Title:

Chemical Engineering Education in the 21st Century

Authors:

A. B. A. Borges¹, W.S. Oliveira², Faculdade de Engenharia Química, Departamento de Engenharia de Materiais e Bioprocessos, Universidade Estadual de Campinas¹

ababorges@gmail.com¹, oliveira@feq.unicamp.br²

Abstract

Formal education is a learning mechanism that is directly linked to the relationship between student and teacher. The search for the knowledge has many variables. It is possible to enrich this process with countless proposals that stimulate the active participation of the student at the classroom and improve the learning process, creating a practical, critical and political view of the society that surrounds him or her.

In this 21st century, the range of options for the Chemical Engineer professional is diversified, since it is possible to work on several fields such as the oilfield industry, plastics, paints and varnishes, environmental engineering, among many others.

Due to the intense changing nature of the teaching techniques and modern society’s dynamics, that demands a more and more multidisciplinary professional, this study presents future demands of the graduation course of Chemical Engineering for the next 30 years.

Keywords: course, chemical engineering, teaching, future, delphi.
1. Introduction

The world is moved by many political or military transformations. After the cyber-revolution, society needs more and more people that are apt to solve problems with many different degrees of complexity. People that are able to act effectively on many areas of human knowledge. Education is the main route to provide knowledge to many individuals, so that they can adapt to the community they belong to.

Education is the process that guarantees survival for the human species. It is the driving force that guides technology, which improves society’s life quality. The transmission of knowledge from generation to generation is the mechanism that allows that improvement. In other words, it is relatively safe to state that the survival of humanity depends, basically, on three factors:

- Environment: with the elements of nature, it’s possible to find feedstock to be utilized for one’s own good;

- Technology: it is the technique to be applied in order to transform feedstock in product for society’s maintenance;

- Education: it is the foundation for the bond between environment and technology. With education, society is able to use the environment through technology.

The term education applies to every knowledge that is passed on, personally or socially, thus training is considered a subarea of education that relates to specific topics, in practical or in routine events.

In order to understand and project an effective process in education a holistic approach – which is applied to several types of education, such as chemical engineering – is required (Gillett, 2001).

Chemical Engineering education is constantly evolving and being adapted. Throughout its history, some paradigms have been the foundation of teaching techniques in that field. Etymologically, that word “paradigm” originated from the Greek term “paradeigma”, which means model or pattern, among other words meaning a set of ideas that will serve as a model or an example to be followed in certain situations. Available: https://www.significados.com.br/paradigma/

In Linguistics, the word first appeared in Ferdinand de Saussure’s theory of the linguistic sign, which associated the sign to the set of elements that constitute the language. Available: https://www.significados.com.br/paradigma/

In terms of science and chemical engineering evolution, the American physicist and philosopher Thomas Samuel Kuhn (1922-1996) determined the concept of paradigm. In his book “The Structure of Scientific Revolutions”, which defines a scientific paradigm as “models that generate problems and solutions, for a fairly long period of time and in a fairly explicit manner, guiding the following development of research aroused by them.” [Bratu, 1976]

In 1887, the process of the knowledge now called chemical engineering initiated. British George Davis gathered his knowledge, acquired throughout his career as a security inspector of industries in London, and identified the necessity of creating the new profession, ministering a series of lessons about chemical industry in Manchester Technical College. Those lessons would later form the Handbook of Chemical Engineering.
There are four paradigms in chemical engineering education:

- Unit Operations;
- Transport phenomena;
- Chemical products engineering;
- Sustainability.

The first two paradigms have guided engineering education. They include a series of techniques, theories and methodologies that structure the fundamentals of the course.

The technological revolution has led chemical products engineering and, more recently, sustainability to be taken into consideration in chemical engineering education. [WOINAROSCHY, 2016]

In a chemical engineer educational background, we should take several factors into consideration. Amongst them is the need for specific and general development that will allow the future professional to act successfully in their workplace. [ABET, 2017]

Those abilities are developed during the chemical engineering degree. Specific abilities are consequences of the disciplinary and professional character of chemical engineering (i.e. basic knowledge in Science, knowing how to apply the engineering sciences such as projecting, calculus, design and foreseeing operation characteristics of an equipment). General abilities are developed during the student’s education, such as instrumental (analyzing and solving problems), interpersonal (communication and decision-making) and systematic (teamwork). [PASSOW, 2012]

According to Accreditation Bureau of Engineering and Technology (ABET), the new abilities that a future chemical engineering must have are:

- The ability of applying mathematical, scientific and engineering knowledge on a daily basis;
- The ability to project experiments, analyzing and interpreting data;
- The ability to project chemical processes;
- The ability to use modern engineering tools;
- The ability to work in multidisciplinary groups;
- The comprehension of ethics and professionalism;
- The ability to effectively communicate;
- The ability to understand engineering in a worldwide scope, and in a social context;
- Knowing how to evaluate and having a refined learning capacity;
- Having knowledge about the most modern issues discussed in society.

Continuously reflecting about the evolution of curricular grade content in the chemical engineering course is always beneficial. Those constant improvements aid in future adaptation to the industry, to new technologies and in enhancing students’ experience.[BUSSAMAKER et al, 2017]
2. Methodology

This study presents the perspective of teachers in the main chemical engineering schools worldwide about what are the priorities regarding curricular grades and the future of those professionals. A study aims the investigation of the best structure for the chemical engineering course and possible changes in the way it is currently known.

The chosen methodology for predicting the mid-term future of chemical engineering education was the Delphi Technique. That selection happened because teaching is not dependent on a mathematical model, but on the methodology’s level of acceptance by the group of people. Furthermore, there are no previous data on the selected approach.

It is important emphasize the necessity of constant curricular base analysis for chemical engineering education, since we live in a very dynamic society that will always have new demands and needs in terms of knowledge and technology, which will require study from the new professional of the field. Thus, discussing curricular grade is always of great importance.

2.1 The Delphi Methodology

The Delphi methodology is a prospection technique based on questions and answers from specialists in the field of knowledge; furthermore, the method grants anonymity for the interviewee, so that they feel more comfortable giving their real opinion regarding the subject being addressed.

Figure 01 is a flow chart presenting the phases that methodology may have while it is being utilized.

It is recognized as one of the best techniques for qualitative prediction. It may be applied to several areas, but the current most common application is technological prediction. It is recommended when there are no historical data regarding the issue that is being investigated, or, in other terms, when there is a lack of quantitative data about it. (ROWE & WRIGHT, 1999).

The method’s principle is based on an intuitive and interactive medium. It is necessary to form a group of specialists in the field of knowledge about which the prospection is desired. Those specialists answer a series of questions, previously elaborated by the researcher. The obtained results are analyzed, statistically treated, then the median and the inter quartile amplitude are calculated. Then, a synthesis of all the results is made and passed onto the members of the group of specialists, who once more answer the questions. Many interactions are made – the amount corresponds to the number of interactions required to establish a consensus, or almost one. In a group where the interviewer has no direct contact with the group of interviewees, about 10% of the specialists who receive the questions are expected to answer.

Generally, the “Delphi” method is distinguished in three characteristics:

1) Anonymity;
2) Interaction with controlled feedback;
3) Statistic answers in the group.
The “Delphi” method offers two advantages: a relatively low cost, and it suppresses a possible pressure that the participants might feel in a confrontation. It provides structured communication, anonymity, feedback for the participants, and statistic responses based on the group. Furthermore, it allows the identification of many models and perceptions by the specialists that would not be feasible in mathematical models, besides counting on intuition (ROWE e WRIGHT, 1999). However, the main disadvantage of the method is that it is not always simple to identify the specialist, which could lead to biased answers, depending on the choice of the group that answers. Choosing members requires, thus, some attention.

2.2 Question Pro

In order to send the questions, the website Question Pro [2], a platform that allows its users to create and send surveys, was used. In it, it is possible to create an easily accessible platform to the user, so that they can develop many types of surveys: dissertative answers, multiple choice or grading, among others. After the survey is ready and being applied to the respondents, the tool allows the user to view graphics with their answers, and also a geographic scale that shows where they are from, which percentage actually viewed the survey and how many of them answered it from start to finish. This tool is very versatile, and it is ideal for the research conducted in this study.
3. Discussion

All the questions that were proposed for the survey will be presented within the conclusion of this study. This article will focus on some of the results obtained from questions made to the specialists, and will present answers regarding some changes that the curricular grade that the course should have within the next years, as much as the best ways to evaluate a student.

According to the specialists, the evaluation of the student throughout the course will remain as it is nowadays. They believe that the best means of evaluation are written tests, individual assignments and oral tests. Group assignments are also pointed as important criteria, since they develop the ability to work as a team. According to Figure 01, where the percentages correspond to the degree of consensus among the interviewees, electronic tools are the only ones the specialists do not consider important for evaluation. This shows that, despite the increasing development of computer technology, professors still don’t feel comfortable with this technique, and they will choose more traditional means to evaluate a student.

During their chemical engineering graduation course, the student is required to choose a number of additional modules. In face of that requirement, the specialists answered about which modules that are currently offered will continue on as fundamentals for the curricular grade. Among the modules that are mentioned in the survey, “Ethics and Moral” was pointed as the most indispensable, as shown in Table 01. According to Longo (1992), the future engineer should be competent in both technical and social skills. In addition, that social aspect is the approach of “Ethics and Moral”. With it, the future professional will learn...
important concepts about social behavior, and moral values, so that the apprentice engineer gains the capacity to evaluate their attitude and opinions for society’s greater good. Accident analysis was also mentioned as a fundamental module, due to the fact that it offers knowledge on how to avoid accidents, and how to deal with them in case they happen, since employee’s security is one of the main concerns in any company.

Table 01 – Specialists’ opinion on which additional modules are fundamental in the Chemical Engineering graduation course in the 21st century.

<table>
<thead>
<tr>
<th>Module</th>
<th>Irrelevant</th>
<th>Low Importance</th>
<th>Medium Importance</th>
<th>Very Important</th>
<th>Indispensable</th>
</tr>
</thead>
<tbody>
<tr>
<td>Accidents analysis</td>
<td>0,00%</td>
<td>6,94%</td>
<td>25,00%</td>
<td>50,00%</td>
<td>18,06%</td>
</tr>
<tr>
<td>Law</td>
<td>4,29%</td>
<td>31,43%</td>
<td>41,43%</td>
<td>18,57%</td>
<td>4,29%</td>
</tr>
<tr>
<td>Economics</td>
<td>1,39%</td>
<td>4,17%</td>
<td>23,61%</td>
<td>58,33%</td>
<td>12,50%</td>
</tr>
<tr>
<td>Ethics and Moral</td>
<td>0,00%</td>
<td>2,78%</td>
<td>19,44%</td>
<td>47,22%</td>
<td>30,56%</td>
</tr>
<tr>
<td>Methodological of technological prediction</td>
<td>0,00%</td>
<td>9,72%</td>
<td>44,44%</td>
<td>34,72%</td>
<td>11,11%</td>
</tr>
<tr>
<td>Business planning and management</td>
<td>0,00%</td>
<td>8,33%</td>
<td>27,78%</td>
<td>45,83%</td>
<td>18,06%</td>
</tr>
<tr>
<td>Psychology and Sociology</td>
<td>4,17%</td>
<td>25,00%</td>
<td>45,83%</td>
<td>20,83%</td>
<td>4,17%</td>
</tr>
<tr>
<td>Industrial location theory</td>
<td>6,94%</td>
<td>26,39%</td>
<td>38,89%</td>
<td>23,61%</td>
<td>4,17%</td>
</tr>
</tbody>
</table>

Economics was also pointed as another module of great importance. Its value comes from the fact that the future engineer needs to be able to analyses the financial viability of the project they are inserted in. With basic notions about micro and macroeconomics, they will also be capable of understanding a wider spectrum of human behavior and society’s needs.

It was also asked the specialists which changes in the curricular grade they would suggest in order to improve the future chemical engineers’ education. Most of them pointed to an increase of the interaction between professors and students as the most important improvement. That interaction is of great importance, since the professor, as a master of knowledge about the subject being taught, could guide and prepare the student in a more effective manner with a more extensive contact. One of the main leaning phases is based on the students’ curiosity, thus it is important for the professor to know how to instigate that curiosity while being able to take them on to clarify any existing doubts.
Table 02 – Specialists’ opinion on which changes there should be in order to improve Chemical Engineering education.

<table>
<thead>
<tr>
<th></th>
<th>Irrelevant</th>
<th>Low Importance</th>
<th>Medium Importance</th>
<th>Very Important</th>
<th>Indispensable</th>
</tr>
</thead>
<tbody>
<tr>
<td>Greater interaction between student and professor</td>
<td>1.45%</td>
<td>15.94%</td>
<td>18.84%</td>
<td>36.23%</td>
<td>27.54%</td>
</tr>
<tr>
<td>Drastic Changes in curricular grade</td>
<td>20.59%</td>
<td>26.47%</td>
<td>38.24%</td>
<td>11.76%</td>
<td>2.94%</td>
</tr>
<tr>
<td>Greater student participation in Chemical Engineering practice</td>
<td>1.43%</td>
<td>0.00%</td>
<td>17.14%</td>
<td>54.29%</td>
<td>27.14%</td>
</tr>
<tr>
<td>Modules involving real day-to-day situations in Chemical Engineering</td>
<td>1.41%</td>
<td>7.04%</td>
<td>7.04%</td>
<td>46.48%</td>
<td>38.03%</td>
</tr>
</tbody>
</table>

Still in Table 01, it is possible to notice that the specialists recommend there to be a greater involvement of the students in the day-to-day practice of Chemical Engineering, which could be implemented through increases of technical visits and/or internship programs. They also feel the need of a module that shows situational issues in a daily practical life of an engineer.

As computer technology advanced, several electronic devices arose within the market in order to aid and improve people’s lives and necessities. Classes became more dynamic with the use of computers. Slide presentations, PowerPoint, videoconference, among others, allowing the professor to take a greater amount of knowledge to the classroom. Some professors, throughout the best universities in the world, have been experimenting with the utilization of new technology in class. They use clickers, for instance, as aid in the learning process. Regarding the practicality offered by technology, the specialists were asked whether those resources are valid in classes. All interviewees agreed with the statement that technology enhances knowledge and enriches the experience in class, but there is still resistance to relying completely on electronic devices for evaluating students. Table 02 presents the specialists’ perspective on the use of electronic devices in classes.
The specialists were also asked which sector of society would have more importance for the chemical engineer in the next 30 years. The fields of interest pointed out as a focal point in the 21st century are:

- Energy (95,65% of favorable opinions)
- Environmental protection (89,86% of favorable opinions)
- Nanotechnology (88,41% of favorable opinions)
- Biotechnology (86,76% of favorable opinions)
- Interface surfaces (67,65% of favorable opinions)
- Workplace safety (61,76% of favorable opinions)

The areas pointed out as less important or not important are:

- Medical (48,68% of favorable opinions)
- Microelectronics (34,33% of favorable opinions)
- Business administration (27,27% of favorable opinions)
- Spatial (20,90% of favorable opinions)
- Military (16,67% of favorable opinions)

A large majority of the specialists believe the main focus will be in the fields of knowledge related to Energy and Environmental Protection, with biotechnology right behind them. That result is very coherent and expected, since there is a widely spread concern about the indiscriminate combustion of fossil fuels and the tireless search for an efficient and practical alternate energy source in the 21st century. Many studies have been conducted to find the best source of the so-called clean energy (such as direct use of solar energy, biomass, fuel cells, among others). Still based on published studies, many researchers point to the fact that, with the
Genoma Project, presented in the beginning of the 21st century, biology and its branches will be on the spotlight, thus having great importance in the future. Many studies will be made possible through this project, paving the way, for example, many proteins synthesis (which can aid in the cure for many diseases, accelerate some biological processes, and other benefits). Those studies open the door to developing separation and purification techniques, and also enzymatic studies.

4. Conclusion

Education has always been under great interest in research and discussion. Currently, the market values the student that expands their knowledge beyond the classroom, being able to aggregate more value to the content that is taught. In universities, sometimes a professor does not have a set of educational techniques to teach effectively, thus creating a blank in the learning process. In chemical engineering, that blank is supplied with direct contact with real practice in industries and through internship, which is called learning through practice. In this study, it is possible to conclude that the relation between student and professor will still have a key role in the process of learning. The fact that students in the university are more independent in the learning process makes it necessary for the student to have more experience with real situations in industries (cases) and the technical internship so that they can learn the real operations of an industry.

In the 21st century, we will have some changes in the fields of interest in society, slightly altering the approach in chemical engineering. The tendency is that fossil fuels will no longer be humanity’s main source of energy. Thus, the future chemical engineer will have a vast work market, research and the necessity of knowledge in areas such as Energy. That change in the type of energy utilized is attached mainly to two factors: the first is the exhaustion of sources of petroleum as a reality close to ours, and the second are the chaotic level of pollution that has been generated (which is harmful to the environment to the point of causing environmental imbalance). Due to this, research and studies on clean energy and environmental protection will be featured and be of extreme interest for the future chemical engineer.

Despite all the technological revolution and cyber-revolution, education will still be attached to the physical presence, and electronic resources will be utilized only as an element of aid in the learning process in class.
Reference:


BRATU, E. (1976); Chemical engineering, reception speech to the Romain Academy, Romainian Academy Press, Bucharest.


