CHAPTER 1

Introduction, Background and Objectives

1.1 Introduction

When looking at Chemical Engineering education system in general, it is important to realize that it is tailored more or less exclusively for an industrial workplace. The present study of Chemical Engineering education system derives its reason for existence solely in the overall objective to achieve higher standard of living by enhancing technology performance. Priority number one is to investigate current and future work environment in order to design appropriate education to ensure that the graduates leaving Chemical Engineering schools have the best possible skill-set when entering a workplace. Therefore it is appropriate to begin by providing a brief history of industrial development in the past century.

Industrial work place is a concept which is about one hundred years old [1-3]. It can be rooted in three industrial revolutions:

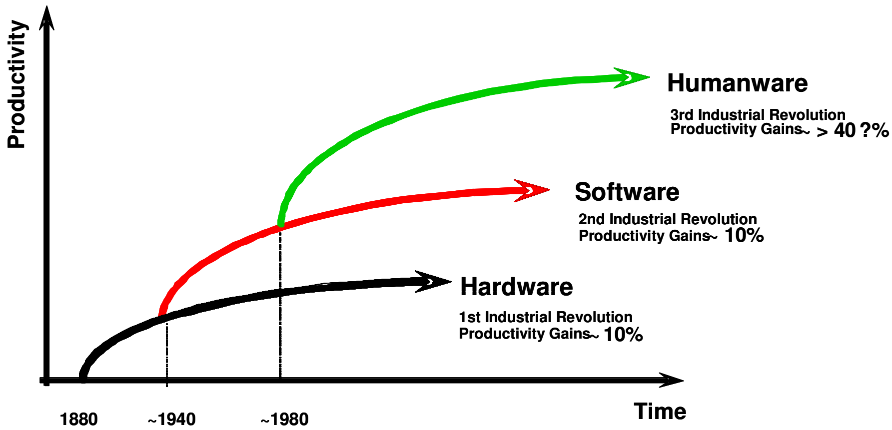

Figure 1.1. A Century of Industrial Development

During the first industrial revolution, the emphasis clearly fell on “hardware”. The tasks of chemical engineers evolved in the direction of improving operations and particularly the machinery to enhance productivity and output. One has to keep in mind that then the workforce available was clearly uneducated and relied on engineers and management to run the factories and decision making has been carried out by higher hierarchal institutions. The second era of this journey is characterized by “software” introduction. The first computers for industrial application appeared on the horizon, like the Zuse 1 (interestingly enough that huge machine had a programming capacity which is nowadays contained in the equivalent of a greeting music card [4]). Naturally that technological breakthrough created a tremendous shift in workplace and prompted a revisit of the entire curriculum of Chemical Engineering, subsequently introducing subjects like programming, automation, process control, etc.

The third industrial revolution, the era of “humanware” or the “communication age” is also called “the logarithmic world” [5]. The reason for calling it so lies in the simple fact that tremendous changes are hitting today’s society at speed close to exponential. The following facts support this hypothesis [5,6]:

- Television took 38 years to reach 50 million people, the Internet took only 4
- From April 1995 – April 1996, the capitalization of Internet companies rose from $0 to $10 billion
- In the United States per year, the rate of jobs being eliminated (about 20%) is equal to the amount of new jobs created
- The life span of new products launched has been reduced from about 2 years to now 6-12 months in the last 5 years

Given today’s globalization and tremendous interdependency of societal developments (e.g. the customer’s demand for safety, ecology, etc.) and political and economical power, it has become close to impossible to predict trends and to forecast potential developments in the marketplace.

One example of this trend is illustrated in figure 1.2 [5].

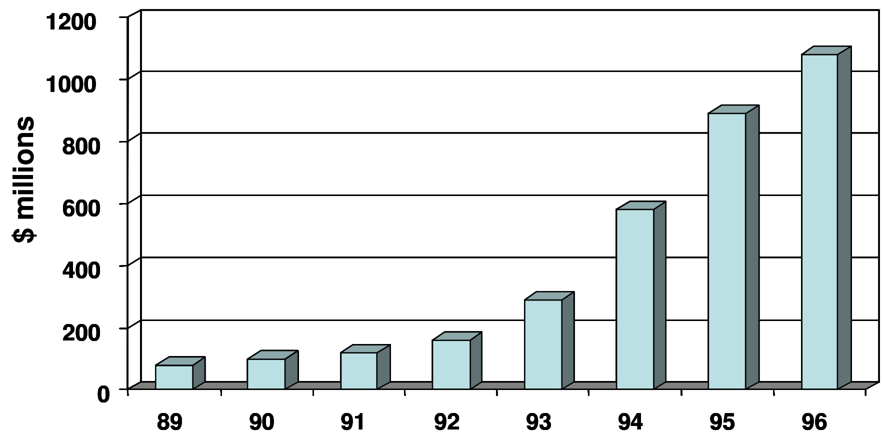

Figure 1.2. Size of Market for Pre-prepared Lettuce

Over the past two decades, tremendous changes in the work environment took place, which in turn have caused significant changes in role clarity between males and females. Dual careers for females have merely become a standard in industrialized western hemisphere. As a consequence of these societal changes, behavior patterns such as eating habits have also changed. As females with dual careers have less time to spend in the household, a market for the “pre-washed, pre-chopped, pre-packaged lettuce” has exponentially grown from being non-existent in the early 90’s to being a $1 billion market today. Evidently this is just one example of many showing the interdependency of societal trends and changes in the marketplace. The question at hand is: would a chemical engineer in charge of designing and manufacturing a product unit (e.g. for lettuce pre-packaging) build enough expansion capacity to cope with the rapidly growing demand or at least challenged the marketing and planning function with projecting future demand? Would this engineer undertake appropriate studying/research and in anticipation of future needs build ahead of demand? So when the market is booming, the production unit is already up and running, thus promoting this particular organization to the comfort of market leadership. Would this engineer summarize the research undertaken and present it to senior management? These are the types of questions and challenges future engineers will be faced with.

Another example of globalization and challenges in today's work place is taken out of the automotive industry. For a BMW 3 series, circa 40% of the components are coming from about 18 different countries [7].

Figure 1.3. Components of a BMW 3 Series

For an engineer this constellation of countries poses many challenges, not only from a logistics but also from a social point of view as one would have to communicate worldwide with all kinds of suppliers to organize the "just in time" delivery.

Similar to previous industrial revolutions, a tremendous shift within markets and societal trends is provoking a revisit of the engineering curriculum. The task at hand is to undertake this major challenge once again, now with an ever-increasing work pace and shortened response time to tomorrow's challenges.

Current societal, political and economical changes are impacting the workplace directly and immediately. As a consequence, the skill set of the employees has changed dramatically and will continue to change. As full-time jobs and work engagements in the classical sense potentially become a privilege [8] employees have to watch out the skill-set trends needed to be competitive in a global marketplace. In the following, the potential outline of the skill set of the chemical engineer of tomorrow is examined in more detail.

1.2 Skill-Set of the Future

In the previous chapter, the dynamics of a fast changing world and consequently a fast changing work environment have been described. As a counter measure, the chemical engineering education has to be adjusted to the current/future needs as the engineers' prime task is that of improving and developing productivity of industries in general.

Over the past years there has been quite some dissatisfaction expressed regarding the level of education of chemical engineers, either by the industry or by governmental authorities [9].

It is a common belief in today's economy that the competitiveness of an industrialized nation depends to a great extent on its social and technological capability for innovation and the ability to create "sustainable growth" [10]. Chemical engineers are primarily an attribute of advanced and industrialized societies, which in turn implies that these societies/nations are highly competitive.

The official definition of a nation's competitiveness as provided by the OECD (Organization for Economic Cooperation and Development) is "the degree to which a country can, under free and fair market conditions, produce goods and services which meet the test of international markets, while simultaneously maintaining and expanding the real incomes of its people over the long term". Economists of the 20th century like Schumpeter, Solow, Porter, etc. [10, 11] have unanimously agreed that entrepreneurship, technical innovation, and increased knowledge with the ability to link these factors are crucial constituents of a nation's competitiveness. To create this competitiveness and even more so to put it into practice and make it sustainable is one of the engineer's prime tasks. In addition, when implementing this task the engineers will be measured against the extent to which their technologies and production is socially and ecologically affordable and sustainable.

When reviewing literature on how the above challenges (for a future global engineer) are addressed, one can find that the USA and Germany play a leading role in driving this development [9]. This does not come as a surprise since these two countries are world-leaders in the area of Chemical Engineering, with Germany enjoying a long standing tradition in engineering science and in exporting products and technologies [10]. Consequently, two transatlantic conferences called "Engineers in the Global Economy" have been organized to address the fundamental issues of chemical engineering education. During these conferences a number of key themes surfaced:

- The profile of the engineer of tomorrow is the one of many talents
- Social competencies are critical
- Universities have to change to address these dynamics
- The change of engineering curricula has to be achieved without neglecting the depths of traditional technical expertise
- The change in demographics (for example male/female) has to be reflected
- All of the above has to be positioned to make the future of Chemical Engineering more attractive, bearing in mind that the chemical industry image ranks low in perception of society [12]

When looking at all the above challenges it becomes evident that there is no easy solution to the questions raised. But the challenge of incorporating social competencies into the chemical engineering curricula seems to be the crucial one. In this context and thereafter a competency can be understood as "a combination of 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" [13]. In the following, an approach on how to focus on building the social competencies and how to integrate them into chemical engineering curriculum without loosing perspective on technical expertise is outlined.

1.3 Social Competencies Identification

The industry representatives participating in conferences [9] expressed a need for a number of competencies as a prerequisite for the success of future engineers. Below is a list of some of these competencies:

- Teamwork
- Collaborative active learning
- Communication
- Leadership
- A system perspective
- An understanding and appreciation of diversity of students, faculty, and staff
- An appreciation of different cultures and business practices in a global environment
- Ethical conduct
- A commitment to quality, timeliness, and continuous improvement
- Understanding of the societal economic and environmental impacts of engineering decisions
- Business process competencies
- Foreign languages
- Project management competencies
- Value management
- Entrepreneurial competencies
- Conflict resolution
- Media competence
- Knowledge management competencies
- Change management

Being quite an impressive list, it captures the key themes of focus in future engineering education in addition to conventional technical expertise. When going through this list and reviewing publications on the same subject [14] there seems to be an agreement that the following four social competencies should be included in the future engineering curriculum:

- Teamwork and cooperation
- Human Interaction with Communication
- Leadership
- System thinking

Also, there is a growing agreement that integrating these and other social competencies into the curriculum will fundamentally enhance the ability to acquire technical knowledge, a key part of the hypothesis of this research project. A brief description of these four competencies is provided below:

Teamwork and Cooperation. Given the complexity and speed of today's work environment, there are very few tasks left which can be performed by one individual exclusively. Consequently the ability to work with other individuals/colleagues is not only a prerequisite, but similar to the other social competencies, is becoming more and more of a competitive advantage. Unfortunately, traditional school curricula do not take that into account as they still focus primarily on individual work as opposed to group work [14]. This pattern is reinforced as part of traditional occidental cultures [15]. Only those engineers who understand their own strengths and weaknesses are able to correlate these to the other team members' skills and are able to solve complex tasks in the most effective way. It is not without reason that companies hiring young graduates spend considerable amount of money on building team competencies during an early stage of their careers [16,17]. To know reconciliation techniques and how to deal with conflicts is important in a world that is turning into a "global village"; organizations start realizing the complexity of cultural diversity. Simple tasks akin to greeting a Japanese senior manager or proposing a business dinner at appropriate time can have an enormous impact on success or failure of a business relationship and its subsequent advancement. Global companies are investing great efforts into educating their workforce in the area of cultural diversity and sensitivity [15]. It is not only socially and ethically correct, it is also productive. In this case in point, companies are learning that there is productivity gain to be had which has not been harvested to its full potential.

Human Interaction with Communication. The further mankind advances to the "age of communication", the more conscious it becomes of the importance of effective communication competencies. Once hired in a large company, people communicate with colleagues both in person and virtually. Given this fact, it is evident that the ability to communicate effectively has tremendous impact on success and productivity of any work unit and ultimately on any given organization [18].

Leadership. The ability to lead other people, particularly in case where there is no direct hierarchal leader engaged is clearly an asset in current and future work environment. Very often the task at hand for a team leader is to engage team mates to solve a complex task within tight deadlines and with limited resources devoid of formal hierarchal authority. Given this challenging task, the ability to lead people effectively is a criterion for success and will ultimately have tremendous impact on career advancement of team leaders and on team performance.

System Thinking. Traditionally organizations have been portrayed in forms of "pyramids" or organizational charts. However, this thinking goes back to the first industrial revolution [19] and for sure then had its validity given the low educational level of the workforce. The current school of thinking within industry, states that organizations have to be looked at as a system or a living organism or else a socio-technical system [20-22]. Consequently changes in one part of an organization affect other parts of that same organization. If a chemical engineer decides to have process improvements implemented, he/she needs to be aware of a series of implications on other work units. That might be as remote as verifying performance specification to check whether the product in its new version will display the same performance patterns as before the process improvements. Thus the understanding of systems interdependency and the ability to forecast organizational behavior pattern changes is yet again a desirable skill for a global engineer. System thinking is particularly difficult in Chemical Engineering as this faculty is traditionally based on a deterministic view of the world [23].

1.4 Redesigning the Engineering Curriculum

Redesigning the engineering curriculum is an intricate task, as it is not possible to simply add on more subjects to an already filled up curriculum. Numerous failures in that direction [10] have shown that this route does not lead to success. As a result the question of building social competencies without decreasing the technical quality of education of chemical engineers remains open. The potential risk of “overloading” the curriculum is not the only pitfall in this change effort.

A comprehensive research study sponsored by the German Federal Ministry of Education and research [9] reveals the following major pitfalls when academic organizations like universities embark on re-engineering efforts like the one of fundamentally changing a curriculum:

- Speed of re-engineering not adequate and change not radical enough
- Social competencies not integrated, just put on top of existing curriculum
- Not enough leadership to drive change
- Unavailability of change management expertise
- University curricula are not reflecting today’s trends and demands
- Inadequate preparation and acceptance for change in roles
- New learning not sustainable
- Inadequate training and education
- Interaction between university management and legislation not dynamic enough
- Universities too disconnected from the market

In order to increase chances for success, it is desirable to translate the learning from the above mentioned trials into design principles, which should be adhered to:

- The social competencies should be integrated
- The social competencies should enhance technical learning
- The re-design should incorporate supporting systems, structures and processes
- During the re-design new faculty culture should be created
- The necessary education of faculty members should be an integral part of the change
- The involvement of key stakeholders is critical

Contrary to the less successful approaches mentioned before, there are encouraging pilots and tests which are trying to incorporate social skill building by integrating these topics into existing curriculum [10]. These approaches look very promising as they try to improve technical education through social competencies, an approach which is endorsed by this research project.
The more successful route to re-engineer the curriculum is creating project tasks, whereby the task as such is a conventional engineering problem. However, the

way to solve it involves designing an educational model where past successful approaches [24-27] could be integrated and their continuous development sustained. Different learning resources and teaching styles have to be used in order to make that approach successful. Lastly this route is only successful if the culture, i.e. organizational behavior of the total faculty changes simultaneously. In the following section a description of previous approaches pursued at the School of Chemical Engineering in Tarragona (ETSEQ) is provided.

1.5 The ETSEQ Approach

The School of Chemical Engineering (ETSEQ) of the University Rovira Virgili at Tarragona has offered, since 1993, a five-year undergraduate Chemical Engineering program with emphasis on both the acquisition of knowledge and the development of organizational oriented values and competencies [28]. Thus, teamwork, communication, leadership, cultural diversity and system thinking, and organizational behavior, together with management by project, quality management and creative thinking have been considered in the curriculum and fostered through active learning methodologies. The development of such methodologies has required extensive field testing. Over the past fifteen years, different approaches and strategies to attain and maintain the involvement of professors and students in team-oriented, effective teaching activities, such as early-design projects have been introduced [24-26]. The development of early-design mini-projects in Tarragona by groups of students working cooperatively without an external leader has encountered the same difficulties as those reported for the first-year chemical engineering team projects carried out at Imperial College of London [28]. These are:

1) Roles are not distributed among members and agreement for the election of a leader within the team is seldom reached
2) Groups are not able to organize time properly and prioritize work correctly. Deadlines, if established, are often ignored
3) Lack of planning and late motivation of group members leads to a typical concentration of work during the last two weeks of the semester
4) Queries are to be resolved mostly by the professor, which is not an efficient approach, instead of being thoroughly discussed first by the group
5) Low attendance and lack of punctuality are common in meetings held outside class hours
6) Teamwork often results in duplication of tasks and poor checking of results
7) Friction between group members develops, and solving interpersonal conflicts with external mediation is a difficult task
8) The participation of individuals in group activities is uneven, and communication is ineffective and inefficient
9) Information collected by members is not available when needed by the group
10) Division of labor is often inequitable, and the more gifted students soon become frustrated
11) No clear criteria are established to grade peers

The above issues and complaints highlight the difference between a group of people put to work together and a team of students learning cooperatively while working together towards a common goal. As a result, several alternatives previously reported for effective engineering education were considered to improve the outcome of early design projects at ETSEQ and move toward the concept of the global engineer [29–31]. Examples of these alternatives are:

- implementation of design projects [28,32–35]
- vertical integration of these projects throughout the curriculum [36,37]
- use of Total Quality Management (TQM) concepts and tools to improve teaching and learning [38–41]
- introduction of the latter in cooperative learning workshops [42,43]
- horizontal integration of several subjects of the engineering curriculum [35,44]

None of these proposals, however, addressed the question of the simultaneous horizontal and vertical integration of engineering education with the corresponding involvement of professors and students of different years in the undergraduate academic organization.

The holistic approach for engineering education adopted at the ETSEQ to implement effective teaching and self-sustainable curriculum improvement strategies across the academic organization, is summarized in Figure 1.4. This ETSEQ approach, which should be the basis for the development of a competency based educational model, encompasses the above mentioned methods for effective education and goes one step beyond. It integrates several first and fourth year subjects into a common design project. Teams of first year students are led by one fourth year student enrolled in the elective Project Management Practice course so that engineering skills, including project and quality management, are introduced from year one of undergraduate studies without decreasing the weight of sciences and mathematics [45]. In addition, the role of fourth year students as project managers and team leaders, and the establishment of adequate rules, foster active learning and professors' involvement (see reference 26). The learning environment that evolves is also appropriate to deal with the diversity of learning and teaching styles observed in students and professors [46].

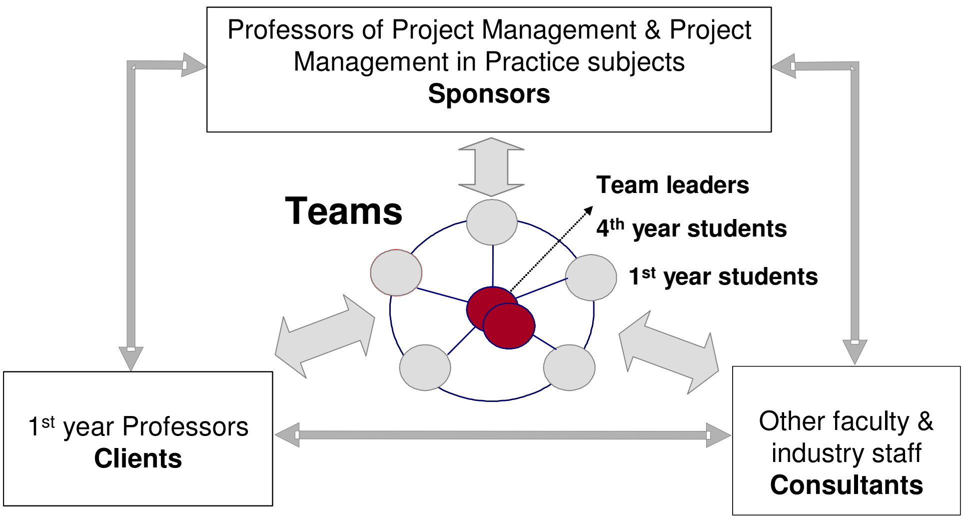

Figure 1.4. Integrated Design Project Organization at the ETSEQ

The above figure illustrates how the project organization involves 1st and 4th year students (vertical integration) and several 1st year courses (horizontal integration). It is worthwhile to emphasize that the deployment of the vertically and horizontally integrated design project responded to a long term strategic plan for the ETSEQ to improve the quality of education with effective teaching throughout the curriculum,1 while keeping the interest and enthusiasm of faculty as a team [47]. As mentioned in subsection 1.4, reengineering the curriculum should involve, in the case of the ETSEQ, the introduction of competencies into the 1st and 4th year integrated design project illustrated in figure 1.4, and the simultaneous extension of the approach into the other academic years of the chemical engineering curriculum.

1.6 General Purpose

The purpose of this thesis is to develop a competency-based educational model that could be field tested and implemented at the ETSEQ. Since such a model requires the development of social competencies without hindering technical competence, a partnership with Dow Chemical Ibérica was established in 1997 to assist in the required organizational change. The current endeavor, together with the historical deployment of student centered instructional approaches applied at the ETSEQ, is highlighted in Figure 1.5.

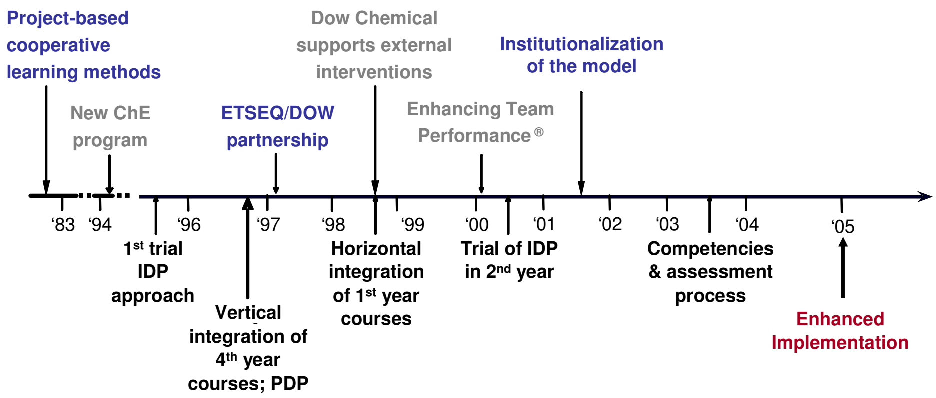

Figure 1.5. Landmarks of Integrated Design Projects (IDP) at the ETSEQ

Chapter 2 describes the background, underlying hypothesis and framework that support the implementation of a competency educational model, where technical foundation, business competence and social competencies are all simultaneously considered. The partnership with Dow Chemical Ibérica facilitated the adoption of external interventions to support social competency development. Since the ETSEQ educational tradition was that of integrated projects, the teamwork competency was chosen to introduce social competencies into the educational system and to field-test the convenience of external interventions. Chapter 3 describes and evaluates how effective the delivery of an external intervention dedicated to teamwork, such as “Enhancing Team Performance”© [48] can be, when taught to 1st and 4th year students working in the integrated design project of figure 1.4. The information provided by the evaluation of this external intervention supported the development of the competency-based educational model given in Chapter 4.

Chapter 4 presents the model adopted and provides the rationale for the ten social competencies, including the four mentioned above, that have been selected as key enablers to learn science and engineering, and for the successful operation of the educational model. How the whole model gravitates around client orientation and follows an experiential learning approach, including integrated design projects, competency-oriented external interventions, and the competency assessment process is also described in this chapter. The implementation journey and the corresponding change management effort made so far at the ETSEQ with the facilitation of professional consultants from Dow Chemical Iberica (from here on in referred to as Dow) is also provided. Moreover, a preliminary evaluation of the competency profile of our graduating students carried out by Dow is presented. Finally, concluding remarks and the recommendations to assure the complete and successful implementation of the new model at the ETSEQ are presented in Chapter 5.

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