and 2009-2010 (see http://www.dbtechnet.org). During the first project phase we identified important knowledge areas of *database systems* and syllabi of courses. The syllabi were later extended to a taxonomy and integrated within a unified learning concept.

A couple of example e-learning modules have been developed as testing material and these courses were used as teaching material for virtual workshops conducted during the second project. For the virtual workshop the e-learning platform was enhanced by communication and collaboration tools like Skype, discussion boards and upload areas for deliverables. Teaching material was structured and furnished with exercises and assignments for the students. The exercises used the previously described virtual infrastructure to guaranty a predefined and fully functional environment. Assessment of the student was done by on-line tests preferably in form of multiple choice questions.

The methodologies used to evaluate and assess our concept included informal and formal (survey conducted via the e-learning platform) feedback and self evaluation, discussions with students, and the results of written examinations (open and multiple choice questions).

The answers to the multiple choice questions were collected and assessed with the help of the e-learning system. However, the type of questions allowed only to test the analytical skills and not the construction of knowledge or

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innovative solutions. As consequence the project work was only assessed manually at the partner's institutions.

In Reutlingen study projects of real world problems are incorporated into the curriculum since more than 10 years. Over many generations of students the feedback was uniformly positive. Students appraise the real life character of the projects. In about one third of the projects, the problem was posed by a company that also collaborated with the students team. From the didactics point of view the motivation was kept high if the company or the university committed itself to use the project results. In most cases this was a software to be developed by the students.

Problem based learning confirmed the proposed high motivation if in addition the knowledge background of the project team was sufficient to master the problem. It was not necessary that each of the participants was an expert programmer or had managing competence. It was sufficient to have at least one with the necessary capability. In most cases this stimulated the team and resulted in an intensive team internal learning process. The supervising professor has the responsibility to make sure that the students with less knowledge will not become frustrated. The intervention could be additional training for the "weaker" students or to assign a different role to the "dominant" student. In individual situations we have been successful if the more knowledgeable student acts as a trainer for a while.

Comparing student teams that work physically together outperform teams that only work together virtually. In feedback discussions the students state a lower motivation and commitment to the project team if they worked remote without meeting each other. Asking for reasons the students named the missing personal contact and commitment. In contrast the teams that met regularly developed a culture of responsibility that supported motivation and contributed to the project success.

VI. Conclusion

The outstanding lessons learned of this long term e-learning experience can be summarized in three statements:

1) A key success factor is the adequate slicing of the knowledge domain. Only if this requirement is granted, the necessary small chunks of information are identified and can be prepared according to our e-learning model. If the chunks are not small and sufficiently independent it is hard to provide e-learning modules that can be worked through without the constant help of the teacher.
2) E-Learning is not superior to face-to-face teaching. It is more difficult to motivate the students. The preparation of study material is much more elaborate than for traditional teaching.
3) E-Learning scales better only for knowledge and comprehension level (Bloom's taxonomy) and partially for the application level. For higher level (deeper understanding) as synthesis, evaluation and analysis a stronger communication seems to be necessary for this cognitive levels.
We found no way to automate the assessment of creative and constructive results like the assessment of a project or a software. This is a challenge for future work.

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