Implementing a New Approach for the Design of an E-Learning Platform in Engineering Education

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ABSTRACT: Modern corporations, institutions, universities and schools consider e-education as a way of educating larger groups of students in less time and of reducing the use of various resources. Since setting up a web-system for e-education requires a significant amount of time, as well as the necessity of having a computer and other resources, the assessment of the goals and desired effects of the online system should be made in the preparation phase. It is important to highlight that only putting course contents on the web, without using appropriate pedagogical models and principles, without appropriate means of communication between participants and instructors and without the use of modern information technologies to present the learning content is not enough to fulfil educational goals. It should be noted that, after the substantial initial investment and excitement about the possibilities of e-education, many sources of difficulty and dissatisfaction regarding online learning have emerged. Most e-learning studies propose possible improvements in course material, with little attempt to explore the learners’ dimension, context, pedagogical considerations or technology aspects. In this article, we have analysed the aspects that need to be considered when designing an e-learning platform for engineering education and we have proposed a methodology, based on the Quality Function Deployment approach, useful for the preparation phase of distance learning systems. Finally, we have explained the impact of new information technologies (Web3D technologies) on online engineering education and highlighted how these tools have been implemented in the e-learning platforms for mechanical engineering that we have developed. © 2012 Wiley Periodicals, Inc. Comput Appl Eng Educ; View this article online at wileyonlinelibrary.com/journal/cae; DOI 10.1002/cae.21564

Keywords: distance education; technology integration/innovation; interactive learning environments; lifelong learning; pedagogical issues; engineering education

INTRODUCTION

E-learning has been described as the use of telecommunication technology to deliver, support and enhance teaching and learning. Due to the rapid growth in Internet, web-based learning (WBL), computer-based training (CBT), computer-assisted learning (CAL), computer-based instruction (CBI), distance education, distance learning and e-learning are becoming synonymous [1].

Distance education has evolved from correspondence studies, open universities, teleconferencing, networks and multimedia delivery to today’s Web-based technologies [2,3]. With the development of information and communication technology, e-learning has emerged as the paradigm of modern education.

E-learning is basically a web-based system that makes information or knowledge available to users or learners and disregards time restrictions or geographical proximity, permitting freer interaction between learners and instructors, or learners and learners [4].

The development of an online educational system for a university course, seminar or corporate training can be justified as:

• It is easier for a large number of participants to successfully and more completely acquire educational content.
• It involves fewer expenses and less time for those students who have to travel to the class venue.
• It gives a better impression of the teacher/instructor and the institution that organises the course.
• It results in lower costs, which make the time and effort financially worthwhile for the institutions.
• It offers a chance to master new educational technologies and be part of contemporary trends.
• Investing in e-education is profitable in the long term. As Andrade et al. [5] have stated, the market targeted by WBL has been variously defined to include the following groups:
  • working adults who do not have the desire or resources to attend on-campus programs;
  • adults in jobs where their employers (e.g. the high technology sector) cannot afford to provide long leaves of absence;
  • adults in developing countries or isolated communities who do not otherwise have access to brick and mortar institutions;
  • single parents or economically disadvantaged adults who have to work full time;
  • working adults who travel too much to attend regular programs;
  • undergraduate students who need or want an alternative to on-campus programs for economic, social, personal or practical reasons.

The article is organised as follows: the first section considers the aspects that should be taken into consideration when setting up a web-system for e-education. The second section describes a methodology that can be applied for the preparation of an online instructional module and which illustrates the effectiveness of Web3D technologies in the creation of an e-learning system.

The third section illustrates the e-learning platforms that have been developed by the authors and describes the implementation of the Web3D techniques in the e-learning systems adopted in the authors’ university.

FACTORS TO CONSIDER IN THE DESIGN OF E-LEARNING PLATFORMS FOR ENGINEERING EDUCATION

Sun et al. [4] and Piccoli et al. [6] have stated that although online learning offers advantages over traditional face-to-face education, the high failure rate of e-learning deserves attention already from the initial phase of development.

WBL differs from conventional learning, which is student-centred, knowledge-centred, assessment-centred and community-centred [7]. WBL environments have transformed the roles of instructors, students and course materials so much that a new relationship has emerged between these three elements of learning [8].

In order to design an e-learning system for engineering education and to improve and stimulate the process of knowledge acquisition in an e-learning context, our study has sought:

• to establish the final users and beneficiaries of distance learning modules in engineering education;
• to gain a deeper understanding of learning theories, communication tools and the Information and Communications Technology (ICT) dimension;
• to decide which pedagogical approach and which information and communication technology should be employed.

Final Users and Beneficiaries of E-Learning Systems in Engineering Education

The characteristics of E-learning fulfill the requirements of learning in a modern society and have created a great demand for e-learning from businesses and institutes of higher education [4].

Andrade et al. [5] and Rosenberg [9] have stated that e-learning is mainly focused on two student types (a) traditional pupils (i.e. people who acquire knowledge and abilities prior to the start of their professional life) and (b) workers that have to acquire new knowledge or improve the knowledge they already possess in order to keep up with their job requirements (i.e. lifelong learning).

The irrelevance of the location where the course takes place and the inexistence of the restrictions associated with a traditional timetable are the most important advantages provided by e-learning.

The flexibility of time, place and programs offered via Web training is appealing to students who are trying to balance school with work and home responsibilities. They can mix modes of instruction, accumulate college credits and meet residency requirements for their degrees.

Workers who seek flexible working hours and telecommuting work arrangements are being drawn to companies that offer opportunities for them to upgrade their skills.

The World of the School. The last decade has witnessed a significant change in broad areas of social and cultural systems.

Education has also had to accommodate change, which is reflected in the ever-growing student population that occupies places on existing or newly developed courses, which cover a very broad range of subjects. The results of these changes are an increase in the student/staff ratio and a reduction in the hours of contact with students. If conventional educational practices persist, they will lead to diminishing quality of the offered learning experience [10].

Such pressures on the educational system are clearly reflected in the growth and development of computer technology, with applications in diverse areas, such as in engineering education.

Day and Suri [11] affirm that engineering learning is achieved through wider reading and by incorporating supplementary ideas that provide a broader perspective within the course syllabus. Developing knowledge through rigid reference to one mandatory textbook, or from course notes alone, may result in a narrow system of limited educational value, and also make engineering training more difficult and less interesting.

In addition, practice is very important in technical and vocational education, alongside theoretical education. Most of the lecturers in technical education institutions around the world agree that learning by practice helps facilitate retention more than learning by reading [12]. Practical experience is essential in the training of an engineer, as it helps to balance the
companies that have spent thousands of dollars on personal computers, networks and servers have invested in Web-based training as yet another application that justifies the organisation's spending on technical infrastructures.

Taking all these considerations into account, our aim was to provide education and training for a specific group of learners: employees of small and medium sized enterprises (SMEs) in the Computer Aided Design (CAD)/Computer Aided Engineering (CAE)/Reverse Engineering (RE) sector. SMEs are a vital part of the European economy and they face a number of problems concerning the maintenance and the development of their employees' skills. SMEs are characterised by small training budgets and limited release time, which makes it difficult for their staff to study full-time or on block-release courses away from the workplace [19,20].

SMEs could improve their organisational effectiveness by updating the skills of their workforce and SME employees could embark on personalised training programmes, gain recognised certifications and facilitate their work in the development of new and more complex and competitive products.

Communication Tools

The web site Reference Center for Teaching Methods and Communication in e-Education (Accessed 23.04.2010) [21] describes the process of learning in the academic environment. It is not only related to individual efforts to acquire knowledge and skills, but it is also based on social interaction between the users and the instructor, as well as between the users themselves.

This is why, for an educational process to be successful, it is not sufficient for the participants of online courses to receive information that is available in literature and in electronic sources; it is instead necessary to obtain help and support in acquiring the educational content through communication with the instructor, as well as to obtain feedback on the participants' progress and their way of working.

In distance education, technology provides a basis for different types of communication, which can be categorised as either asynchronous or synchronous [22,23].

Asynchronous communication is communication that is a time-delayed or time-deferred computer mediated mode of delivery. In an asynchronous environment, the sender and receiver do not have to be present at the same time for communication to occur. Asynchronous types of communication are: forums, e-mails and discussion boards.

Synchronous communication is communication that takes place real-time. In a synchronous environment, the sender and receiver have to be present at the same time for communication to take place. Examples of the synchronous communication mode of delivery are audio/video conferencing, chatting, shared whiteboards and instant messaging.

The possibility of using several separate communication channels should be taken into consideration when planning an online educational system since:

- individual participants may prefer to use or avoid using a certain communication channel, for example some people prefer to use more private means of communication through e-mails rather than public discussion forums;
- sometimes, the participants may need urgent information or help, for example if they cannot do or understand
something related to the use of the online system or their assignments, for example;
- some messages are hard to convey or understand properly without face-to-face communication such as videoconferences or video records of the instructor’s/lecturer’s presentation.

The Dimension of Information and Communication Technology (ICT)

For the website Reference Center for Teaching Methods and Communication in e-Education (Accessed 23.04.2010) [21], the e-education content is usually digitalised and placed online in order to be available to participants at any location and at any time through the Internet. However, in distance education, the lecturer/instructor cannot stimulate the learners to participate more actively through the pitch of his/her voice or gestures. Instruction cannot monitor the attention or motivation of the participants nor the interaction. Also, providing real-time and face-to-face help is often not possible.

For these reasons, the educational content of e-education should be prepared according to the following principles:
- the texts should be interesting and useful with examples, case studies, short exercises, games and quizzes;
- the technical and expert content should be clear, with sufficient explanation of the less familiar and new notions;
- the complex content should be presented by using graphs, diagrams, models and flow charts;
- the content should be divided into sections that are more suitable for the computer medium (content displayed on the screen);
- interactivity, animations, simulations, sound and video, as well as video records of the lectures should be part of the learning materials [24];
- the contents (hierarchy, grids, etc.) and the interrelations of the content elements should be clearly distributed and organised.

The presentation of the contents in e-education is influenced by the technologies that are available and by different technological capabilities. Some of the positive effects of their use concern gaining the participants’ attention, a greater level of interest, motivation and satisfaction of the participants, a better understanding of the content, a more efficient learning of new notions and better memorisation of the content as well as the possibility of applying the acquired knowledge in new situations.

Correlation Between Learning Theories and ICT

Learning is an individual activity which results in the acquisition of certain knowledge, skills and habits. Different learning theories describe how people and animals learn, and thereby help us understand the inherently complex process of learning. Learning theories fall into different categories or philosophical frameworks such as behaviourism, cognitivism and constructivism. Different learning theories have also been developed for more specific purposes: the andragogy theory, which concerns helping adults learn, and the multimedia learning theory, which is related to the effective use of multimedia in learning.

In this article, the authors have investigated the human learning mechanisms and other issues from cognitive sciences, in order to take advantage of modern technologies and new media. Ronchi [25] has illustrated two methods of acquiring, elaborating and communicating knowledge that are defined by cognitive psychology as:
- The symbolic–reconstructive method, which involves decoding symbols (language) and then mentally reconstructing the concept.
- The perceptive–motory method, which involves watching, touching, testing and then imitating or retesting, in other words, learning by doing.

The symbolic–reconstructive method is associated with learning processes such as reading, interpreting, understanding, reflecting, reasoning, induction and deduction. It involves consciously processing information and being aware.

The second method is not as obvious as the first, even though it is known. People use this approach when they learn a skill, for example. This primary mechanism of perception (visual, tactile, kinaesthetic) is embedded in human beings and in some animals. Objects and the environment are perceived by watching and by touching them and, above all, by noting the resulting reactions and behaviour.

The second method is really the primary mechanism, from a biological and psychological point of view (phylogenetic). It is the method that is embedded in the human organism and it is the method by which a child initially experiences and learns until he/she artificially develops the symbolic–reconstructive method. The perceptive–motory mechanism is without doubt the one that has been around the longest, and is the one that becomes the most well-developed over the course of our lives, and this sense, the most powerful.

The only limit to this mechanism (although it is an important one) is that people can only apply it to visible and tangible objects, such as objects that exist physically.

The authors believe that interactive Web3D technologies represent, in this context, the tools that can allow the perceptive–motory system to be directly connected to non-physical objects that is, to virtual digital objects.

With virtual technology, it is possible, for example to materialise a mathematical space, overcome the difficulties that learners have in reading mechanical drawings and their need for mental capacity, spatial vision and physical coordination required by mechanical drawing, demonstrate engineering design concepts and so on [26–29].

In fact, a mechanical object can be touched, its structure can be modified and its mechanism can be explored from the inside.

These technologies make it possible to create a virtual world, and can be used to animate objects. This enables users to navigate around the virtual environment, to move in three dimensions, to interact with objects, to look behind or under them and to examine them from different points of view, as if they were in the physical world.

3D approaches try to create visualisations that are closer to real-world metaphors: the user is able to rotate and move 3D objects and inspect inside a 3D world [30–32]. These tools should provide not only effective visual representations, but also effective interaction styles to ease exploration [33,34].
THE QUALITY FUNCTION DEPLOYMENT (QFD) METHODOLOGY

E-education systems contain numerous visualisations, simulations, different interactive elements, tests, quizzes, forums, mailing lists and other forms of information presentation and communication with the participants, and as a consequence, investments in the preparation of an online instructional module are usually greater than they are for traditional offline instruction.

In order to facilitate the preparation phase of an online instructional module, a methodology has been proposed that uses the Quality Function Deployment (QFD) approach and which takes into account the previously described aspects.

Even though QFD is normally adopted to define the most important technical parameters that should characterise the development of a new product [35], this section employs the QFD in order to select the most important tools that characterise learning so as to achieve the maximum transfer of knowledge.

QFD is a team-based technique that provides a means of identifying and translating a customer’s requirements into technical specifications for product planning, design, process and production [36].

The term Quality Function Deployment is a loose translation of the Japanese name of this methodology, that is, hin shitsu (quality), ki nou (function) and ten kai (deployment). The methodology consists of a structured procedure that starts with the qualities requested by the customer, and it then passes through the functions required to provide these products and/or services, and identifies the means of deploying the available resources to provide these products and/or services.

Research has found that QFD can provide some short-term benefits, such as reducing the cross-functional barriers associated with product development teams and aiding changes in corporate culture. However, over the long-term, QFD has also been shown to address the more tangible benefits of reduced cycle time, reduced development costs and increased productivity. An important benefit of QFD has been its effectiveness in capturing, prioritising and stabilising customer requirements. As with many other business practices, the manner in which QFD is implemented will likely have a significant impact on the benefits that are derived. Team commitment to the methodology is an important factor for success [37,38].

The first step of the QFD method is the identification of the needs ‘Data pertaining to the rows’, which have been identified in Table 1 as pedagogical criteria, ‘world of work’ requirements (from the industrial sector) and ‘world of school’ requirements (from the university, vocational school, etc).

The second step is the identification of the tools ‘Data pertaining to the columns’, which is necessary to deploy and provide the requirements of the customer. In the present case, ‘tools for learning’ and ‘tools for communication’ have been identified.

This information has been collected through a series of interviews that were carried out on a sample of people involved in engineering: students, teachers and employees that employ CAD/CAE/RE tools in their studies or in their normal working activities. In the first step, the interviewer offered the interviewee the possibility of explaining, without any specific questions, what his/her most important needs were to teach or to learn.

It was necessary to express a relative importance for each different need, therefore a scale from 1 to 5 was used. Considering the relative importance value $d_i$, expressed over each need, it was possible to create an organised importance list, like the one shown in Table 2.

Exploring the results obtained from an examination of the rows in Table 2 has confirmed that pedagogical criteria, such as ‘To overcome the need of computer skills, mental capability, spatial vision and physical coordination’, ‘To demonstrate engineering design concepts’, ‘To overcome the difficulty of learners in reading drawings’, ‘To dynamically show many situations and concepts that are often difficult for learners to comprehend’, ‘To expand and generalise the use of the perceptive–motor system’ contribute to a great extent to CAD/CAE/RE competence building.

In addition, some of the ‘world of school’ requirements in Table 2 have clearly indicated the typical critical situation of university and schools.

Finally, it was not surprising to discover that some rows in the ‘world of work’ category, in Table 2, such as ‘Need of lifelong learning’, ‘Need of trained product developers to develop innovative and competitive products (who possess a broad spectrum of professional abilities)’, ‘To help people to acquire knowledge and abilities prior to the start of their professional life’, showed the importance of training in the industrial sectors.

The second phase of the method was the definition of the most important tools, ‘Column Data’, that characterise the learning and communication identified in Table 3.

Once all the needs and all the tools had been identified, it was necessary to define the correlation level between the tools and needs employing three different values: 9, 3 and 1. This involved understanding which tools were the most appropriate for the needs. The definition of the correlation level $r_{ij}$ was drawn up by various academic members of staff from the different universities involved in the project. The result obtained was an average correlation matrix.

\[ \begin{array}{c|c|c}
\hline
\text{Needs} & \text{Tools for learning} & \text{Tools for communication} \\
\hline
\text{Pedagogical criteria} & & \\
\text{World of School (university, vocational school, etc)} & & \\
\text{World of Work (industrial sector)} & & \\
\hline
\end{array} \]
<table>
<thead>
<tr>
<th>Pedagogical criteria</th>
<th>The World of School (university, vocational school, etc.)</th>
<th>The World of Work (industrial sector)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Need of direct immersion in a problem or situation</td>
<td>4 To offer a valid support to the first level courses followed by a large number of students</td>
<td>4 Need of lifelong learning</td>
</tr>
<tr>
<td>To avoid to have passive students and to fall into an objectivist mode of instruction in which there is simply a transfer of information from the lecturer to the learner</td>
<td>4 To offer alternative solutions to the laboratory replication in the large courses</td>
<td>4 Need of trained product developers to develop innovative and competitive products (who possess a broad spectrum of professional abilities)</td>
</tr>
<tr>
<td>To lower learner anxiety due to the teacher in the face-face lessons</td>
<td>3 To avoid laboratory accidents during the practical sessions</td>
<td>4 To help people to acquire knowledge and abilities prior to the start of their professional life</td>
</tr>
<tr>
<td>To enhance student motivation and engagement</td>
<td>4 To avoid the using of expensive devices (for example RE devices) by the learners with the possibility of damages</td>
<td>3 To help increasingly dispersed, mobile and diversified work-force</td>
</tr>
<tr>
<td>To overcome the need of computer skills, mental capability, spatial vision and physical coordination required by the design (for example)</td>
<td>5 Need of more hours to practice during the course</td>
<td>3 To help workers who have to acquire new knowledge or improve the knowledge they already possess in order to keep up with their job requirements</td>
</tr>
<tr>
<td>To demonstrate engineering design concepts</td>
<td>5 To overcome the problem of a large number of students per practice groups</td>
<td>4</td>
</tr>
<tr>
<td>To overcome the difficulty of the learners in reading drawings</td>
<td>5 To avoid dedicated classroom (for example CAD laboratories)</td>
<td>3</td>
</tr>
<tr>
<td>To put the stress on specific issues that we find particularly hard to assimilate by the students</td>
<td>4 To avoid additional dedication by the teacher to prepare the practical classes</td>
<td>2</td>
</tr>
<tr>
<td>To promote the notion of constructionist learning, where a student learns from his or her own experiences, resulting in a student-centred learning environment</td>
<td>5 To avoid not having enough computers for the practical classes</td>
<td>2</td>
</tr>
<tr>
<td>Need of learning by doing</td>
<td>5 To avoid additional time employed by the teacher to correct the practical classes</td>
<td>2</td>
</tr>
<tr>
<td>To promote the experiential learning theory that defines learning as ‘the process whereby knowledge is created through the transformation of experience’</td>
<td>5 To help many of the students who cannot attend the course for short periods of time</td>
<td>3</td>
</tr>
<tr>
<td>To develop the ability to solve problems that represent different (more or less complex) situations oriented to development of products</td>
<td>5 To help many of the students who work and study at the same time and cannot attend all lessons</td>
<td>3</td>
</tr>
<tr>
<td>To facilitate the knowledge building</td>
<td>4 Need of practical exercises to correct continuously, for example, weekly</td>
<td>3</td>
</tr>
<tr>
<td>To dynamically show many situations and concepts that are often difficult for learners to apprehend</td>
<td>5 Need of an end of year work to assess</td>
<td>3</td>
</tr>
<tr>
<td>To provide tools for structuring and coordinating the learning activity</td>
<td>4 Need of a final examination to assess</td>
<td>3</td>
</tr>
<tr>
<td>To expand and generalise the use of the perceptive–motor system</td>
<td>5 Importance of the practical exercises carried out by the students during the course form part of their final marks for the subject (continuous monitoring for assessment)</td>
<td>2</td>
</tr>
<tr>
<td>Easy of use of the learning tools</td>
<td>5 Need of graduating the increase in the difficulty offered by the exercises</td>
<td>3</td>
</tr>
<tr>
<td>To overcome the learner computer anxiety</td>
<td>3 To prevent the copying among students during the assessment or the practical classes</td>
<td>3</td>
</tr>
<tr>
<td>To promote the learner attitude toward computers</td>
<td>3 To be a complement to the classroom lessons</td>
<td>3</td>
</tr>
<tr>
<td>To allow creativity within a rich media environment</td>
<td>4 To facilitate the interaction with their teachers and other students to ask questions in order to clarify specific aspects of the tasks they are performing</td>
<td>2</td>
</tr>
<tr>
<td>To increase a sense of shared presence</td>
<td>2 To facilitate the teacher to know all the activity carried out by each student in the platform: number of visits, time spent doing each task, scores, etc</td>
<td>2</td>
</tr>
<tr>
<td>To accommodate learning preferences</td>
<td>3 To allow the students to carry out a pre-training activity outside the laboratory and possibly at home</td>
<td>3</td>
</tr>
<tr>
<td>Need of a complementary balance between training and theoretical information</td>
<td>3 Inexistence of the restrictions associated to a traditional timetable</td>
<td>2</td>
</tr>
<tr>
<td>To improve and stimulate the process of knowledge acquisition in an e-learning context</td>
<td>4 Easy uploading and downloading of contents</td>
<td>3</td>
</tr>
<tr>
<td></td>
<td>To generate communities of learners, to encourage outside-of-class discussions on class related topics, to support study groups among the students, to negotiate ideas, to communicate logistics, to share knowledge, to carry out student-to-student and study teaching activities</td>
<td>3</td>
</tr>
<tr>
<td></td>
<td>To reduce the massive and qualified assistance required by the large number of students (first level courses) who enter the laboratory</td>
<td>4</td>
</tr>
</tbody>
</table>
highlighted that asynchronous and synchronous communication
ality, simulations and Web3D technologies.

for online mechanical engineering education are the virtual re-
the Table 4, and they show that the most suitable learning tools
The results of the authors’ analysis are shown in the last row of

The final step of the QFD approach involved the evaluation
of the absolute importance level $w_j$ inside the tools and the
relative level $w_j$, in order to show the features considered the
most important as learning tools and communication tools. This
final piece of information was obtained following the Independent
Scoring Method [39], as a combination of the correlation
between the needs, the tools and the relative importance of
the specific need $d_{ij}$:

$$w_j = \sum_{i=1}^{n} d_{ij} r_{ij}$$

$$w_j^* = \frac{w_j}{\sum_{j=1}^{m} w_j}$$

where $n$ is the number of needs and $m$ is the number of tools.
The results of the authors’ analysis are shown in the last row of
the Table 4, and they show that the most suitable learning tools
for online mechanical engineering education are the virtual rea-
ity, simulations and Web3D technologies.

As far as communication tools are concerned, it has been
highlighted that asynchronous and synchronous communication
tools are generally almost equally adopted and considered use-
ful to improve the learning process, but there is a slight prefer-
ce to synchronous communication tools.

RESULTS

Web3D Technologies: Implementation

Taking in account the results of the illustrated QFD approach,
this article points out the effectiveness of the Web3D technolo-
gies in the mechanical engineering field in visualising and in-
teracting with objects in three dimensions. In addition, the article
highlights how these tools have been implemented in two e-
learning systems: the WEBD platform and 3DWebEPL platform.

The first effort involved the international pilot project
known as Web-based training and learning in the field of engi-
neering and biomedical design (WEBD). It was deployed
through the Leonardo da Vinci project and it had the main
objective of developing a platform-independent prototype in
order to describe three-dimensional, interactive virtual worlds
linked to the World Wide Web using Web3D technologies (Fig. 1).

The third dimension was introduced and promoted in
distance learning for the first time in Europe in this project
[40–42].

The subsequent project was the Leonardo Multilateral
Project ‘Transfer of innovation’ 3D Web-based learning and
training in the field of the Enterprise Product Lifecycle (3DWe-
beEPL). The aim of this project was to transfer and adapt the
3D innovative contents and results of the previous Leonardo
WEBD project to meet the requirements of industrial sectors,
above all small and medium sized enterprises (SMEs), Vocca-
tional Education and Training systems, and universities, and
in particular in the mechanical field [43–45].

The 3DWebEPL e-learning system is based on a Moodle
platform (http://www.gig.etsii.upm.es/moodle), that is, a course
management system that is able to handle a large number of
courses and users. The basic organisational unit of Moodle is
the course, which is accessed through a web page, such as the
one shown in Figure 2.

The course is organised into sections that correspond to
topics and which appear in the middle column of the page. It is
possible to include different resources and activities in each
section. Each activity corresponds to a so-called module.

The 3DWebEPL platform contains different courses on
CAD/CAE/RE, Kinematic Analysis of Multibody Systems,
Dynamic Analysis of Multibody Systems, Virtual Reality (VR)
and Digital Mock-Up and medical devices, and each course
includes theoretical and practical lessons that have been trans-
lated into English, Italian, Spanish, Turkish and Romanian.

The CAD course in the 3DWebEPL system is based on
the integration of texts, audio, video, animations, 2D images
and interactive 3D objects created using Web3D technologies.

These technologies offer the possibility

- of promoting a sort of sharing of 3D models of any CAD
format, because of the smaller dimensions of the 3D files
that can be generated and the easier way these new files

- of providing intelligent interpretation tools (3D Pointer,
Virtual Folding, Animated Drawing Views, interactive 3D
animations) that help the user easily understand and navi-
gate the data;

- of creating files that can immediately be viewed by any-
one with a Windows operating system. No additional
CAD/CAE software or viewers are required.

In addition, Web3D technologies allow text labels to be
applied (for example, to indicate some manufacturing informa-
tion) to the 3D models, and allow the users to study the consid-
ered object in an easier way, because of its more interactive
approach. In fact, anyone can work on these new files and could
even measure distances, or add some other information con-
cerning materials, textures, colours, etc. by just ‘playing’ with
the 3D objects. It is possible to turn 3D objects in many ways,
creating or modifying point of views, zooming into or out of
them, hiding/showing parts and examining their cross-sections,
creating realistic animations, adding lights or shades and creat-
ing high-resolution images, etc. [46–49].

Table 3: Identification of Tools for Learning and Tools for Communication

<table>
<thead>
<tr>
<th>Tools for learning</th>
<th>Communication</th>
</tr>
</thead>
<tbody>
<tr>
<td>Diversity in assessment (tests, quizzes, games)</td>
<td>Participation in collaborative/group tasks</td>
</tr>
<tr>
<td>Use of virtual reality and simulations</td>
<td>History reports about the student’s usage of the platform and their performance</td>
</tr>
<tr>
<td>Use of Web3D technologies</td>
<td>Calendar, Tele-pointer, Whiteboarding</td>
</tr>
<tr>
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</table>
**Table 4** Final Results of the QFD Methodology

<table>
<thead>
<tr>
<th>Pedagogical criteria</th>
<th>Tools for learning</th>
<th>Tools for communications</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Diversity in assessment (tests, quizzes, games)</td>
<td>Use of virtual reality and simulations</td>
</tr>
<tr>
<td>Need of direct immersion in a problem or situation</td>
<td>4</td>
<td>9</td>
</tr>
<tr>
<td>To avoid to have passive students and to fall into an objectivist mode of instruction in which there is simply a transfer of information from the lecturer to the learner</td>
<td>4</td>
<td>9</td>
</tr>
<tr>
<td>To lower learner anxiety due to the teacher in face-face lessons</td>
<td>3</td>
<td>9</td>
</tr>
<tr>
<td>To enhance student motivation and engagement</td>
<td>4</td>
<td>9</td>
</tr>
<tr>
<td>To overcome the need of computer skills, mental capability, spatial vision and physical coordination required by the design (for example)</td>
<td>5</td>
<td>9</td>
</tr>
<tr>
<td>To demonstrate engineering design concepts</td>
<td>5</td>
<td>9</td>
</tr>
<tr>
<td>To overcome the difficulty of the learners in reading drawings</td>
<td>5</td>
<td>9</td>
</tr>
<tr>
<td>To put the stress on specific issues that we find particularly hard to assimilate by the students</td>
<td>4</td>
<td>9</td>
</tr>
<tr>
<td>To promote the notion of constructionist learning, where a student learns from his or her own experiences, resulting in a student-centred learning environment</td>
<td>5</td>
<td>9</td>
</tr>
<tr>
<td>Need of learning by doing</td>
<td>5</td>
<td>9</td>
</tr>
<tr>
<td>To promote the experiential learning theory that defines learning as “the process whereby knowledge is created through the transformation of experience”</td>
<td>5</td>
<td>9</td>
</tr>
<tr>
<td>To develop the ability to solve problems that represent different (more or less complex) situations oriented to development of products</td>
<td>5</td>
<td>9</td>
</tr>
<tr>
<td>To facilitate the knowledge building</td>
<td>4</td>
<td>3</td>
</tr>
<tr>
<td>To dynamically show many situations and concepts that are often difficult to apprehend by the learners</td>
<td>5</td>
<td>9</td>
</tr>
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(Continued)
<table>
<thead>
<tr>
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<tbody>
<tr>
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<td>Use of virtual reality and simulations</td>
</tr>
<tr>
<td>Use of Web3D technologies</td>
<td>Use of Web3D technologies</td>
</tr>
<tr>
<td>Collections of problems and exercises</td>
<td>Collections of theoretical notes</td>
</tr>
<tr>
<td>Videos, mp3s, scanned images, links to other web sites and animations</td>
<td>Use of electronic forums, mail systems, blogs</td>
</tr>
<tr>
<td>Wikis</td>
<td>Participation in collaborative/group tasks</td>
</tr>
<tr>
<td>Use of real laboratories</td>
<td>History reports about the student’s usage of the platform and their performance</td>
</tr>
<tr>
<td>To provide tools for structuring and coordinating the learning activity</td>
<td>Calendar, Tele-pointer, Whiteboarding</td>
</tr>
<tr>
<td>To expand and generalise the use of the perceptive–motor system</td>
<td>Instant messaging, chatting</td>
</tr>
<tr>
<td>Easy of use of the learning tools</td>
<td>Pictures of members, display list of members</td>
</tr>
<tr>
<td>To overcome the learner computer anxiety</td>
<td>World of School (university, vocational school, etc.)</td>
</tr>
<tr>
<td>To facilitate the learner attitude toward computers</td>
<td>To offer a valid support to the first level courses followed by a large number of students</td>
</tr>
<tr>
<td>To allow creativity within a rich media environment</td>
<td>To offer alternative solutions to the laboratory replication in the large courses</td>
</tr>
<tr>
<td>To increase a sense of shared presence</td>
<td>To avoid laboratory accidents during the practical sessions</td>
</tr>
<tr>
<td>To accommodate learning preferences</td>
<td>To avoid the using of expensive devices (for example RE devices) by the learners with the possibility of damages</td>
</tr>
<tr>
<td>Need of a complementary balance between training and theoretical information</td>
<td>Need of more hours to practice during the course</td>
</tr>
<tr>
<td>To improve and stimulate the process of knowledge acquisition in an e-learning context</td>
<td>To overcome the problem of a large number of students per practice groups</td>
</tr>
<tr>
<td></td>
<td>To avoid dedicated classroom (for example CAD laboratories)</td>
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<tr>
<td></td>
<td>To avoid additional dedication by the teacher to prepare the practical classes</td>
</tr>
<tr>
<td></td>
<td>To avoid not having enough computers for the practical classes</td>
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<td>Tools for communications</td>
<td>Use of collaborative services</td>
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</tr>
<tr>
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<td>Use of 3D models</td>
</tr>
<tr>
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<td>Videos, mp3s, scanned images, links to other web sites and animations</td>
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To generate communities of learners, to encourage outside-of-class discussions on class-related topics, to support study-groups among the students, to negotiate ideas, to communicate logistics, to share knowledge, to carry out student-to-student and student-to-instructor interaction.

To reduce the massive and qualified assistance required by the large number of students (first-level courses) who enter the laboratory.

World of Work (industrial sector)

<table>
<thead>
<tr>
<th>Need of lifelong learning</th>
<th>Need of trained product developers to develop innovative and competitive products (who possess a broad spectrum of professional abilities)</th>
</tr>
</thead>
<tbody>
<tr>
<td>To help people to acquire knowledge and abilities prior to the start of their professional life</td>
<td>To help increasingly dispersed, mobile and diversified work-force</td>
</tr>
<tr>
<td>To help workers who have to acquire new knowledge or improve the knowledge they already possess in order to keep up with their job requirements</td>
<td></td>
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<table>
<thead>
<tr>
<th>$d_j$</th>
<th>3</th>
</tr>
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<tbody>
<tr>
<td>9</td>
<td>9</td>
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<tr>
<td>3</td>
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<td>3</td>
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<tr>
<td>3</td>
<td>3</td>
</tr>
</tbody>
</table>

$w_j$ | 330 | 1500 | 1545 | 300 | 327 | 762 | 228 | 900 |

$w_j/\%$ | 4.2 | 19.1 | 19.6 | 3.8 | 4.2 | 9.7 | 2.9 | 11.4 |

To help people to acquire knowledge and abilities prior to the start of their professional life.

To help increasingly dispersed, mobile and diversified work-force.

To help workers who have to acquire new knowledge or improve the knowledge they already possess in order to keep up with their job requirements.

To reduce the massive and qualified assistance required by the large number of students (first-level courses) who enter the laboratory.

To help people to acquire knowledge and abilities prior to the start of their professional life.

To help increasingly dispersed, mobile and diversified work-force.

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To help people to acquire knowledge and abilities prior to the start of their professional life.

To help increasingly dispersed, mobile and diversified work-force.

To help workers who have to acquire new knowledge or improve the knowledge they already possess in order to keep up with their job requirements.
The 3DWebEPL system, because of its Web3D technologies, is having a deep impact on the traditional ways of teaching, training and learning in CAD courses (Fig. 3). For example in the ‘CSG Representation’ module of the CAD course in the 3DWebEPL platform, it is possible to understand the concept of Boolean operations between two simple solid shapes, though a reasonable representation of the operation result. The results of the union, the subtraction and the intersection operations are visible in the three virtual models shown in Figure 3 and they can be rotated, panned or even interacted with.

In the ‘Basic Assembly Modelling’ module, Web3D technologies have permitted styles and intelligent views to be created in order to ensure visual consistency. The 3D assembly of the module has full transparency and reflectivity, and it allows...
movement so as to show the object as it really is, and even its smallest details. The exploded views of the assembly have been created and annotated with labels and balloons (Fig. 4).

It is possible for students to navigate around the assembly, move it in three dimensions, interact with the components of the assembly, look behind or under them and examine them from different points of view, as if they were physically touching the actual assembly.

These Web3D tools provide effective interaction styles to ease exploration. In fact, the presence of text labels on the virtual models enables each trainer to identify the parts of the considered objects in an easier way and offer him/her the possibility of measuring distances from the objects while facilitating the knowledge of some dimensions of the object (Fig. 5).

Web3D technologies can record a sequence of actions exerted on some elements of the whole model, and then play back the sequence. These actions can include movements of the camera, or objects, modifications of the properties (changes in colour, modifications of the opacity), and actions of the Digger. For example, in one module of this platform, it is possible to see the animation which, beginning with the same geometric shape, can create different complex solids, such as revolution, extrusion, loft and sweep solids. In fact, the solid can be created from the initial shape by just following the path indicated by the dashed line (Fig. 6).

**Web3D Technologies: Impact**

The 3DWebEPL platform has been a part of the education process of Engineering Drawing Courses for students of the Faculty of Mechanical Engineering at the Politecnico di Torino since 2010.

During the first semester in 2011, 129 students used the e-learning platform as part of their course, and at the end of the
Figure 4 3D model on one module page: assembly view (a)—exploded assembly view with labels during the animation (b). [Color figure can be viewed in the online issue, which is available at wileyonlinelibrary.com.]
semester they filled in a questionnaire in order to evaluate their experience and the benefits they obtained from the use of the 3DWebEPL platform. The results are presented in Figure 7.

The questionnaire showed that the students clearly accepted this educational system. They responded that the e-learning platform helped them reach their planned educational goals, that they fully understood the e-learning platform goals and appreciated the contribution of the Web3D technologies. The students also pointed out that the system is user-friendly and easy to use.

In order to evaluate whether the implementation of Web3D technologies in the 3DWebEPL platform had positive effects on the students, feedback was obtained from 149 students with another online questionnaire. The questionnaire shown in Table 5 was structured considering the analyses conducted by Granic et al. [50] and by Grégoire et al. [51].

Positive results were reported for all the categories of the questionnaire. This result pointed out the great value and success of having applied these technologies to the educational context (Fig. 8).

The last analysis here presented, is related to the failure to pass examinations, a factor of paramount importance in higher education because it affects educational institutions, teaching staff and students.

In the first semester in 2010, 293 students attended a traditional Engineering Drawing Course, without Web3D technologies, while 149 students attended an Engineering Drawing Course with Web3D technologies in the first semester of 2011. At the end of the courses, these students sat the final exam. Details of the percentage of students who passed the final examination in each semester are shown in Figure 9 and the qualitative evaluations (marks awarded on a 30-point scale) are shown in Figure 10. The minimum pass mark is 18/30, while 30/30 is the best mark.

With such positive results, it is hoped that those teachers who are employed in vocational schools or universities and trainers who train employees in companies on specific topics will be encouraged to consider the use and the application of Web3D technologies as part of their educational programs.

CONCLUSIONS

E-learning is a type of instruction education that has been using terms like CAL, or CBI for over 30 years, along with other similar terms and abbreviations for the use of Information and Technology in education. Progress has been made in the use of computers in education thanks to the use of multimedia technology, and the technological and pedagogical revolution that has occurred in distance education due to the development of the World Wide Web.

The e-learning system offers the following benefits:

(1) To the learner:
- ready access to course contents and knowledge (also in the evenings and at weekends);
- identification of the weak/strong areas of subject knowledge;
- improved understanding of weak areas through repeated interactions;
- assessment on individual subjects;
- the possibility of preparing for forthcoming lectures and catching up on any missed lectures;
- guidance/references for further reading;
- support for traditional lecture material;
- familiarisation with course requirements.

(2) To the teacher:
- reduction in tutorial and advice times;
- support for conventional lecture material;
- consolidation of course material;
- removal of routine queries;
- incorporation of research in subject material;
- ready definition of course contents and provision of a reference base.

E-education systems contain numerous visualisations, simulations, different interactive elements, tests, quizzes and other forms of information presentation.

E-education not only involves content presentation and knowledge checks, but also interaction with the participants through the use of appropriate communication tools which encourage the participants towards greater motivation, acceptance and acquisition of educational systems and technologies, towards interest in the educational content, experience of the interpersonal contact with the instructor, as well as encouraging a feeling of social affiliation with a certain educational group.
Figure 6  Example of animations: extrusion (a), loft (b), sweep (c), revolution (d). [Color figure can be viewed in the online issue, which is available at wileyonlinelibrary.com.]

Figure 7  Students’ questionnaire: character and organisation of the 3DWebEPL platform.
For all these reasons, investments in the preparation of an online instructional module are usually greater than they are for traditional offline instruction.

Some years ago, the Politecnico di Torino was involved in activating distance learning courses and decided to invest resources to develop a product, based on the new technologies offered by CBT and on pedagogic and communication aspects.

The final product of the project was a web platform for distance learning, based on Web3D technologies and which could be used by a variety of users (mechanical engineering students and employees) throughout the European territory.

This platform has made it possible to:

- develop effective and modern educational tools in order to overcome some of the drawbacks of conventional teaching methods in the training of fundamental CAD/CAE/RE concepts;
- use new technology that offers students the opportunity of interacting with rich learning resources and in animated environments, calling on information and knowledge when needed to solve problems, and investigating the subject matter at their own pace and in the order that they

---

**Table 5**  Effects of the Implementation of Web3D Technologies

<table>
<thead>
<tr>
<th>The specific learning achieved</th>
<th>Web3D technologies stimulate the development of intellectual skills such as reasoning and problem solving ability, learning by doing, and creativity</th>
</tr>
</thead>
<tbody>
<tr>
<td>The development of various intellectual skills</td>
<td>Web3D technologies contribute to better learning and to the development of various skills and attitudes</td>
</tr>
<tr>
<td>The specificity of learning using WEB3D technologies</td>
<td>The attention span or concentration of students are greater when they use a Web3D technology than when they are in a traditional setting using traditional resources</td>
</tr>
<tr>
<td>Student motivation</td>
<td>The students show greater spontaneous interest in a learning activity that uses a Web3D technology than in the traditional approaches</td>
</tr>
<tr>
<td>Interest in a learning activity</td>
<td>The Web3D technologies have the power to stimulate the search for more extensive information on a subject, a more satisfying solution to a problem, and more generally, a greater number of relationships among various pieces of knowledge or data</td>
</tr>
<tr>
<td>The time and attention devoted to learning activities</td>
<td>The Web3D applications do not generally change the teaching strategy but do assist in making learning independent as well as helping to reduce the need for direct teacher involvement</td>
</tr>
<tr>
<td>Relationship of students to knowledge</td>
<td>The Web3D technologies contribute to better learning and to the development of various skills and attitudes</td>
</tr>
<tr>
<td>Developing research spirit</td>
<td>The students show greater spontaneous interest in a learning activity that uses a Web3D technology than in the traditional approaches</td>
</tr>
<tr>
<td>The consequences of appropriate use of WEB3D technologies on the teaching function of teachers</td>
<td>The attention span or concentration of students are greater when they use a Web3D technology than when they are in a traditional setting using traditional resources</td>
</tr>
<tr>
<td>The planning of teaching</td>
<td>The Web3D applications do not generally change the teaching strategy but do assist in making learning independent as well as helping to reduce the need for direct teacher involvement</td>
</tr>
</tbody>
</table>

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**Figure 8**  Students’ questionnaire: effects of the implementation of Web3D technologies.
choose, without following lectures planned by the instructor;
• stimulate the students’ interest, creativity and thinking, and thus, encourage them to pursue higher training.

In this article, the influence of new information technologies on online mechanical engineering education and training has been pointed out. A QFD tool has been developed that is useful in the preparation phase of distance learning systems and the efforts to design, implement and successfully distribute an e-learning system, called 3DWebEPL, have been explained.

ACKNOWLEDGMENTS
The authors wish to thank Prof. Stefano Tornincasa for coordinating the 3DWebEPL project.
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BIOGRAPHIES

Maria Grazia Violante is currently Assistant Professor of Technical Drawing and Design Tools for Industrial Engineering at the Department of Management and Production Engineering of the Politecnico di Torino. From the same Politecnico she received her Master Degree in Industrial Engineering. In 2006 she was a visiting researcher at Wolfson School of Mechanical and Manufacturing Engineering - Loughborough University. She is author of technical papers on product design and development. Her research interests are focused on Rapid Prototyping, Computer Aided Design, Virtual Reality, and E-learning.

Enrico Vezzetti received the Master Degree in Industrial Engineering from the Politecnico di Torino in 1997, and the PhD Degree in Manufacturing Engineering from the University of Parma in 2001. In 1998 he was in the 3D Printing Laboratory of the Massachusetts Institute of Technology, USA. He is currently Associate Professor of Technical Drawing and Design Tools for Industrial Engineering at Department of Management and Production Engineering of the Politecnico di Torino. He is author of more than 80 technical papers on product design and development with specific attention on reverse engineering, rapid prototyping and collaborative design topics. His research interests include Computer Aided Design, Computer Aided Inspection, 3D Scanners and Virtual Reality.