Int. J. Engng Ed. Vol. 23, No. 4, pp. 748–758, 2007
Printed in Great Britain.

0949-149X/91 $3.00+0.00

Cost Estimating Training by Doing: a Web-based, Process-centred Approach*

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Cost estimates are fundamental criteria to make design and manufacturing decisions in engineering. The achievement of an estimate requires knowledge and skills. Traditionally, engineers give more relevance to performance and technical requirements than to cost. Education plays an important role in this matter. A process-centred approach is presented to train professionals on cost estimating. Training in cost estimating and the relevance of using a generic process as the core around which training material is provided are discussed. The six pedagogical variables defined in the development of a web-based, cost estimating training solution are presented. The developed solution makes use of three training techniques: by doing, by lectures and by discussions.

Keywords: process-centred training; web-based training; cost estimating training

INTRODUCTION

ENGINEERING STUDIES focus mainly on technological aspects, demanding the application of scientific knowledge to resolve practical problems. Engineering could be defined as 'the application of scientific knowledge to the life cycle of solutions'. The solution may need to be: compliant with customer demands, cost–effective, compliant with specific performance features, compliant with safety regulations, compliant with a business strategy, etc. A 'problem' to resolve or a 'need' to satisfy is needed to engineer a 'solution'. Depending on the kind of problem or need, the engineer will have to make use of specific scientific and engineering knowledge.

Engineering courses dealing with design and manufacturing tend to focus more on technical aspects. For instance, Vizzini [1] presents the details of a course focus on design and manufacturing of composites prototypes, where cost is considered to be one of the major learning elements. The cost estimation is presented in one lecture. Students are required to estimate cost based on equipment, labour and material rates, which are the typical cost drivers considered when creating a detailed or bottom-up cost estimate. One of the findings presented by the author points out that cost is the least understood aspect by the students. This situation may imply that future engineers do not have an explicit understanding and awareness of the cost implications of their design and manufacturing decisions. Such an outcome is not unusual in many engineering courses and supports the traditional view that engineers consider cost as less important than performance or technical requirements. This situation has been widely acknowledged by industry, quoting [2]: 'A design that fails to meet its cost specification is not better than one that fails to satisfy its performance requirements. Furthermore, when all other factors are equal, the decision by the customer whether or not to buy a product is largely determined by its cost'. In industry, this is addressed through a discipline called: 'Cost Engineering'.

Cost Engineering (CE) has a wide scope (3):

> . . . is concerned with cost estimation, cost control, business planning and management science, including problems of project management, planning, scheduling, profitability analysis of engineering projects and processes'.
>
> Quoting [4]: 'The alternative offered by cost engineering is to have cost information available when design choices are being made, so that they will be made in the knowledge of approximately what the different potential solutions are likely to cost. This awareness of the likely cost is essential to be able to make effective cost/benefit trade-offs.

Several topics included in such discipline are addressed in different subjects in engineering teaching programmes. Universities also offer double degree programmes in engineering and economics, and there are postgraduate cost engineering programmes mainly in the areas of civil engineering and industrial management. Professional bodies have also paid attention to CE training. The most significant case is the certification programme from the association AACE Interna-

* Accepted 15 December 2006

tional, which also proposes a Master's degree programme with emphasis on cost engineering [5].

This research is focused on cost estimating, which can be seen as the first stage of cost engineering. In industry, cost estimating is performed at different product life cycle stages, with the objective of approximating, in an independent, objective, accurate and reliable way, the true cost of producing a product. The accuracy of an estimate depends heavily on factors such as: who created the estimate, how the estimate was done and which data were available at the time of its creation. These factors also depend on the product/project life cycle stage where the estimate is developed [6, 7].

The manufacturing industry has recognized two key collaborative factors: to achieve cost-effective performance and to share understanding of cost. That is why original equipment manufacturers (OEMs) such as: ESA, Airbus, Boeing, Rolls-Royce, Ford, Daimler-Chrysler, Fiat, and so on, promote cost engineering practices and even share data along their supply chain. In the same direction, the adoption of a common top-level process to create cost estimates is perceived as a good initiative to enhance the accuracy of the estimates and the common understanding.

In the context of design and manufacturing, the importance of the cost estimating professionals' competence has been recognized as a key aspect. When examining training in cost estimating for manufacturing, the courses focus on specific subjects rather than on the cost estimating processes (detailed or bottom-up, parametric and analogy). From the training perspective, the definition of such processes and their use as a guiding path are the kernel of the 'learning by doing' approach proposed in this research. Cost estimating processes have been deployed in a web-based environment to provide process-centred e-training for cost estimating [8, 9].

COST ESTIMATING AND PROCESS-CENTRED TRAINING

The idea of using a particular process as a kernel to train professionals and students prompts a set of questions regarding how generic the process should be, how to define the process, what kind of key learning objectives are pursued and how the training should be deployed.

There are three main techniques for elaborating a cost estimate: detailed or bottom-up, parametric and analogy. The selection of the technique to be used depends mainly on which stage of the product life cycle the estimate is conducted. The product life cycle stage has a strong influence on the data available and the accuracy expected [10, 11].

The research conducted was focused on the training of professionals from industry. However, the relation between industry and academia, and the influence that industry has in higher education should also be considered. For instance, an area of concern and debate is the impact of the skills approach in engineering studies [12]. This is particularly relevant because the creation of a cost estimate demands: skills, knowledge and experience (Fig. 1) [8, 13]. The definition of the skills needed for a particular job position, e.g. cost estimator, depends on the tasks that the person will have to perform. Depending on the cost estimating process, the tasks could be different, and it is at this point that the question how generic and independent of any particular company the cost estimating process should be, arises in all its relevance. As Pascali [12] points out, the definition of skills has three phases: prescriptive, descriptive and deliberation. The skills approach has also two options: generic skills and occupation-specific skills [14]. What seems to be clear is that general academic knowledge and skills are needed first in order to acquire a later field-specific one. However, an earlier understanding and awareness of field-specific problems helps to motivate and increase the effectiveness of the overall learning process [14]. When aiming to define a generic approach, there is a need to evaluate and compare different alternatives, and to make a final abstraction to create a generic model that still gives a reasonable result to the different initial alternatives. This is the approach adopted in this work, where the inputs come from industrial partners, external professionals and documentation from different organizations [9].

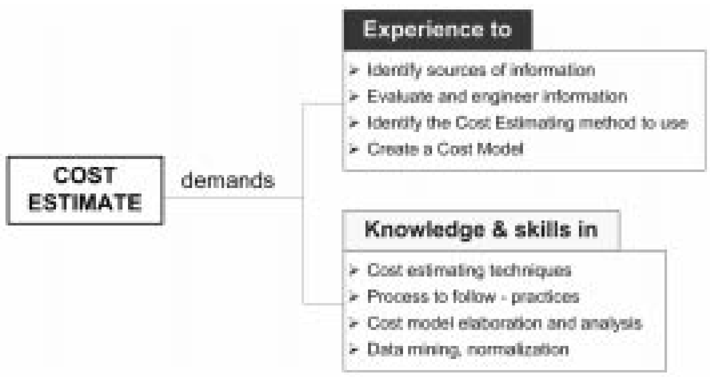

Fig. 1. Cost estimate demand for knowledge, skills and experience.

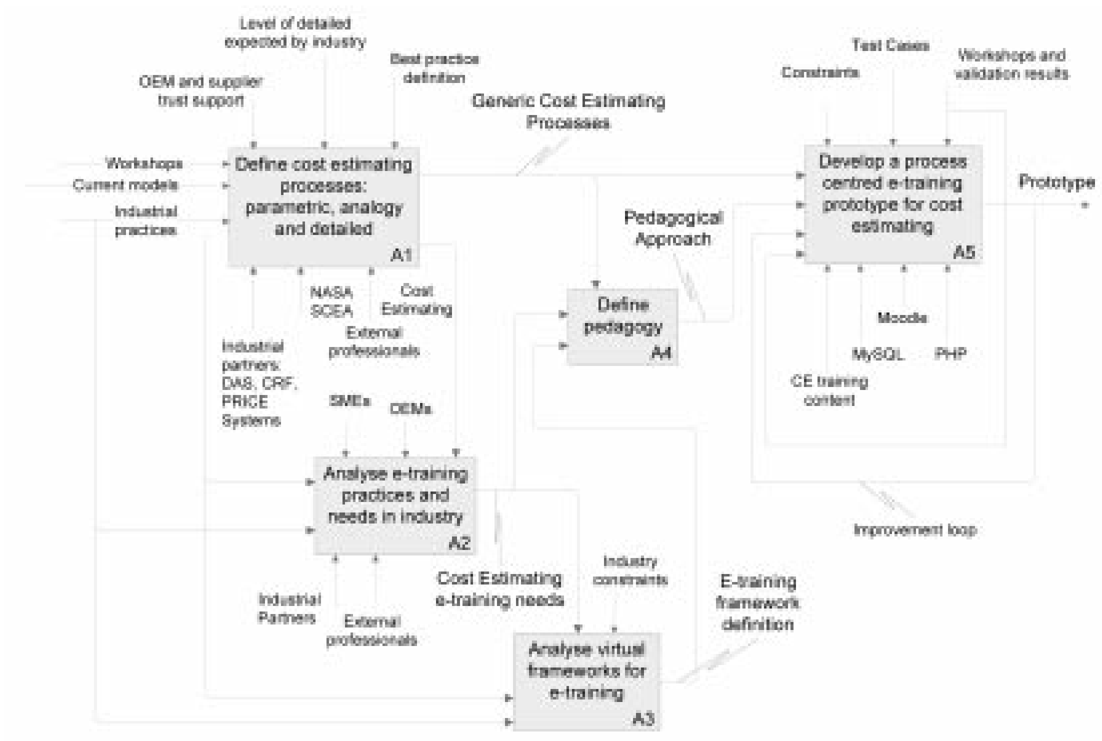

Fig. 2. Main research tasks conducted.

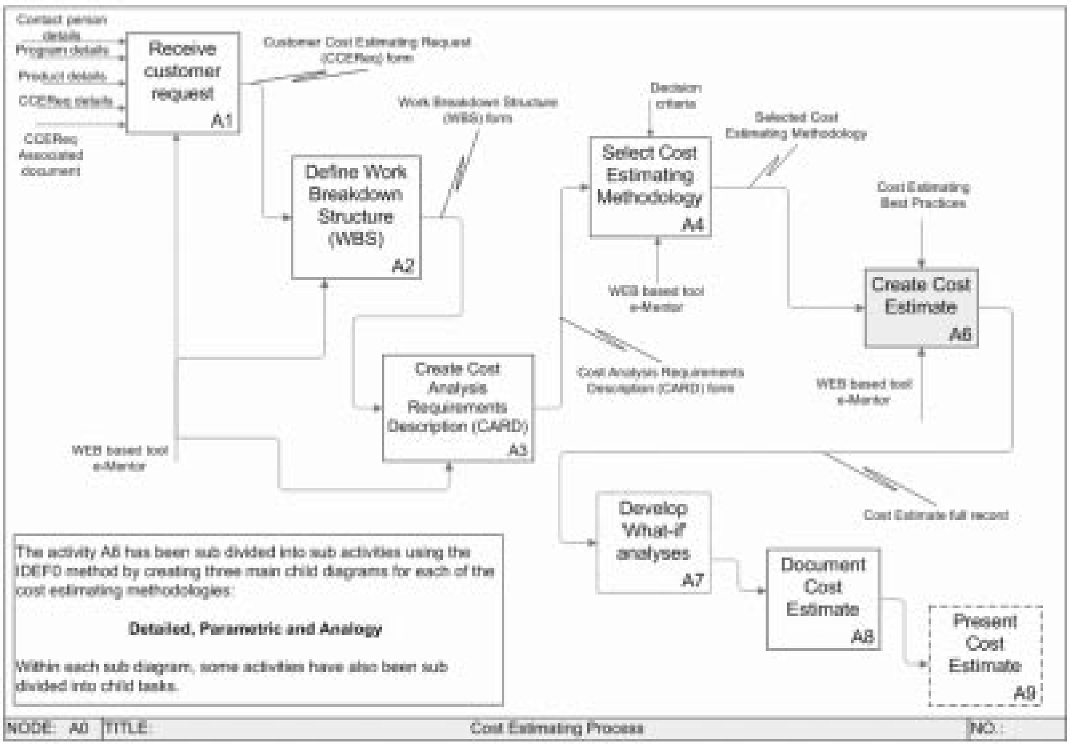

Fig. 3. Simplified IDEF0 diagram of the top level cost estimating process.

Taking into consideration the questions previously mentioned, a set of research tasks was conducted to define: generic cost estimating processes, training needs, e-training practices, e-training tools and the prototype to implement (Fig. 2).

The first task (A1) was the definition of a top level set of activities to carry out when creating a cost estimate (Fig. 3). The three cost estimating processes: bottom-up, parametric and analogy have specific subtasks under the activity A6. The processes were modelled using the IDEF0 methodology, and the data structure needed to document the cost estimate creation was defined using the IDEF1X method [9].

The tasks defined in the cost estimating process are generic and independent of any company specific practices. In fact, the overall process proposed can be considered representative of best practice [9]. Some of the tasks demand that the trainee has some previous academic knowledge, i.e. in performing statistical analysis (Activity A6.6) and test relationships and analysing correlation (Activity A6.7), both part of the parametric cost estimating process [9]. Such knowledge is applied in a field specific area: cost estimating in manufacturing. In this sense, the relevance of having a good knowledge of statistics is reinforced by its application to a specific industrial process, and as was mentioned before, it should be a point of motivation for the trainee.

PEDAGOGICAL APPROACH

The development and implementation of any effective learning or training solution demands that its pedagogical aspects be addressed. Pedagogy is a discipline dealing mainly with educational theories, strategies of teaching and learning styles. This aspect was addressed in activity A4, which has as control and input elements the results from the three previous studies: define cost estimating processes (A1), analyse e-training practices and industry needs (A2) and analyse virtual frameworks for e-training (A3) (Fig. 2).

The link of pedagogy with the teaching and learning solution to be adopted can be done through what is called 'the six pedagogical variables':

(1) Educational results: why, for what?
(2) Psycho-structure: who?
(3) Subject matter: what?
(4) Social structure: where?
(5) Media: with what?
(6) Teaching method: How, when? [15].

Fig. 4 shows a summary of the six variables applied to the cost estimating training solution adopted in the project.

Why, for what?

This variable focuses on identifying the aims and objectives of the training, the expected outcomes in knowledge, skills and attitudes, and how such outcomes will be measure. Before the identification of such elements, a set of definitions was adopted (Fig. 5): knowledge, skills, attitudes, competency and training [16].

In general, training is understood as an integration of two main approaches: cognitive (with a change in the mental processing of information) and behaviourist (with a change in behaviour) [16]. In this case, the solution adopted is process oriented, with a cognitive approach involving concept learning and problem solving. The main

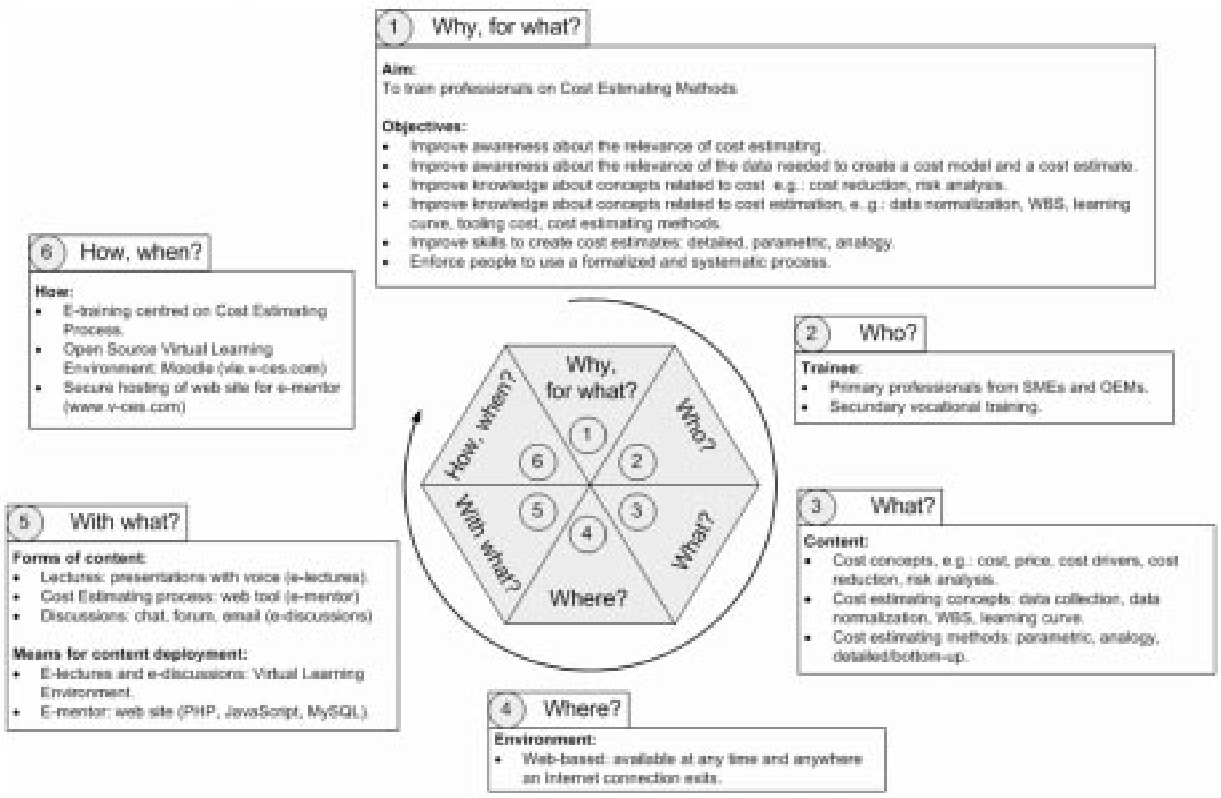

Fig. 4. Six pedagogical variables applied to cost estimating training—summary.

Knowledge (K).
It can be categorized in three types:

a) Declarative: Information acquired and place into memory by people.
b) Procedural: Understanding of how and when to apply the declarative knowledge.
c) Strategic: Awareness of the procedural and declarative knowledge, how it was learned and how can be applied to achieve a specific goal.

Skills (S).
They are capacities needed to perform a set of tasks. Skills are dependent on knowledge in the sense that the person must know 'what to do' and 'when' to do it. A gap separates knowing those things from actually being able 'to do' them. Two possible levels: compilation (when the person thinks about what she is doing while performing the skill) and automaticity (when the person perform the tasks without really thinking about specific actions).

Attitudes (A).
They are employee beliefs and opinions that support or inhibit behaviour. They are important since they affect motivation.

Competency.
It is a broad grouping of knowledge, skills, and attitudes that enable a person to be successful at a number of similar tasks.

Training.
It is a systematic process focused on the acquisition of KSAs needed to perform more effectively a particular job.

Source: Blanchard and Thacker [16]

Fig. 5. Basic definitions adopted.

(1) Why, for what?

Aim:
To train professionals on Cost Estimating Methods

Objectives:
- Improve awareness about the relevance of cost estimating.
- Improve awareness about the relevance of the data needed to create a cost model and a cost estimate.
- Improve knowledge about concepts related to cost e.g.: cost reduction, risk analysis.
- Improve knowledge about concepts related to cost estimation, e..g.: data normalization, WBS, learning curve, tooling cost, cost estimating methods.
- Improve skills to create cost estimates: detailed, parametric, analogy.
- Enforce people to use a formalized and systematic process.

Expected outcomes in knowledge:
- Understanding of the relevance of cost in design and manufacturing.
- Understanding of the concepts: cost, price, data normalization, Work Breakdown Structure (WBS), Learning Curve (LC).
- Understanding of the relevance of documenting the cost estimating process.
- Understanding of the relevance of following a systematic process to estimate cost.
- Understanding of cost modeling: detailed, analogy and parametric.

Expected outcomes in skills:
- Cost data collection.
- Cost data normalization.
- Creation of WBS.
- Application of LC
- Creation of a detail/bottom-up cost estimate.
- Creation of a parametric cost estimate.
- Creation of a analogy cost estimate.

Expected outcomes in attitudes:
- Positive attitude towards data and information sharing.
- Positive attitude towards collaborative work.
- Positive attitude towards sharing of cost practices.

Measurement:
- Quizzes (objective)
- Cost estimate review by mentor (objective & subjective)
- External feedback from colleagues (subjective)
- Guided self-assessment (subjective)

Fig. 6. First pedagogical variable: why, for what?

focus is on enhancing the declarative knowledge, the procedural and the skills of the trainee in specific topics related to cost estimating. It is also expected that a positive attitude towards collaboration and sharing of information would be achieved (Fig. 6).

Psycho-structure, who?

This variable addresses the definition of the trainee's and professionals' profile, teacher and mentor, and learning, teaching and mentoring styles (Fig. 7). Based on the responses obtained from a questionnaire and in interviews with professionals, a survey was conducted to identify the potential user's technical capabilities. The questionnaire was created to assess the background, cost engineering activities, cost estimating practices and the computing environment of cost estimating professionals. The main results are presented under the headline 'Professionals profile' (Fig. 7) [8]. After the presentation in several forums of the first results, the possibility of addressing vocational training was also considered.

From the teaching perspective, two figures were identified: teacher or tutor and mentor. And it is the mentor role, the one that turns out to be more challenging. It demands competencies about the domain rather than knowledge about specific academic disciplines; because of that a professional from industry was identified as a more suitable person. And it would also help to enhance the attitude of the trainees towards the positive effects derived from collaboration and sharing of practices. In this direction, an online professional community on cost engineering would also help [17].

The learning style proposed is based on three

(2) Who?

Trainee:
- Primary professionals from SMEs and OEMs.
- Secundary vocational training.

Professionals profile:
- Range from medium level of vocational training to professionals with a university degree.
- Most of them have a backgroung on: manufacturing, design and/or management.
- Have a limited awareness of different cost estimating techniques apart from the ones used in their daily work.
- Most of them are users of cost models, but they are not involved in cost functions definition and cost models development.
- Some of them may perform other activities in addition to pure cost estimates creation, such as: Risk Analysis, Value Analysis, Cost Modelling, and Design to Cost.
- Many of them may not have a clear picture of the benefits of sharing practices within and outside the company. However, professionals from OEMs involved in the evaluation of bids are the ones with a clearer picture of the benefits.
- Most of them have a user level in IT.
- Most of them are self-motivated and some have incentives from the company.

Teacher or tutor & mentor:
There are two main roles: teacher or tutor and mentor. The former role could be done by an academic or a professional from industry, but the mentor role should be performed by an expert from industry if possible.

Learning style:
- Attendance of e-courses (learning by lectures).
- Self-study.
- Creation of cost estimates using the e-mentor tool (learning by doing).
- Use of supporting material: glossaries, suggested sources of information.
- E-Dialogues with teacher and mentor (learning by discussions).
- Interaction with colleagues: face to face and electronically (learning by discussions).

Teaching style:
- Lectures.
- Cost estimating process.
- Assignments.
- Discussions.

Mentoring style:
- Guidance in the cost estimating process (e-mentor)
- Group discussions (electronically and face to face if possible)
- Mentor-mentee dialogues (electronically and face to face if possible)

Fig. 7. Second pedagogical variable: who?

3 What?

Content:

- Cost concepts, e.g.: cost, price, cost drivers, cost reduction, risk analysis.
- Cost estimating concepts: data collection, data normalization, WBS, learning curve.
- Cost estimating methods: parametric, analogy, detailed/bottom-up.

Trainees' tasks:

- Guided self-assessment to identify profile of the user: novice or expert.
- Guided self-assessment to identify training path.
- Undertake specific courses.
- Undertake cost estimate creation.
- Discuss with peers, teacher and mentor.

Content presentation:

- Guided self assessment tools: wizard e-tool based in filling of e-forms.
- Courses: e-lectures, e-quizzes, e-forums.
- Cost estimate creation (parametric, detailed, analogy): e-mentor wizard tool based on cost estimating processes.
- Discussions: asynchronous and synchronous communication (chat, forums, emails).

Fig. 8. Third pedagogical variable: what?

techniques: by lectures, by doing and by discussions. And the mentoring role has been divided into e-mentoring and human mentoring when possible. The e-mentoring approach is based on the guidance provided along the cost estimating process and in computer-mediated communication via e-mail and forums. How effective this kind of communication is for mentoring is under discussion; however, it seems to be better than not having any contact with a mentor at all [18].

Subject matter: what?

The definition of the content of the training, how it is presented and the trainees' tasks are defined in this variable (Fig. 8). It demands also analysis of the curriculum, its aim and the programme where the content is included. In the implementation, the curriculum was directed at professionals who wanted to improve their cost estimating competences. Inputs from AACE recommendations were taken [5, 13]. A deeper study of academic programmes would be needed if an applicant for vocational training and engineering studies pursued them in the future. However, the current approach seems to fit an engineering design and manufacturing subject similar to the one presented by Vizzini [1].

Social structure: where?

The environment where the training will take place, the learning situation and the social trends are the main aspects defined by this variable (Fig. 9).

The first decision taken in the project was to deploy the solution in a web-based environment,

4 Where?

Environment:

- Web-based: available at any time and anywhere an Internet connection exits.

Societal trends and learning situation:

- The market is shifting to be content-led, within a collaborative environment, with a higher preference for asyncronous communication and with the use of 'learning by doing techniques'.
- SMEs demand inexpensive ways of e-training, but they are willing to make use of it.
- Training should be provided in the local language of the country or region.
- Knowledge workers
- Many SMEs lack a basic learning culture or organised training plans and infrastructure
- There is a lack of support from managers to introduce e-learning/training.
- Cost engineering methods are clearly used more and more; the 'design to cost' approach demands a better understanding of cost drivers and the familiarisation of engineers with cost concepts.
- There is a need to have a transparent description of the cost structure, showing the origing of the cost drivers, to have a better visibility of the basis upon which a decision is based.
- The e-learning market is growing globally.
- The content of the cost engineering training courses is mainly focus on cost general concepts, cost management and cost control. No course has been identified in the area of cost estimating and centred on the cost estimating processes.

Fig. 9. Fourth pedagogical variable: where?

5 With what?

Means for content definition:

- Cost estimating manuals, industrial practices, publications.
- Cost estimating experts from industry.
- Professional associations.
- IDEF0 modelling for cost estimating processes representation.
- IDEF1X modelling for databases definition.

Forms of content:

- Lectures: presentations with voice (e-lectures).
- Cost Estimating process: web tool (e-mentor)
- Discussions: chat, forum, email (e-discussions)

Means for content deployment:

- E-lectures and e-discussions: Virtual Learning Environment.
- E-mentor: web site (PHP, JavaScript, MySQL).

Fig. 10. Fifth pedagogical variable: with what?

leading to the development of an e-training solution. As a consequence, the societal acceptance of electronic solutions for training needed to be addressed. Special attention was given to small and medium-size enterprises (SMEs), since there is a widely recognized need to enhance their technological standing and some of their practices. The higher rate of use of computers within these organizations makes it easier to integrate e-training into daily work [19]. In this context, it was important to consider the factors that may impinge on the integration of the e-training solution and its acceptance by potential users. In this sense, apart from results related to cost engineering training gathered during the project, experiences from other sectors were reviewed. The main conclusion is that the e-training system has to provide useful content, and this is mainly perceived when users improve their job performance or productivity [20, 21].

Media: with what?

Teaching means are the focus here: means for content definition, forms of content and means for content deployment (Fig. 10).

The definition of content is linked to the cost estimating processes: detailed, parametric and

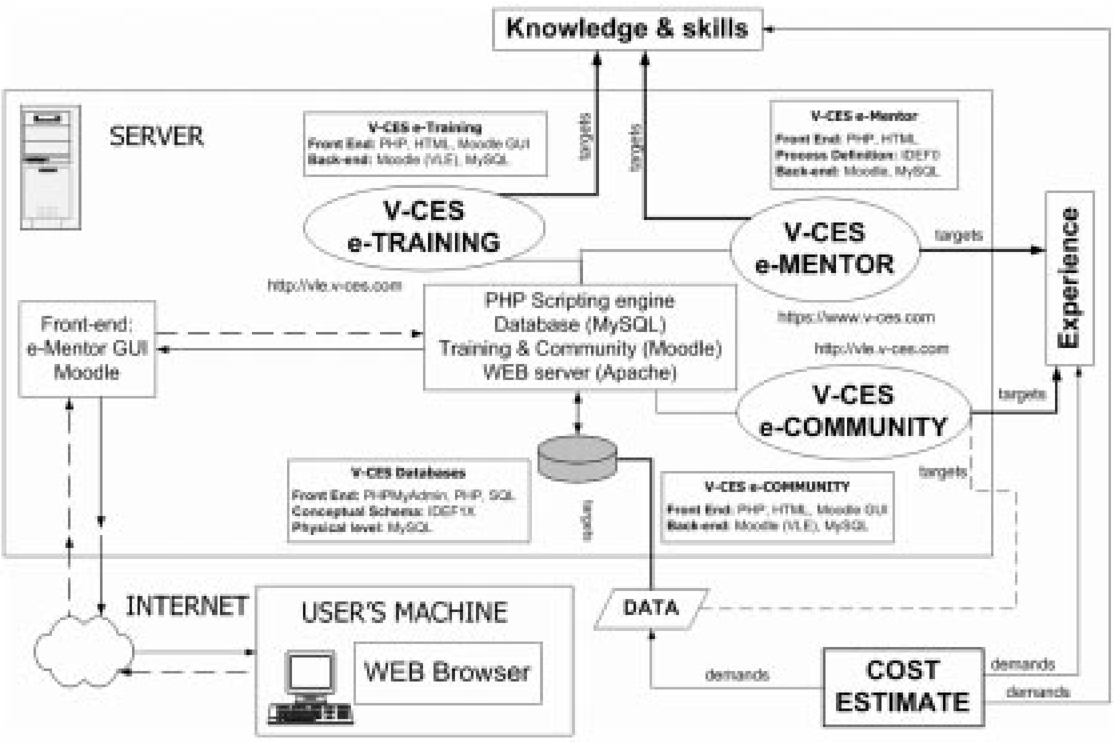

Fig. 11. Web-based cost estimating e-training solution.

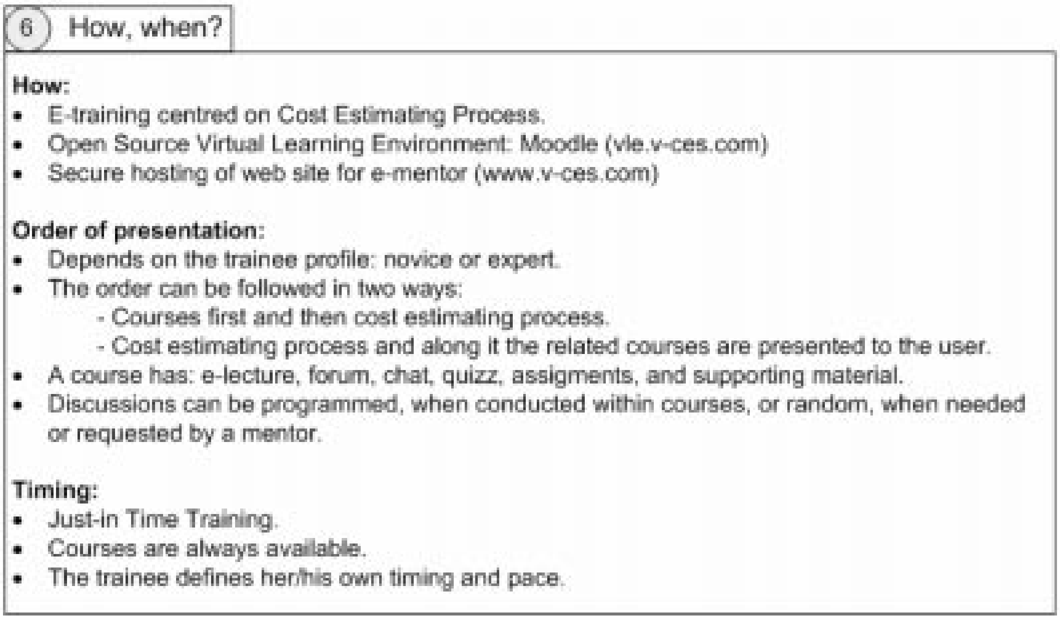

Fig. 12. Sixth pedagogical variable: how, when?

analogy. As previously discussed, this is the kernel of the system and an important amount of information and opinions were gathered and used in its definition [8, 9].

The deployment of the content is restricted by a prior decision: *the* solution had to be web-based. The architecture was designed to address the main needs identified in terms of knowledge, skills and experience (Fig. 11). Three kinds of e-training actions were defined:

- E-training by doing: wizard for cost estimating process (e-mentor). The user is guided through the different tasks, step by step, to complete a cost estimate. The tasks are presented in an IDEF0 look. Each terminal task has an associated form to fill in, where information needed to complete the cost estimate is requested to the user.
- E-Training by lectures: e-lectures linked to the cost estimating process (e-training). A set of tasks were identified that needed to have training material in the form of lectures, in this case a hyperlink to the e-lecture is located in the task page.
- E-Training by discussions: community of practice with synchronous and asynchronous communication tools (e-community). This is the space where interactions among trainees and mentors can take place.

The database allows the user to get some data to create the cost estimates but it is also expected that some data could be gathered through the e-community [9].

Teaching method: how, when?

This is the last pedagogical variable to be defined and it deals with the teaching procedures (Fig. 12). The teaching method has two options:

- Following the step by step process to create a cost estimate, and then undertaking along it the suggested e-lectures.
- Following the courses suggested according to the objectives of the trainee.

In the current prototype, the pace is determined by the interaction of the trainee and a limitation in time has not been defined. A suggestion in the training path is provided to the user based on the answers given in a competence questionnaire, where the user specifies the current status and the one to be achieved, a list of knowledge and skills for cost estimating are provided as guidance. From the evaluation of the answers, the user is qualified as novice (N1 or N2) or expert (E1 or E2). Based on the qualification and the user's aimed competences, the user is proposed to undertake a set of courses. Also, during the execution of the cost estimating process (e-training by doing), training material is presented to the user in two different ways: before completing a task (novice) or as optional material (expert) [22].

CONCLUSIONS

The paper has presented the process-centred e-training solution developed in a web-based tool for cost estimating training. The cost estimating processes used in its development were validated both internally and externally and qualified as 'best practice'. It represents an innovative approach to the training in cost engineering. Such an approach and the resulting prototype respond to industrial needs; however, its use in an academic environment both in vocational training and in engineering has been qualified as interesting. Based on this external feedback, further work to analyse the use and the impact of this tool in an engineering course has to be done.

Briefly, it can be concluded that:

- The process-centred approach adopted is innovative in terms of research and the solutions commercially available. The cost estimating processes are generic, an important factor when considering the use of this solution in vocational training and engineering education. This is reinforced by the fact that it complies with industry requirements for better understanding, visibility and transparency in the creation of cost estimates.
- The spread and common understanding of cost estimating techniques can be improved by a web-based tool to support and train professionals.
- Improvement of the prototype discussed in this paper leads to more support in terms of training guidance and e-mentoring, a relevant aspect partially addressed by Planas [22].
- Further research has to be undertaken to evaluate the feasibility of using also a process-centred approach in education and training in other topics within design and manufacturing.

Acknowledgement—This work was funded by the European Commission through IST Project V-CES: Virtual Cost Engineering Studio (No.: IST-2003–507041). The authors wish to acknowledge the Commission for their support. Our gratitude to the Polytechnic University of Madrid for the economical support provided under the Innovation in Education Programme, Project IE05525048. We also wish to acknowledge our gratitude for their contribution to other members of our organizations and project partners: Decision Engineering Research Team at Cranfield, CR FIAT, PRICE Systems, DAS and IZET.

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