Int. J. Engng Ed. Vol. 22, No. 2, pp. 218–235, 2006
Printed in Great Britain.

0949-149X/91 $3.00+0.00

A Competency-Based Educational Model in a Chemical Engineering School*

HANS-JÖRG WITT,[1] JOAN R. ALABART, FRANCESC GIRALT, JOAN HERRERO, LLUÍS VERNIS,[2] and MAGDA MEDIR

Departament d'Enginyeria Química, Universitat Rovira i Virgili, Av. Països Catalans 26, 43007 Tarragona, Catalunya, Spain. E-mail: fgiralt@urv.net

An educational model has been designed and implemented at the School of Chemical Engineering (ETSEQ) at Tarragona, Spain, to enable ChE students to acquire and integrate technical and scientific knowledge through the simultaneous and gradual development of competencies encompassing social and management skills. This model is based on the large-scale deployment of a project-based cooperative learning approach throughout the ChE curriculum. This extensive deployment can only be effective if it is supported by experts in change management and the systematic development of student teams that, in turn, requires that individual students develop key social and management skills. To this end, a partnership between the ETSEQ and Dow Chemical Ibérica was established in 1997. The expertise of Dow Chemical in team development and change management methodologies, gained from nearly a decade of implementation work, has complemented the practice of the ETSEQ with experiential learning methodologies. A set of external training interventions has been designed to support the development of competencies by students. In the new educational system student teams grow from leader-directed teams in the first semester of the first academic year to self-directed or empowered teams in the fifth year of the curriculum. In this empowerment journey, fourth-year students play a key role as they act as facilitative leaders of first-year and second-year project teams, adjusting their facilitative leadership role according to the team development stage. The core of the competency-based educational model is client orientation. The need to satisfy clients and to adapt to their changing needs triggers the development of competencies related to the transformation of the individual students (versatility, entrepreneurship and innovation, systemic thinking, etc.), of the organization (facilitative leadership, teamwork and cooperation), and of the institution (organizational development and performance, and organizational leadership). Preliminary results show that student attendance has increased, that drop out has decreased, that more professors act as facilitators in the classroom, and that active-oriented and student-centered educational methodologies are increasingly applied. In addition, the number of internships and first-job hirings at Dow has increased by nearly tenfold and threefold, respectively, since the first students educated under the new system graduated.

INTRODUCTION

INDUSTRY HAS repeatedly and clearly demanded that higher education institutions explicitly broaden the scope of undergraduate engineering education objectives [1–3]. The globalization process has intensified this trend and corporations currently consider social and management skills such as client orientation, teamwork, and leadership, as valuable as technical expertise and know-how in first job-hiring for engineers. The profile of an engineer in the fast growing technology market is also evolving towards that of an entrepreneur and, as a consequence, basic management skills are essential for the engineering profession.

The ABET's Engineering Criteria 2000 [4], the U.S. standard for accreditation, explicitly requires that engineering programs demonstrate that their graduates possess communication, multidisciplinary teamwork, and lifelong learning skills. The Industrial Research and Development Advisory Committee (IRDAC) has adopted a similar stand when advising the European Commission about the revision of higher education European programs; the Bologna Process specifically calls for a greater investment in new basic skills such as digital literacy, learning to learn, social skills, entrepreneurial skills, and language learning [5]. On the other hand, the question at university level is how can engineering curricula accommodate all these additional learning requirements without extending studies or losing depth [6]. The task at hand is to vigorously and comprehensively reform the curricula and overcome the Taylorist paradigm [7] of fragmented curricula, organized around disciplinary boundaries. The challenge is to re-engineer programs, including the teaching processes, in such a way that scientific and engineering knowledge and skills can be acquired together with social and management skills.The purpose of this paper is to describe the competency-based educational model that is being field-tested and implemented at the ETSEQ. The background, underlying hypotheses and framework

* Accepted 13 September 2005.
[1] President of Witt & Partner, Germany
[2] Dow Chemical Ibérica, Ctra. de Salou, s/n, 43006 Tarragona, Catalunya, Spain

that support the competency model are presented in the next section. This section also defines and provides the rationale for the ten competencies, embracing social and management skills, that have been selected as key enablers to learning science and engineering, and for the successful operation of the educational model. The following section describes the three basic components of the competency-based educational model: the experiential learning approach, including the integrated design projects, the competency-oriented courses and interventions, and the competency assessment process. Deployment and Preliminary Evaluation of the model at ETSEQ, deals with the implementation journey and the corresponding change management effort made so far at the ETSEQ with the facilitation of professional consultants from Dow Chemical Ibérica (hereafter referred to as Dow). Moreover, a preliminary evaluation of the competency profile of our graduating students carried out by Dow is presented. Finally, the concluding remarks are presented.

THE EDUCATIONAL MODEL

Background

The ETSEQ has a long-standing experience with student-centered instructional approaches [8–10] as a result of the project-based cooperative learning methodologies applied since the 1980's, as summarized in Fig. 1. The new five-year chemical engineering undergraduate program implemented in 1994 at Tarragona was established in close collaboration with most of the best-ranked chemical manufacturers worldwide. The contributions from these stakeholders and clients focused on the definition of the profile for a global chemical engineer. Figure 2 illustrates in a brief and comprehensive manner the abilities that then best described a global engineer, classified in terms of technical foundation, business competence and social skills. The challenge was to embed into the chemical engineering curriculum the competencies given in Fig. 2. Project-based and cooperative learning methodologies were both considered as they would enable students to acquire technical and scientific knowledge and simultaneously to develop the social and management skills needed in real-life work settings [1], i.e., solving real-life problems in collaboration with others. During the first semester of the 1995–96 academic year, the so-called integrated design project (IDP) was tested in the first year of the ChE program [11]. This approach combined the two learning methodologies mentioned above with the particularity that the first year students work in teams led by fourth year students enrolled in a project design practice course (PDP). This gave an indirect method of integrating knowledge and processes vertically. Initially the IDP had integrated only two first-year engineering science subjects horizontally and was very restricted in scope.

The success of this initial test of horizontal and vertical integration of knowledge and resources led to the current IDP scheme depicted in Fig. 3. The fact that the IDP approach started in the first year of the ChE program gave an opportunity to reinforce the continuous practice, feedback, and positive reinforcement of competencies stemming from social and management skills development throughout the curriculum, and to consider the possibility of minimising other less active methodologies such as lecturing and demonstrations [12]. It also posed interesting questions such as: Could these competencies enable or enhance technical and scientific competences? What were the competencies most relevant to this purpose and those needed for a professionally successful chemical engineering career? Was it possible to disseminate the IDP across the curriculum with a consistent deployment of team organizations leading to the empowerment of individual students and teams? How could we involve instructors and professors in the application of the integrated design project approach? Did we have the necessary knowledge,

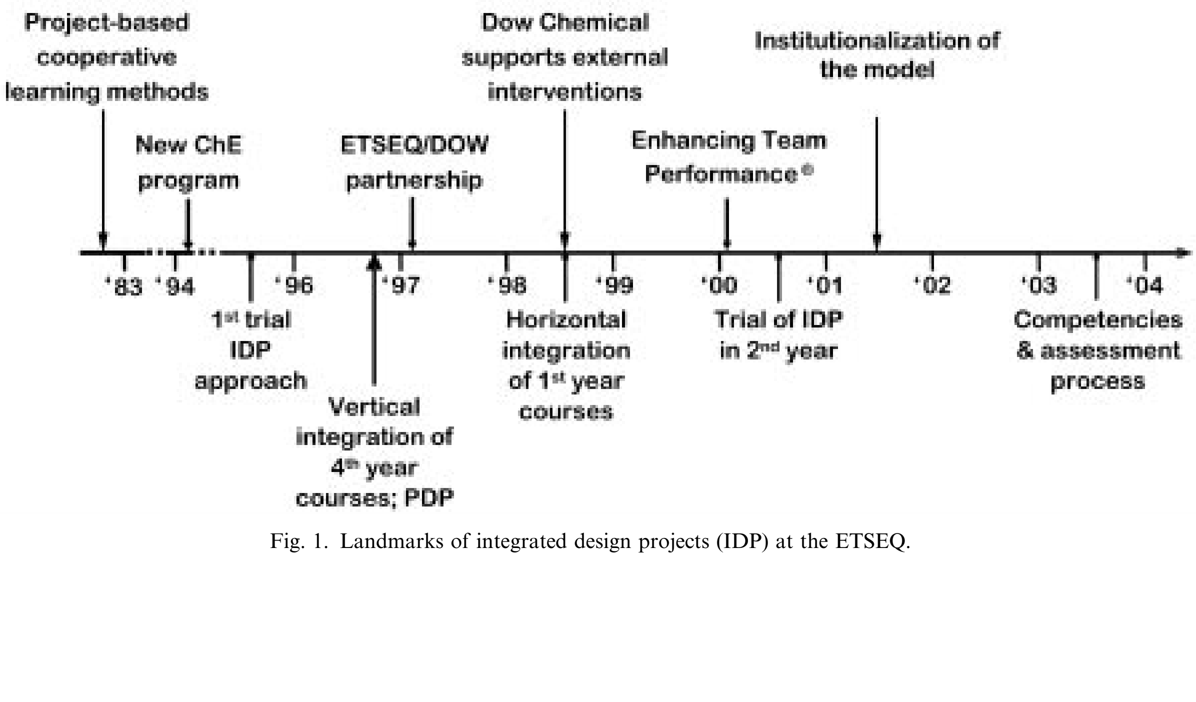


Fig. 1. Landmarks of integrated design projects (IDP) at the ETSEQ.

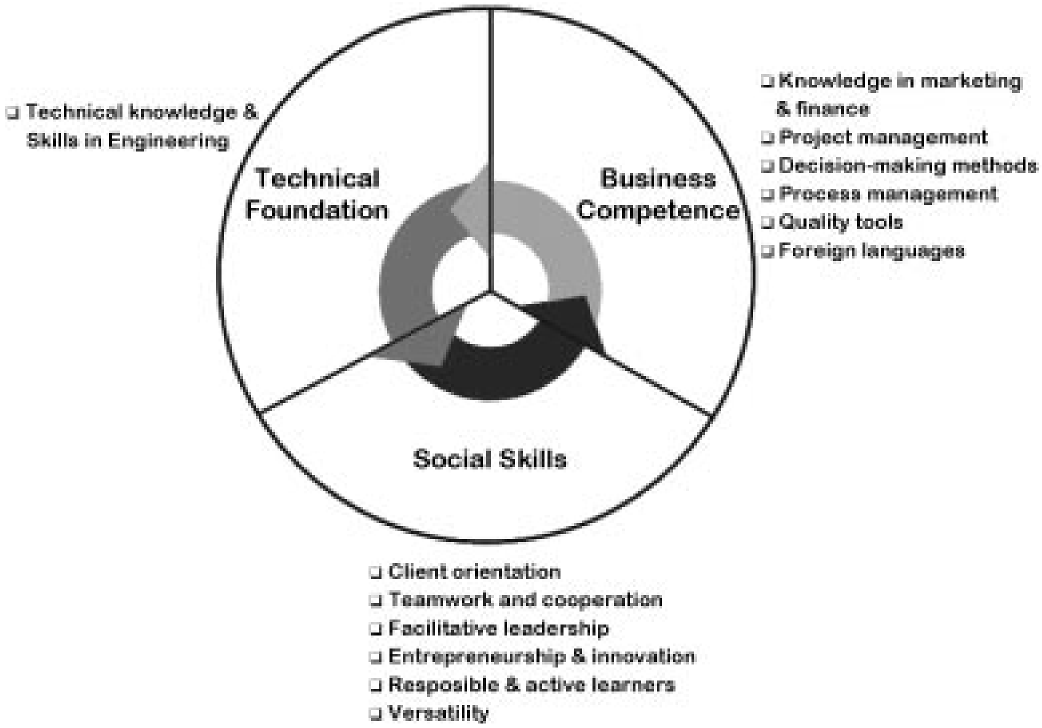


Fig. 2. Underlying abilities for a global chemical engineer suggested by chemical manufacturers in 1994.

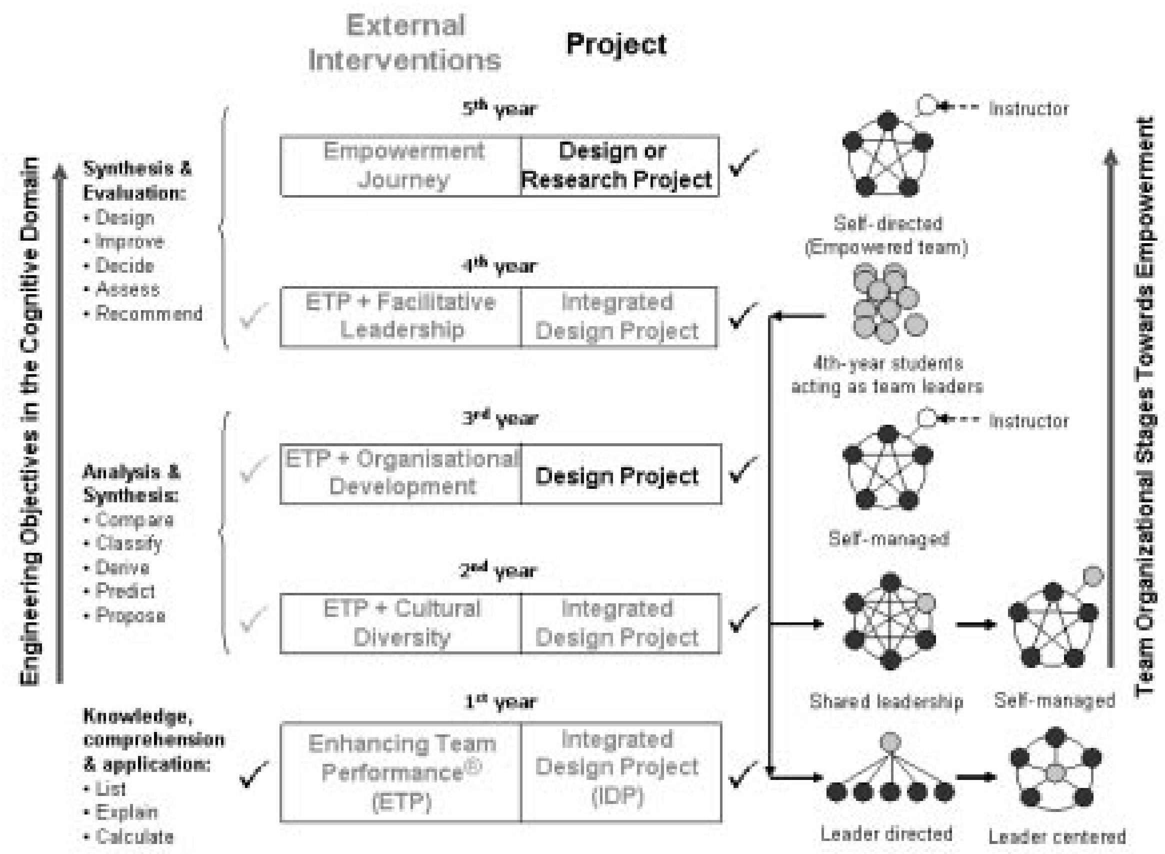


Fig. 3. The project-based educational model organization as it facilitates the deployment of empowered teams in a naturally evolving cognitive domain.

educational technologies and resources in our own organization to undergo such a drastic change or did we need help from experts outside the university system? Was it possible to design a model that could incorporate most of these challenging and innovative ideas? The outcome was to set up a list of hypotheses and requirements for the educational model. While past successful experiences in instructional development programs and engineering faculty development at the ETSEQ [10] and elsewhere [13] provided the necessary solid ground for model building, a partnership with Dow Chemical Ibérica was established to obtain expertise in change management as well as human and technical resources. The advantages of the synergistic interaction between industry and academia have been already demonstrated in many engineering clinics (see, for example, [14] and [15]).

Hypothesis

There is much indirect evidence in the history of humankind, i.e., in prehistory, evolutionary anthropology and psychology, that communication of information and learning among hominids takes place through social development [16]. In fact, both technical and natural selection has played a role in the evolution of the genus homo over the last 2,500,000 years. Social learning and social cognition theories provide direct evidence that learning time through the consequences of one's actions, which is a tedious and hazardous process of trial and error, can be shortened through social modelling of knowledge and competencies, which takes a prominent role in human motivation, thought, and action [17–19]. Also, self-efficacy or the beliefs in one's capabilities to organize and execute the courses of action required to manage prospective situations is key to developing self-regulatory strategies, motivation and achievement (in academic settings) [20].

Consequently, the first hypothesis was that the development of competencies related to social and management skills should (not compete with but) enhance the construction of scientific knowledge and the acquisition of technical competence, even over the short timescale of the duration of an undergraduate education, if consistently and experimentally worked out all the way through the curriculum. This could be accomplished smoothly with IDP's carried out with students working in teams, as indicated by our own experiences [8–11]. The preliminary results of the engineering clinic carried out at Rowan University to introduce students to formal engineering design techniques, while providing them with the necessary communication skills, already showed an increase in students' confidence in both technical and writing skills [21].

The second hypothesis was that empowerment of individual students and teams could be accomplished simultaneously within the social learning environment if the model to be implemented considered the appropriate evolution of team organizational stages, from an initial leader-directed and leader-centered scheme in the first year to a self-managed or self-directed organization just before graduation at the fifth year of studies. Table 1 describes these team organizations in terms of the responsibilities and activities of team members that was adopted at the ETSEQ and which has been inspired by the team organizations considered at Dow. The nineteen activities listed in Table 1 are exhaustive and fit very well those typically needed to carry out the design projects at the ETSEQ. Within the self-managed and self-directed team organizations, deployed in the third and fifth years respectively, students become progressively empowered since they are given the right to make decisions and take actions on their own without previous approval by instructors. This authority to act encourages students to assume further responsibility for their actions, which also results in an improvement of the model.

The third hypothesis was that the progressive deployment of the IDP approach, with team organizations matching students' skills and needs (see Table 1), should facilitate the adoption of a competency-based educational model. In the context of the current study, a competency is a combination of the tangible (skills and knowledge) and intangible (social role, self-concept, traits and motives) underlying characteristics of an individual that is causally related to criterion-referenced effective and/or superior performance in a job situation [22].

The fourth and last hypothesis was that the faculty and the school system would accept that the educational system did not possess the know-how to manage the cultural changes [23] involved in the shift towards the competency-based educational model referred to in the previous three hypotheses and would, thus, be willing to work in partnership with a chemical manufacturer, such as Dow. The fact that Dow was willing in 1997 to establish a partnership (see Fig. 1) and to facilitate this process by providing expertise and technologies, such as workshops, on (1) team development, (2) knowledge/awareness of critical competencies, and (3) methodologies to manage change, were assumed to be a sufficient incentive to facilitate and sustain the required change. The workshop materials should support or facilitate the development of competencies and taught as compulsory external interventions initially by consultants and human resource personnel from Dow and later on by previously trained faculty. An external intervention is an extra-curriculum activity that is carried out at especially allocated hours in the academic timetable.

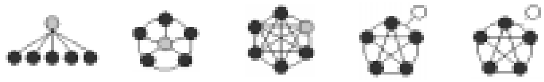
Framework

The four hypotheses stated in the previous section led to the educational model depicted schematically in Fig. 3. The model framework spans dynamically over the five years of studies both in the cognitive domain pertaining to science

Table 1. Team organizations defined according to responsibilities and activities of team members (see Fig. 3)

Responsibility of Activities

Leader
Shared between Leader & TM (not necessarily 50/50)
Shared between Instructor & TM (not necessarily 50/50)
Team Members (TM)



Activities	**Leader directed**	**Leader centered**	**Shared leadership**	**Self-managed**	**Self-directed**
1. Formulate team objectives (project scope)	Leader & TM	Leader & TM	TM	TM	TM
2. Identify learning issues and apply learning processes	Leader	Leader & TM	Leader & TM	Instructor & TM	TM
3. Establish team norms	Leader & TM	Leader & TM	TM	TM	TM
4. Communicate with project clients	Leader & TM	Leader & TM	TM	TM	TM
5. Communicate with project sponsors	Leader	Leader	Leader & TM	TM	TM
6. Provide feedback to team members	Leader & TM	TM	TM	TM	TM
7. Manage conflicts	Leader	Leader	Leader & TM	Instructor & TM	TM
8. Manage decision-making process	Leader	Leader & TM	Leader & TM	Instructor & TM	TM
9. Design and apply a balance of consequences system	Leader	Leader & TM	Leader & TM	TM	TM
10. Define and improve teamwork procedures	Leader	Leader & TM	Leader & TM	TM	TM
11. Determine the required reviews and approvals	Leader	Leader	Leader & TM	TM	TM
12. Manage project's risks	Leader	Leader & TM	Leader & TM	TM	TM
13. Schedule project's activities and create a project budget	Leader	Leader & TM	Leader & TM	TM	TM
14. Establish quality standards for activities	Leader	Leader & TM	TM	TM	TM
15. Assign activities to team members	Leader	Leader & TM	TM	TM	TM
16. Monitor project progress	Leader	Leader & TM	Leader & TM	Instructor & TM	TM
17. Integrate new team members	Leader	Leader	Leader & TM	TM	TM
18. Assess individual performance and competency development	Leader & TM	Leader & TM	Leader & TM	TM	TM
19. Evaluate team performance	Leader & TM	Leader & TM	Leader & TM	TM	TM

and engineering contents and processes, according to Bloom's taxonomy [24], and over different team organization stages towards empowerment. In the context of the current work, Bloom's taxonomy has to be understood as expanding over engineering objectives, i.e., beyond the integrated set of the formal operations that any adult, educated person performs in real life. The ticks in Fig. 3 indicate the current level of implementation, from fully operational (bold tick), under field testing (gray) to pending (no ticks).

The model is based on integrated projects in the first, second and fourth years and in projects carried out by self-managed and self-directed teams in the third and fifth years, to assure the right setup and environment for the development of social and professional competencies. Activities carried out during project development and project closing, which are listed in Table 1, require that students clearly identify project clients (mainly activities 1 and 4 in Table 1). Thus, client orientation is central in the competency structure adopted, with the rest of nine competencies emerging as correlative concentric skins characterized by 'need to do actions' to attain client satisfaction. This is schematized in Fig. 4 in terms of competencies, with the required individual, organizational and institutional transformations identified by the increasingly lighter levels of gray. The inner circles of competencies in Fig. 4 pertain more to individuals working in teams and imply the transformation of both individuals (four inner circles with darker gray) and of the organization (three intermediate gray circles). The two outer circles of competencies (lighter gray) concern more the role of individuals at the institutional level, where student's empowerment can more effectively evolve and be valued, and all changes institutionalized. Clearly, client orientation (black central target in Fig. 4) first requires that any individual should adapt to client's changes, i.e., be versatile, and subsequently find creative solutions to these new challenges, i.e., be entrepreneurial and innovative. This in turn raises the need for system thinking and so on in the concentric structure depicted in Fig. 4, which is self-explanatory.

Since current competencies have to grow from a client orientation perspective and be developed by team members simultaneously and in conjunction with regular academic activities, such as lectures, laboratories, seminars, etc., the educational and competency models shown respectively in Figs. 3 and 4 are supported by the set of five hands-on, external interventions stated in Fig. 3. These interventions have been conceived and designed to be delivered by professionals in the field and/or faculty previously trained in the respective topics and on the educational technologies used. The topics of the five external interventions, briefly described in Table 2, match both the team organizational stages planned for each of the five years of studies and the client oriented competency model of Fig. 4. The following subsection presents and discusses the ten competencies that have been adopted at the ETSEQ, which are summarised in the concentric model depicted in Fig. 4.

Fig.4. Concentric structure of competencies centered at client orientation. The gray levels identify sequentially outward the individual, organizational and institutional transformations required to attain the central client satisfaction and the development of the ten selected competencies.

Table 2. External interventions supporting the educational model and the competency structure

Interventions	Description
Enhancing Team Performance® (ETP)	Modular workshop (fundamentals, common purpose, team capabilities, change, norms, communication/conflict, recognition/reward, operating procedures, new member integration, evaluation)
Cultural diversity	Workshop based on the resource *Managing Across Cultures®* from Dow Chemical (Trompenaars, Hampton-Turner; 2000) to develop concepts around culture and to relate cultural patterns with behaviours and actions
Organizational development	A modular workshop has been designed jointly with Dow to build the foundation for core values and to enhance competencies such as client orientation and system thinking (organizational design, strategy development and implementation, business processes)
Facilitative leadership	The learning resource selected is *Advanced Facilitation for Teams and Groups®* developed and sponsored by the Dow Chemical Company. It deals with the complexity of resolving conflicts and leading teams without exercising managerial power
Empowerment journey	Based on Dow's *Global Empowerment Assessment Workshop* to help tracking the progress of team organizational stages toward empowerment, to ensure that team members and leaders display appropriate behaviours, and to become aware of the processes and methods available to develop, implement, evaluate and improve continuously the management system of any organization

Table 3. Definitions of the ten competencies selected according to the concentric structure of Fig. 4

Client orientation	The ability to identify and listen actively to clients, to anticipate and identify what clients need and value, and to seize opportunities in a responsive manner
Versatility	The ability to be open to changes and new information. To adapt behaviour and work methods in response to new information, changing conditions, or unexpected obstacles. To deal effectively with pressure; maintain focus and intensity, remain optimistic and persistent even under adversity. To be resilient and capable of dealing with disappointments and setbacks
Entrepreneurship and innovation	The capability to identify and solve problems with creativity, to have a bias for action, and to take appropriate risks. The confidence to try something different without being afraid of making mistakes. The determination and ability to challenge the status quo with new and valuable ideas and to apply existing ones in new and improved ways
System thinking	The ability to deliver technical capability based on a vision of the big picture and to manage any individual or collective endeavor according to a holistic model. The capacity to recognize patterns and complete the big picture from partial information
Responsible and active learners	Takes responsibility for one's own learning and development by acquiring and refining technical and professional skills needed in job-related areas. Obtains developmental opportunities proactively. Applies knowledge and/or information gained as appropriate
Facilitative leadership	The ability to help other people to improve performance, to promote an environment that fosters the development of others, to influence and guide others toward identifying and achieving objectives, to provide purpose and direction, and to motivate and enthuse others
Teamwork and cooperation	The capability to contribute to effective team output by cooperation, participation and a commitment to share vision and goals, and to achieve interdependence with personal accountability
Human interaction	The ability to communicate effectively in interpersonal and group situations, whether through written or oral means
Organizational development and performance	Contributes effectively to increasing organizational performance by the knowledge of relevant management methodologies and their implementation
Organizational leadership	Establishes directions, objectives and resource requirements needed to respond to the organization's needs and opportunities. Thinks strategically about longer term needs and the capabilities required to address these needs

Competencies and rationale

Table 3 lists the ten key competencies, together with their operational definitions, that have been identified at the ETSEQ, and that should also be enablers for technical competence as stated in the 'Hypothesis' section. The current selection is consistent with the extensive research reported on the trends and changes that influence the economic and social environment in which industry is operating [25–28] and with the experience gained with the implementation and continuous refining of the first–fourth year IDP at the ETSEQ [11, 29]. Dow and other chemical corporations have also identified these or equivalent competencies as critical components in their recruiting processes. Finally, the set of competencies listed in Table 3 is in accordance with the opinion of other educators and policy-making institutions [2, 4, 5].

The know-how developed by Dow on planned organizational change [30] suggests that the set of competencies of Table 3 constitutes a valid and consistent starting point to implement an effective and sustainable organizational change. Figure 4 illustrates the dynamics of this organizational transformation when it is unambiguously aimed at achieving client satisfaction through client orientation. Every significant change in clients' needs stated in Fig. 4 prompts three waves of transformation involving the individual, the organization and the institution. Research supports the assumption that the only relevant component that should be moulded (changed) in an organization is person's habits, i.e., the attitudes and perspectives of each individual [30, 31]. Change always starts at the individual level. Changes in the individuals bring about organizational transformation. Once organizational transformation has taken place, the new way of working has to be institutionalized in order to ensure that the changes are sustained and that no significant erosion takes place. Erosion would be detrimental as the organization would gradually slide back to the status quo or the starting point of the change initiative.

Table 3 summarizes the operational definitions of the competencies adopted at the ETSEQ. Figure 4 arranges these competencies in 'need to do activities' consistent with client orientation. The central competence of Fig. 4 and the first in Table 3 is *client orientation*, the one that triggers individual transformation. An individual within a client serving organization must be able to perceive a shift in clients' needs and to change accordingly. Productive performance during change requires *versatility*, since the individual is likely to be catapulted out of his/her comfort zone. To cope with inflicted stress, a high degree of versatility is needed as the individual has to adapt by changing their views, perspectives, assumptions and behaviours. The next competency under scrutiny is *entrepreneurship and innovation*. Versatility has brought about capacity to adapt to change. It now has to be followed up with creative ideas to respond to the new challenges posed by the client directly or indirectly through the organization. On an institutional level, entrepreneurship will help translate creative ideas into tangible business opportunities. The next layer of the concentric model in Fig. 4 is *system thinking*. Business opportunities have to be put into perspective, i.e., the whole system of individual and organizational interactions has to be re-considered. Critical reflection of one's position in relation to the new system will consequently trigger new learning. It is most likely that a number of competencies will become obsolete and will have to be replaced by new ones. The skill transformation calls for the *responsible and active learners* competency or else no change will take place. The issue of 'life-long learning' emerges clearly on the business horizon [32]. This notion is quite a challenge in itself as it conflicts with the traditional way of looking at education. The perception that after graduation there is 'only work to be done' is changing rapidly. The first circle after the individual transformations, *facilitative leadership*, leads the sphere of organizational transformation. Facilitative leadership is a pivotal point whereby the impact evolves from the individual to the collective scale. At this point, the individuals affected have completed the personal transformation cycle and are now skilled and ready to spark and facilitate changes in others. The fourth-year students acting as leaders and facilitators in first- and second-year teams respectively assume this pivotal role of facilitation in the current model, as shown in Fig. 3.

Organizational transformation initially starts within the smallest nucleus of the organization, which typically happens to be a team or a small group. The team reinforces the changes via cooperation and the collective analyses of client needs. This is reflected in the *teamwork and cooperation* competency. When several teams or small groups interact, the level of complexity increases exponentially [33]. This calls for a higher competency level of *human interaction*. As change increases, the likelihood of mis-communication and errors by default grows. A good skill-set of human interaction helps minimize these side effects of change. When individuals communicate and interact well with each other, challenges and barriers become opportunities for everybody in the organization, and the number and effects of conflicts decrease. This concludes the intermediate three circles of competencies involved in the transformation of the organization, as depicted in Fig. 4.

Now that the individuals and the organization are mutually aligned to cope with the new scenario of client needs, the changes attained have to be institutionalized. This happens when the individuals acquire the two outer competencies in Fig. 4: organizational development and performance, and organizational leadership. In our educational organization, work and process management competencies have both been integrated into the competency *organizational development and performance*, which characterizes individuals that can plan, implement, and evaluate any action within the organization or in smaller empowered teams of people, as stated in Table 3. This ultimately implies continuously updating and disseminating the relevant procedures and system documentation across the organization. In addition, the interaction across the organization has to be reflected in business and work processes that are aimed at satisfying client needs [34]. The last competency of *organizational leadership*, both in Fig. 4 and Table 3, is characteristic of senior managers, i.e., senior students in our case. It ensures that the transformation is complete and yields the expected results. They have to initiate an appropriate evaluation cycle to validate the degree of transformation implied in Fig. 4 in relation to client satisfaction.

THE KEY COMPETENCY MODEL COMPONENTS

Integrative and Experiential

The experiential learning approach applied at the ETSEQ, which is illustrated in Fig. 3 and has been described in the first section, is the so-called Integrated Design Project (IDP). It is based on a combination of project-based learning [35] and cooperative learning methodologies [36]. Both methodologies are well suited for engineering education because project management and teamwork are key enablers for any design activity, which is the essence of engineering [37]. Issues related to the adoption of design strategies that foster effective and natural interactions in design teams have been presented and discussed elsewhere [38]. A detailed description of the approach as applied to the first year of the ChE program at the ETSEQ has been presented elsewhere [11, 29]. This subsection focuses on those characteristics of the approach that generate the dynamic concentric transformation wave depicted in gray levels in Fig. 4, as explained in the caption.

As client satisfaction plays a pivotal role in Fig. 4, it became apparent from the beginning that project clients should be real and accessible to students. Professors responsible for the different courses that participate in the IDP act as the project's clients and are, consequently, the driving force for the transformations of Fig. 4. The IDP is not a standing-alone course. It is a teaching and learning approach that is horizontally implemented within the regular class hours of the existing courses. At the beginning of each semester, professors who teach courses in the first three years of the ChE program select a set of engineering and project-oriented instructional objectives in the cognitive domain from their corresponding syllabuses and hand them out to the project teams. The objective is that each student achieves the handed-out engineering objectives through the project and, consequently, begin to take on responsibility for their own learning. The level of these objectives varies depending on the year in the ChE program, according to Bloom's taxonomy (knowledge, comprehension, application, analysis, synthesis, and evaluation) [24]. While it is expected that first-year students achieve objectives up to the application level in relation to engineering practice, for example process design, fourth-year students should be able to formulate design problems, evaluate the learning approach itself, etc., that is, to reach up to the highest level of Bloom's taxonomy in relation to engineering practice. The increase of complexity in the level of instructional engineering objectives over the ChE program is shown on the left-hand side of Fig. 3. Together with the set of objectives, instructors allocate 25% of their regular class hours to project design and team work. As a result, students work an average of 5 hours per week on the design project.

As in any real-world experience, students enrolled in the first three years of the ChE program soon realize that each professor/client is a universe by themself. Some professors know very well in advance which results they want to get from a particular project while others keep constantly changing their instructional objectives, even when the project is already approaching the closed-out phase. This dynamic and real environment forces our students to put in place effective communication processes with clients, i.e., to develop the *client orientation* competency repeatedly demanded by chemical manufacturers [25]. It also fosters preventive thinking and triggers the preparation of contingency plans.

The model in Fig. 4 also implies a learning/working environment that facilitates the development of competencies by daily hands-on practice, with coaching support in terms of positive reinforcement and feedback. It is very difficult, if not impossible, to develop a competency up to a professional level only by attending a traditional single-discipline course. Hence the need to deploy extensively the integrated design project structure over the ChE program. It is worth noting that this constant simulation of engineering practice also makes the competency-based educational model an excellent approach to cope with criterion 4 of the ABET 2000 Criteria standard: Professional Component [4].

This gradual growth of competencies is exemplified by the systematic development of project teams throughout the program, as illustrated on the right-hand side of Fig. 3. The experience accumulated during the last decade by the Dow Chemical Company in the development of empowered teams has led to a recommendation that there is a progressive transition from leader-directed student teams in the first semester of the first year to self-managed teams in the third year of the ChE program. Each of the stages in this empowerment journey entails that students are ready to take on additional responsibility for managing the IDP approach and, eventually, for their own learning. Table 1 shows in detail which specific activities are taken on by students as they progress through the different stages towards a self-directed or empowered team. This team development structure represents an organizational transformation that has to be necessarily underpinned by the appropriate individual transformation. For example, at the heart of the shift from the traditional single-discipline lecturing format to a team-based learning approach lies the need that students realize, and hopefully begin to assume personal responsibility and voluntary commitment for their own learning.

One key success factor in this empowerment journey is team leadership, particularly for the leader-directed, leader-centered, and shared-leadership stages. Leadership is a critical component for the success of any team [29]. In addition, any effective organizational transformation requires that *facilitative leadership* competencies be in place, as indicated in Fig. 4. Consequently, it was thought that fourth-year students, who had already experienced deep individual transformations, could act as facilitative leaders of project teams formed either by first-year or second-year students. The participation of fourth-year students as facilitative leaders of first and second-year project teams is in accordance with social learning theory [18] and self-directed change research's findings [39]. The former holds that people learn interpersonal skills from 'behaviour role modelling.' This social modelling of knowledge and competencies can be best realized in teams of peers because of the prominent role that human motivation, thought and action play in this process. The latter shows that people are open to developing a new competency only when they realize that it is important to do their jobs well and that there is a discrepancy between the current and the ideal levels of competence. Therefore, fourth-year students act as role models of the competencies to be developed by first and second-year students and trigger their motivation to work hard to develop such competencies. Furthermore, fourth-year students are in a better position than instructors to create a socially 'safe' and supportive environment in which to learn, experiment with, and practice new learning methodologies and behaviours. This is a basic feature of the model since self-directed behaviour change research strongly suggest that students need to experience a high level of psychological safety to assimilate effectively the integrated design project approach and not see it as a threat. In addition, first- and second-year students see fourth-year students as fellow students who have already passed successfully through the project experience and who can provide valuable support and coaching, raising their own expectations of success [40]. The leadership-role responsibilities also vary depending on the development stage of the team, as shown in Table 1. Finally, it is expected that all third-year project teams will reach the self-managed stage where all activities related to the management of the integrated design project approach are carried out by third-year students exclusively. This outcome should emerge naturally from the experiencing of the earlier team organizations stages shown in Fig. 3 and as a result of the specific courses and external interventions expressly designed and delivered for this purpose.

Specific courses and Interventions

Table 2 describes the external interventions that support the educational model and the competency structure presented in Figs. 3 and 4, respectively. Table 4 extends this information by including the elective and compulsory courses that sustain the whole system from within. As was explained in the last section, teams are the basic organizational unit where students learn and develop competencies emerging from social and management skills. Therefore, the development of the teamwork and cooperation competency, even though located at the concentric skin no. 7 from client orientation in Fig. 4, is a priority and had to be strategically planned and supported by appropriate training interventions from the first year of studies.

The Enhancing Team Performance© (ETP) methodology developed by The Tracom-Reeds Business Group [41] was selected in late 1998 and fully implemented by professors and first year students in 2000 as the external intervention to support teamwork and cooperation in the ChE program, as highlighted in Fig. 1. Dow suggested and offered this resource to the ETSEQ because the ETP is widely used in companies and has a long-standing record of success. It has a modular form and is taught by certified trainers and coaches according to the standards of the vendor. The learning resource comprises an introduction module, called 'Fundamentals,' followed by the following nine additional modules: 'Common Purpose,' 'Team Capabilities,' 'Change,' 'Team Norms,' 'Communication/Conflict,' 'Recognition/Reward,' 'Team Operating Procedures,' 'New Member Integration,' and 'Evaluation.' The ten modules are currently delivered by previously trained faculty members, together with Dow employees.

First-year students are currently trained in the ETP modules 'Fundamentals,' 'Change,' 'Team Operating Procedures,' 'New Member Integration' and 'Recognition/Reward,' as shown in Table 4. Students start working in project teams' right at the second week of the first semester of their studies and they have to be acquainted with the critical components which contribute to optimum team performance. The 'Fundamentals' module shows, in a workshop format, that leadership, relationships and methods are critical components of optimum performance teams. Each of these components contributes with three characteristics: common purpose, team capabilities and change for leadership; team norms, communication/conflict and recognition/reward for relationships; team operating procedures, new member integration and evaluations for methods. The roles of the team leader, members and organization, together with the balances for leadership (guidance–freedom), relationships (support–candour), and methods (consistency–flexibility) are then analyzed, as well as the phases of team formation, solidification and optimum performance. Finally, the cementing of the three components, nine characteristics and balances by trust yields the outcomes of focus in the leadership component, interdependence in the relationships, and innovation in the methods. The module on 'Fundamentals' increases the ability of students to adapt to the new environment and to a decrease in drop-outs. The module on 'Change' deals with the nature of

Table 4. List of compulsory and elective courses, and external interventions supporting the educational model and the competency structure

Year	Course	Semester	Hours	Type
First	Enhancing Team Performance® (ETP) modules *Fundamentals*, *Change*, *Team Operating Procedures*, *New Member Integration* and *Recognition/Reward*	First	15	External compulsory
Second	ETP modules *Common Purpose* and *Team Norms*	First	6	External compulsory
	Communication Techniques for Chemical Engineers	First	30	ChE elective
	Cultural Diversity	Second	15	External compulsory
Third	ETP module *Communication/Conflict*, *Team Capabilities* and *Evaluation*	First	9	External compulsory
	Organizational Development	First	20	External compulsory
Fourth	*Project Management*	Yearly	60	ChE compulsory
	Project Management in Practice	Yearly	120	ChE compulsory
	ETP complete suite of modules	First	30	ChE elective
	Facilitative Leadership	First	10	External compulsory
Fifth	*Empowerment Journey*	First	30	External compulsory

change, how humans react to change, and how change interacts with leadership, relationships and methods in a team. The process of change management is also analyzed, considering the five stages of problem/opportunity recognition, agreement on destination, agreement on course of action, action, and evaluation. The leader and member roles are finally re-analyzed. The 'Change' module helps students to understand the nature of change and the human reaction to it, and stresses the importance of flexibility and adaptability as competencies that help to cope with change. The 'Change' module is imparted in a very practical way since it is applied to manage the change that first-year students undergo. The ETP modules dealing with 'Team Operating Procedures,' 'New Member Integration' and 'Recognition/Reward,' respectively expose first-year students to procedures needed for successful problem solving activities and team meetings, for excluding or integrating members, and for establishing a reward system to recognize accomplishments. This first-year external training intervention is fully implemented as indicated in Fig. 3 by a bold tick.

Second-year project teams start with a shared-leadership team organization in the first semester, which evolves into a self-managed stage during the second semester, according to the model in Fig. 3. This means that the responsibilities of the four-year students leading teams at the second year of IDP shift with respect to those at the first year in line with Table 1. The ETP 'Common Purpose' module helps second-year students to establish their team's vision, mission, objectives and action plans for the team and individual members. It also helps them differentiate between commitment and compliance. The second ETP module 'Team Norms' reinforces the need for norms (initially ground rules) and values within a framework of behavioural expectations. Students become fully aware that they belong to an educational organization that has the purpose of operating as a whole in a similar way and that has values, since every year they receive at registration a complete set of information concerning these matters. Their team's norms and values have to align with those adopted by the school:

- We are a team where people are the most important part;
- A commitment to serve the community beyond the expectations of stakeholders;
- Efficiency, reliability and responsibility;
- Excellence in the generation and dissemination of knowledge;
- Entrepreneurship, initiative, dynamism, versatility and adaptability.

In addition to these two ETP modules on team common purpose and norms, which have already been field tested and are fully operational, the external intervention 'Cultural Diversity' described in Table 2 is also in the process of being delivered to second-year students as a workshop, to give them insight into the relationship between cultural patterns and behaviours and actions. The workshop is based on the resource 'Managing Across Cultures' from Dow Chemical. The field-testing situation of this external intervention is the reason why the second-year external interventions are labelled with a tick in gray in Fig. 3. Finally, the elective course 'Communication Techniques for Chemical Engineers' is an additional and optional resource that has been available since the early years of implementation of the ChE program to help students in their oral, written and multimedia presentation skills. Students are also introduced to the process of improvisation.

Third-year project teams reach the self-managed organizational stage. As shown in Fig. 3, third-year students are left on their own to work as a team after two years of facilitation from fourth-year students. With this critical team organizational change in mind, two types of external interventions have been selected. The first incorporates the modules of ETP that deal with the remaining three characteristics of 'Team Capabilities,' 'Communication/Conflict,' and 'Evaluation' pertaining to the critical team performance components of leadership, relationships and methods, respectively. The second external intervention 'Organizational Development' is complementary to the above and focuses on client orientation and system thinking as mentioned in Table 2. Together with organizational design, strategy development and implementation, and business processes, this external intervention also introduces students to different management models such as the EFQM Excellence Model, the ISO 9001:2000 standard, and the ABET 2000 Engineering criteria so that they can evaluate the competency-based educational model and identify their strengths and areas of improvement. The ETP 'Team Capabilities' module shows how to capitalize on team skills, knowledge, experience and individual differences. The 'Communication/Conflict' module analyses the communication loop, the causes of team tension and conflict, and the standard responses to conflict. The 'Evaluation' module is critical in the concentric competency model of Fig. 4, since it considers the three levels of team evaluation: customer satisfaction, team performance and individual member performance. It is not surprising that the above three ETP modules are highly valued by the third-year students as they have to overcome the organizational barrier of self-management as a team. These three modules of ETP have been successfully tested with professors and students in general and are currently in the field testing stage in the third year of the ChE program as indicated in Fig. 3.

The ChE program offers to fourth-year students, who are the agents that retro-feed into the system the social learning component by acting as leaders and facilitators of first- and second-year teams (Fig. 3), two yearly compulsory courses in project management: Project Management (PM) and Project Management in Practice (PMP). The PM course introduces fourth-year students to the basic managerial methodologies and competencies such as project management and facilitative leadership [29], while the PMP course accounts for the hours that they dedicate to leading and facilitating first- and second-year teams. Since the PM course and the previous experiences accumulated by fourth-year students in previous ChE classes do not assure the smooth development of the PMP course, two types of training interventions are in the process of being field tested. The first is the complete set of ETP modules offered as a ChE elective with the purpose of revisiting the critical components and characteristics of an optimum performing team. The fact that students are credited for this elective course makes this offer very attractive. The second is the external compulsory intervention 'Facilitative Leadership' described in Table 2, and which is currently at a pre-field testing stage.

Finally, the fifth-year external intervention 'Empowerment Journey' has been adopted to cope with the outer competencies in the concentric model of Fig. 4. These management competencies should enable students to develop, implement and improve continuously the management system of any organization. If students have to close their learning process circle, it is required that they reflect both on the results achieved through the competency-based educational model and on the way that these have been reached. In order to reflect on the latter, it is essential that students can understand the management system of the educational model itself. Only in this way, will they be ready to help assess and review the educational model and complete their empowerment journey, sharing the ownership of the School with faculty and staff. The 'Empowerment Journey' course has been designed from the materials of the workshop on 'Global Empowerment Assessment' by Dow, as indicated in Table 2.

Assessment Process

The assessment process has only started at the first–fourth and second–fourth integrated design project (IDP) stages of the model. The initial approach focuses both on 'what' work is done and on 'how' that work is done by individual students acting in the team organizations depicted in Fig. 3 and Table 1, and in accordance with the practices of Performance Management [42]. The 'what' element encompasses the engineering deliverables typical of design projects, which are handed out in the formats of a final report and of a public presentation of results to clients, sponsors and social stakeholders in a poster session. The more technically oriented components of the 'what' element of the assessment process are evaluated during the closeout phases of the project, one per semester. This evaluation gives rise to a score or mark that is common to and shared by all team members. The 'how' element of the assessment encompasses the development and use of the competencies shown in Fig. 4 and Table 3. This element is continuously evaluated through all of the phases of the project, from planning to closeout, with the individual student being appraised in this case. Table 5 describes in detail how both elements, the 'what' and the 'how', are evaluated for the specific case of first-year students participating in the first-fourth year IDP. It can be seen that in this case both elements have the same weight, indicating that achieving good technical deliverables as a team is as important as the path

Table 5. Example of the assessment process of the integrated project related activities at the first year of ChE studies

Assessed Element	Who is Assessed?	What is assessed?	Weight (%)	Who assesses?	How to assess
WHAT? (Final results)	Team	Final report	25	First-year project co-ordinators	According to acceptance criteria.
		Poster	25	First-year professors (Clients)	According to acceptance criteria.
		Learning of instructional objectives		First-year professors (Clients)	Each client asks questions about the content of the project to a member of the team chosen at random. The score is the same for all team members.
HOW? (Processes to achieve final results)	Individual	Development and use of competencies	50	First-year students	First-year students carry out a self-assessment by using a competency form elaborated specifically for this purpose from the dictionary of Spencer and Spencer [43]. Once completed, first-year students meet with their team leaders to discuss self-assessment results. They try to clarify and reach a consensus. If this cannot be reached, the difference in viewpoint is documented and a professor of the Project Management in Practice course (sponsor of the project) mediates to reach a final compromise.

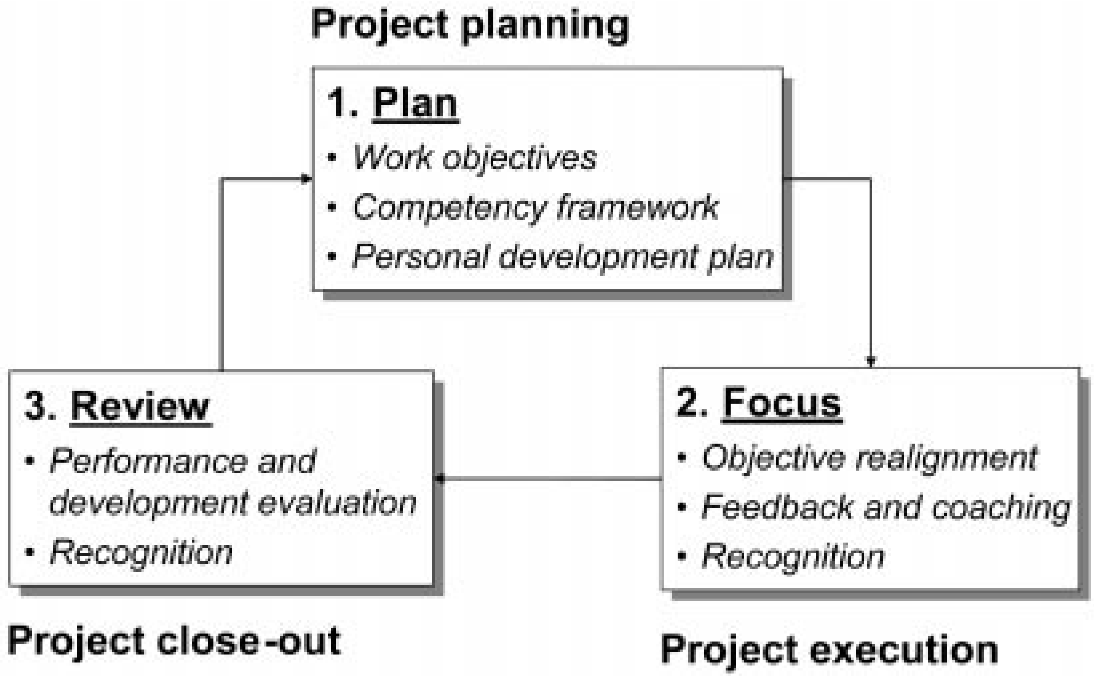


Fig. 5. Evaluation procedure for the use and development of competencies in the integrated design projects.

followed by an individual team member to accomplish them.

The use and development of competencies have been so far evaluated at the first year by applying the procedure sketched in Fig. 5. This procedure is largely inspired by the findings of self-directed behaviour change research [39]. In essence, it states that the more a student controls their change process, from the initial goal-setting stage to the point where their progress toward the goal is evaluated, the higher the likelihood is that they will eventually take on personal responsibility and voluntary commitment to change and to achieve their change goals. Again, it has to be emphasized that self-efficacy or the beliefs in one's own capabilities to organize and execute the courses of action required to manage prospective situations is key to develop self-regulatory strategies, motivation and achievement in our academic setting [20]. Therefore, the IDP is a convenient social environment in which to learn and develop competencies.

During the planning phase of the project, team leaders facilitate the assignment of work objectives to team members and also help them to understand the competencies that will support the achievement of the work objectives. In doing so, team leaders make use of a competency form, in the format of a questionnaire, 10+ pages long, available upon request to the authors, that collects definitions plus behavioural indicators clustered into different levels of competency mastery for all the competencies described in Table 3. This competency form is based largely on generic competency dictionaries such as that proposed by Spencer and Spencer [43]. Students are trained in the use of the competency form and in the overall assessment process right at the beginning of the integrated project. This competency form constitutes a conceptual framework for students to think about their behaviours and become aware of the deviations that may exist between their current level of competence and the desired one. Finally, the competency form facilitates the provision of feedback and recognition by team leaders, team-mates, and professors during the execution phases of the project.

During the closeout phases of the project, each team member holds a meeting with the team leader to reach a consensus about competency evaluation (development and use). Team members, first-year students, bring to this meeting a self-assessment based on the competency form. This self-assessment constitutes the basis for discussion with the team leader who, in turn, uses all the data about team members recorded during the planning and execution phases of the project. In this meeting, the team leader and the team member work to reach consensus on the self-assessment, i.e., on the actual level of competency achieved. They also discuss the developmental goals that are reasonable to consider for the next stage of studies. If consensus is not reached, a professor of the PDP course (sponsor) mediates to search for a final compromise.

DEPLOYMENT AND PRELIMINARY EVALUATION OF THE MODEL AT ETSEQ

The ETSEQ had to undergo the concentric transformation waves shown in Fig. 4 for the competency-based education model described in Fig. 3 to be effectively implemented. An organizational change initiative like this one poses a colossal challenge that requires a large amount of effort and long-term planning. In addition, if this change has to be implemented at a research-oriented university, where the recognition and reward processes are not fully aligned to foster improvements in teaching, the endeavour becomes even more challenging [6]. Ultimately, the whole university system should also undergo the abovementioned transformation waves. In spite of these unfavourable conditions, the ETSEQ has progressed along individual and organizational transformation waves over the last ten years. Figure 1 highlights the milestones of the competency-based education model implementation process at the ETSEQ. Basically, there are two key success factors that have driven, facilitated and sustained such a change.

The first key factor was the strong determination and leadership of a group of professors, about 25% of the total faculty, actively involved in promoting effective teaching methodologies [10]. The second key success factor was the ETSEQ/ Dow Chemical Company partnership that was established in 1997, following the model of industry–university interactions adopted in engineering clinics [14, 15] and further expanding it into the form of a partnership. As a result of this partnership Dow provided professional change management consultants and methodologies to facilitate the organizational change needed at the ETSEQ to deploy effectively the competency-based educational model. A series of workshops were organized in order to create a common vision for the ETSEQ, develop key elements to reach that vision, establish change readiness, and develop change leadership. Most of ETSEQ's professors and staff participated in these workshops and realized how much of a change the competency-based education model would mean to the way of teaching. Dow also provided expertise in team management and team development, and has facilitated the access to several learning resources. For example, the ETSEQ obtained from Dow licences to use the Enhancing Team Performance® workshop materials [41] described previously and instructors to teach this and other competency related topics as external interventions (extra-curriculum activities).

The IDP and the rest of the project-based cooperative learning approaches were institutionalized by the ETSEQ's dean after approval by the governing council at the end of the 2000–01 academic year. The deployment of the approach over the first four years of the ChE program was completed this year, 2005, due to resistances to change encountered at the second year of the program. The approach that was taken to overcome this difficulty has been to involve professors in the new system, rather than imposing a new system on them. As a result, we expect that transformations undergone by the ETSEQ, which follow the model in Fig. 4 inside-out, will be more enduring than if they had started as an institutional initiative and from that rank reached the individuals as an outside-in wave in Fig. 4. The current approach of client-oriented, breakthrough changes is more likely to generate commitment and a sense of ownership among faculty, students and staff.

The backbone of the model in terms of the project-oriented cooperative learning approach (central right column in Fig. 3) is currently (year 2005) in place and operational. The deployment of external training interventions (left column in Fig. 3) is complete in first year and at the field-testing stage in second, third and fourth years. The workshop Enhancing Team Performance®, which has been adopted to train both students and professors about the key components necessary to build a performing team, has enhanced the overall acceptance of the educational model in Figs. 3 and 4 and Table 1. It also accelerates the formation of teams and accelerates the perception among students that working in teams is an advantage in engineering practice. Breaking this barrier or cultural shift from individual to teamwork has in turn facilitated the social modelling of knowledge and competencies that are inherent in the proposed model.

'Empowerment Journey' is the only external intervention that is currently pending. According to Fig. 3 and Table 2, this intervention, which is planned for the last year of studies and has a workshop format, should make pre-graduating students aware of the processes and methods available to develop, implement, evaluate and improve continuously the management system of any organization. To reinforce in these students the corresponding two competencies of 'organizational development and performance' and 'organizational leadership' (see Table 3 and the two outer-circles in Fig. 4), 'Empowerment Journey' should include in the allocated 30 hours of workshop (Table 4), several mini-projects carried out by teams of fifth year students to self-assess the whole organization. These mini-projects should be designed so that they can be carried out in close collaboration with the fourth year students acting as leaders and facilitators of IDP. Also, they should emerge from within the EFQM's cyclic RADAR methodology [44], which involves the phases of **R**esults, **A**pproach, **D**evelopment, **A**ssessment and **R**eview, shown in Fig. 6. At the core and sustaining this cycle are the needs to *integrate* all enabling agents (leadership and processes affecting people, policies and strategies, alliances and resources, and operational processes) and to *measure* all results. The enabling agents are well taken into account by the model itself and by the partnership with Dow. The components of RADAR that are totally or partially missing currently are those related to *measure* (perception measures and indicators), both in the assessment and review, and in the results steps of Fig. 6.

The assessment and review, together with the analysis of results of the competency-based educational model that fifth-year students will carry out,

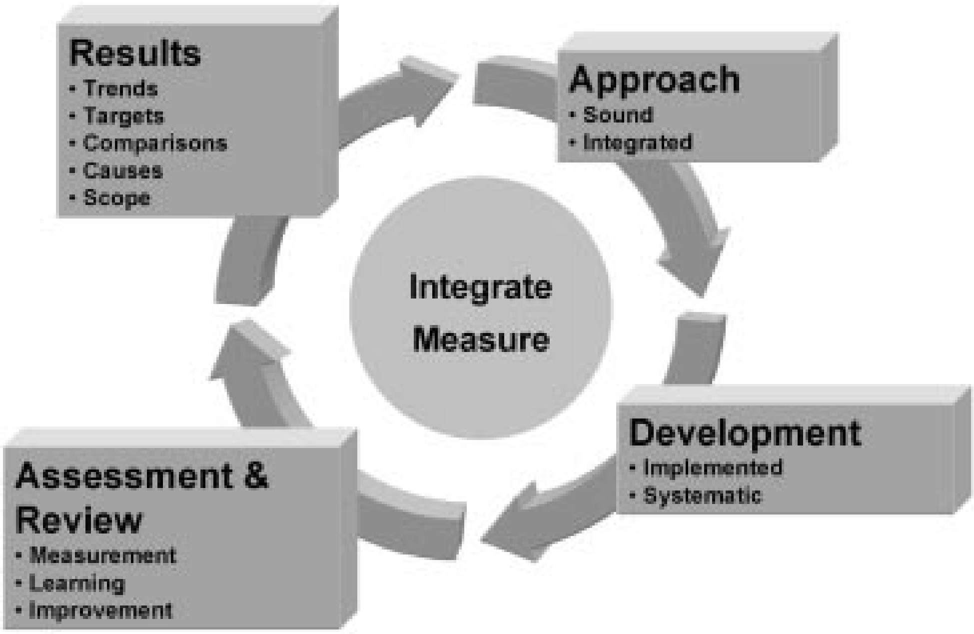


Fig. 6. The self-assessment RADAR cycle of the European Foundation for Quality Management.

should close their own learning process loop and contribute to the institutional transformation wave of Fig. 4, which is a key area of improvement at the ETSEQ itself. Many procedures have been developed and documented throughout the years and the educational model has continually been improved. However, there is not in place an accepted process management system along with its associated process indicators that could be used to assess comprehensively and quantitatively the model and, eventually, identify, prioritise, plan and implement improvements. Probably, it is necessary that the ETSEQ first goes through this institutional transformation wave, which can be facilitated by the ABET and other regional and national accreditation processes in which the ETSEQ is immersed, before the self-assessment related competencies can be developed by senior students. The successful implementation of the last intervention on empowerment is a key factor for the ongoing completion of the last two steps Assessment & Review and Results of the RADAR cycle (Fig. 6) and for the continuous improvement of the current educational model.

Most measures of the assessment currently available are of a qualitative nature but it has been seen that classes are overwhelmingly attended, that drop-out has decreased to background noise levels, that more professors act as facilitators in the classroom, and that teaching methods are more active and student-centered every day. Since the proposed educational system is client-oriented, it is worth stating the opinion of our industrial partner. Dow has felt the positive impact of the competency-based education model of the ETSEQ when selecting chemical engineering students for internships or graduates for new jobs. The first indicator that shows a positive tendency is the number of fifth-year students who carry out their industrial internship at Dow Chemical Ibérica. Placements of ETSEQ students as a percentage of total student internships has increased tenfold, from 5–7% in the late 1990's to an average of 50% in the new century. Dow tutors highlight the fact that ETSEQ students are not only technically well prepared, but they are also highly valued for their ability to overcome difficulties by effectively searching out alternative solutions with initiative and teamwork capabilities. Another indicator that shows a positive tendency is the percentage of ETSEQ chemical engineers hired annually by Dow, which has increased by a factor of nearly three over the same period. It should be noted that Dow follows a competency-based interview scheme for recruiting purposes. The scorings of ETSEQ chemical engineers showed that (1) they possess the technical knowledge required for the job, (2) they are open to new challenges, and (3) they are willing to stretch goals through effective communication, teamwork and joint development.

These preliminary but qualitatively conclusive results (evidence) show that the competency model works and that it has the correct effects on student education. These trends are an encouraging early sign that the four hypotheses stated above are consistent with the scope of the current endeavour. It remains to measure how much this effect is in every competency and to define improvement actions. In doing so, each competency will be divided into measurable components or characteristics. For example, client orientation can be broken down and measured as: (1) Gives a quick and adequate response to (responds to demands, questions, complaints and requests made by) clients; (2) shares information (keeps communication open) with clients; (3) finds solutions to and reaches consensus about (commits to solving) client's problems; (4) involves others (works) to improve service; (5) adds value (economical, environmental, health and safety, etc.) to clients beyond expectations, etc. The process of defining indicators for every competency is the next step in the assessment and review step that fifth-year students will carry out according to the RADAR methodology depicted in Fig. 6.

CONCLUDING REMARKS

The initiative of a team of professors compromised with active teaching methodologies, together with the pressures from ABET and other European accreditation boards, led to the adoption of a competency-based educational model at the ETSEQ. To support the change from a conventional educational organization to a competency-based system with empowered students, a partnership with Dow Chemical Ibérica was established. This partnership facilitated the implementation of a project-based cooperative learning structure and the weakening of resistances opposing change. Key for the success of the implementation have been the adequate selection of ten competencies (client orientation, versatility, entrepreneurship and innovation, systemic thinking, responsible and active learners, facilitative leadership, teamwork and cooperation, human interaction, organizational development and performance, and organizational leadership), the implementation of a team organization coherent with the model, from leader centered to self-directed empowered teams, and the delivery of appropriate external training interventions, designed to foster the development of the above competencies. Preliminary results show that students have developed technical, social and management skills, and have been offered significantly more internships and permanent positions by the partner chemical manufacturer.

REFERENCES

1. German Federal Ministry of Education and Research, New approaches to the education and qualification of engineers: challenges and solutions from a transatlantic perspective, *Report on Two Conferences: Objectives, Results, Guidelines, Prospects*, Bonn (1999).
2. A. Rugarcia, R. M. Felder, D. R. Woods and J. E. Stice, The future of engineering education: Part 1, A vision for a new century, *Chemical Engineering Education,* Winter (2000), pp. 16–25
3. M. Molzahn and K. Wittstock, Chemical engineers for the 21st century: challenges for university education, *Chemical Engineering Technology*, **25**(3) (2002), pp. 231–235.
4. Accreditation Board for Engineering and Technology, http://www.abet.org, accessed June 30th, 2004.
5. Investing Efficiently in Education and Training: an Imperative for Europe. Communication from the European Commission, COM (2002), http://europa.eu.int/scadplus/leg/en/cha/c11066.htm
6. R. M. Felder, J. E. Stice, and A. Rugarcia, The future of engineering education: Part 6, Making reform happen, *Chemical Engineering Education,* Summer (2000), pp. 208–215.
7. A. Verma, Emerging HRM paradigms for a knowledge economy, *HRM Research Quarterly*, **5**(3), (2001) pp. 1–6.
8. F. Giralt, M. Medir, H. Thier, and F. X. Grau, A holistic approach to ChE education: Part 1, Professional and issue-oriented approach, *Chemical Engineering Education*, Spring (1994), pp. 122–127.
9. F. Giralt, A. Fabregat, X. Farriol, F.X. Grau, J. Giralt, and M. Medir, A holistic approach to ChE Education: Part 2, Approach at the introductory level, *Chemical Engineering Education*, Summer (1994), pp. 204–213.
10. F. Giralt, J. Herrero, M. Medir, F. X. Grau, and J. R. Alabart, How to involve faculty in effective teaching, *Chemical Engineering Education*, Summer (1999), pp. 244–249
11. F. Giralt, J. Herrero, F. X. Grau, J. R. Alabart, and M. Medir, Horizontal and vertical integration of education into a human-centered engineering practice in design processes, *Journal of Engineering Education*, April (2000), pp. 219–229
12. D. A. Kolb, *Experiential Learning: Experience as the Source of Learning and Development*, Prentice Hall, Englewood Cliffs, NJ (1984).
13. R. Brent and R. M. Felder, A model for engineering faculty development, *International Journal of Engineering Education,* **19**(2), (2003), pp. 234–240.
14. J. R. Phillips and A. Bright, The Harvey Mudd Engineering Clinic: past, present and future, *Journal of Engineering Education*, **88**(2), (1999), pp. 189–194.
15. S. Farrell, R. P. Hesketh, J. A. Newell, M. J. Savelski and C. S. Slater, A model for synergistic interaction between industry and universities with focus on undergraduate education. in W. Aung, R. Altenkirch, T. Cormak, R.W. King and L. M. Sanchez Ruiz (Eds), *Innovation 2004: World Innovation in Engineering Education and Research*, Begell House Publishing, Arlington (VA) (2004), pp. 355–364.
16. J. Henrich, and R. McElreath, The evolution of cultural evolution, *Evolutionary Anthropology*, **12** (2003), pp. 123–135.
17. A. Bandura, *Social Foundations of Thought and Action: A Social Cognitive Theory*, Prentice-Hall, Englewood Cliffs, NJ (1986).
18. A. Bandura, *Social Learning Theory*, Prentice-Hall, Englewood Cliffs, NJ (1977).
19. A. Bandura, *Self-efficacy: The Exercise of Control*, Freeman, New York (1997)
20. F. Pajares, Self-efficacy beliefs in academic settings, *Review of Educational Research*, **66**(4) (1996), pp. 543–578.

21. J. A. Newell, A. J. Marchese, R. P. Ramachandran, B. Sukumaran and R. Harvey, Multi-disciplinary design and communication: a pedagogical vision, *International Journal of Engineering Education*, **15**(5) (1999), pp. 376–382.
22. D. C. McClelland, Testing for competence rather than intelligence, *American Psychologist*, **28** (1973), pp. 1–24.
23. J. W. Prados and S. I. Proctor, What will it take to reform engineering education?, *Chemical Engineering Progress*, **96**(3) (2000), pp. 91–96.
24. B. S. Bloom, *Taxonomy of Educational Objectives. 1. Cognitive Domain*, Longman, New York (1984).
25. G. J. Huysse, From the classroom to the boardroom, *Quality Progress,* November (1997), pp. 81–82.
26. R. A. Buonopane, Engineering education for the 21st century: Listen to industry!, *Chemical Engineering Education*, **30**(3), (1997), p. 166–167.
27. S. Wearne, Management skills: Not just for the boss, *The Chemical Engineers*, 26–27 August (2003).
28. J. V. Farr and D. N. Merino, Education entry-level engineers: Are broad-based business/managerial skills a key to sustaining the US innovation-based economy?, *International Journal of Engineering Education*, **19**(2), (2003), pp. 252–259.
29. H. J. Witt, J. R. Alabart, F. Giralt, J. Herrero, M. Medir and A. Fabregat, Development of coaching competencies in students through a project-based cooperative learning approach, 32nd ASEE/IEEE Frontiers in Education Conference, Boston, November 2002. *Proceedings—Frontiers in Education Conference,* **2**, F2A/1– 6, IEEE cat. no. 02CH37251 (2002).
30. *Implementing Change Effectively. Leaders Guide*, The Dow Chemical Company, Midland (MI), October (2001).
31. D. Conner and D. R. Conner, *Managing at the Speed of Change*, Villard Books, 1st edn, New York (1993).
32. P.M. Senge, *The Fifth Discipline: The Art and Practice of the Learning Organization*, Currency Doubleday, Century Business (1990).
33. W. Grunwald, Psychologische Gesetzmäßigkeiten der Gruppenarbeit, *Personalführung*, September (1996), pp. 740–750.
34. G. A. Rummler, A. P. Brache, *Improving performance: How to manage the white space on the organization chart*, Jossey Bass Inc. Publishers, 2nd Edition, San Francisco (1995).
35. D. R. Woods, R. M. Felder, A. Rugarcia and J. E. Stice, The future of engineering education. Part 3. Developing critical skills, *Chemical Engineering Education*, Spring (2000), pp. 108–117.
36. R. M. Felder, D. R. Woods, J. E. Stice and A. Rugarcia, The future of engineering education. Part 2. Teaching methods that work, *Chemical Engineering Education*, Winter (2000), pp. 26–39.
37. K. A. Smith, *Project Management and Teamwork*, McGraw-Hill Higher Education, (2000).
38. W. H. Wood, Integrating social issues into design theory, *International Journal of Engineering Education*,**19**(1), (2003), pp. 35–40.
39. D. A. Kolb and R. E. Boyatzis, Goal-setting and self-directed behavior change, *Human Relations*, **23**(5), (1967), pp. . 439–457.
40. D. C. McClelland, Toward a theory of motive acquisition, *American Psychologist*, **20** (1965), pp. 321–333.
41. *Enhancing Team Performance©, A Process and Tools for Developing Teams, Facilitators' Guide*, The TRACOM-REEDS Group, The TRACOM Corporation (1990–1995).
42. J. Rollo, *Performance Management*, GOAL/QPC and Competitive Advantage Consultants Inc., Salem NH (2001).
43. L. M. Spencer and S. M. Spencer, *Competence at Work: Models for Superior Performance*, John Wiley & Sons, New York (1993).
44. *EFQM Excellence Model*, The European Foundation for Quality Management, Brussels (2003).

Hans-Joerg Witt is currently the President of Witt & Partner, a consulting company specializing in organizational effectiveness and change management. Before that, he worked for 25 years for a global petrochemical company and served in various manufacturing positions in Operations before joining Human Resources as an internal consultant. He led the internal consulting profit centre as Global Director of Organizational Effectiveness, servicing more than 25 countries across the world. A chemical engineer by education, he is currently studying for his Ph.D at the Universitat Rovira i Virgili.

Joan R. Alabart is Associate Professor of Chemical Engineering at the Universitat Rovira i Virgili (URV). He received a B.Ch. and a Ph.D. from the University of Barcelona and an MBA from ESADE (Barcelona). His research, consultative, and training projects interests focus on the areas of organizations and people and of leadership, strategy and change. He is co-founder and director of the Master in Business Administration programme at the URV.

Francesc Giralt is a Distinguished Professor and a Distinguished Researcher at the Universitat Rovira i Virgili. He has received a BSCh from the IQS (Barcelona), an MBA from the ICT (Barcelona), a BSChE and an ScD from the University of Barcelona, and a

MASc and PhD from the University of Toronto. His research interests range from experimental and computational transport phenomena to process identification and pattern recognition algorithms. He has been an invited scholar at several renowned universities worldwide. He has been Dean of the School of Chemistry and of the School of Engineering, and has twice chaired the ChE department.

Joan Herrero is Associate Professor of Chemical Engineering at the University Rovira i Virgili, where he has taught for the last fifteen years. He received his BSChE and ScD degrees from the University of Barcelona. His research interests are in transport phenomena and computational fluid dynamics.

Lluís Vernis joined Dow Chemical in 1987 and has developed his entire professional career in the Human Resources field. He has led cross-functional global projects as a certified Six Sigma Black Belt and is currently based in the Middle East (Kuwait). He holds a Master in Psychology from the University of Barcelona and is Professor of People Management in the MBA programme at the Universitat Rovira i Virgili.

Magda Medir is Associate Professor of Chemical Engineering at the Universitat Rovira i Virgili. She received a BSCh from the IQS (Barcelona), a MASc from the University of Toronto, and a BSChE and a ScD from the University of Barcelona. She is the director of the Chemical Education for Public Understanding Program in Spain and her research interests are related to science and engineering education.