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Design Engineering as an Interdisciplinary Graduate Course[1]

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Abstract

This paper presents the circumstances behind the proposal to institute a design engineering option in the graduate program at the University of the Philippines at Diliman (UPD). Originally, the UPD Department of Chemical Engineering proposed a chemical engineering design option in its graduate program. However, the implementation of the proposal did not push through. A similar proposal several years later suffered the same fate. The reason for the failure of implementation was not clear. The problem was resolved through the use of "probing paradigms", developed by this author. The technique enlightened us in identifying the necessary information and components of the option. One was the apparent influence of the undergraduate design course that serves as a capstone course. A paradigm shift was necessary. The interdisciplinary nature of the option became a major consideration. Design engineering subjects are necessary in all fields of engineering. Thus, the subjects are suitable to all engineering disciplines. The design courses would give the necessary background to graduate students whose research requires some aspects in design. The core subjects are: Principles of Design Engineering, Innovation and Creativity in Design, and Design for Environment and Sustainability. Specialized courses from each discipline are to be offered.

Keywords: Engineering design, chemical engineering, probing paradigms, graduate program, interdisciplinary

1. Introduction

In today's era of globalization, knowledge conversion into value is a basis of a country's development. Engineering education is an important factor in this area. Design, a major component of engineering, is essential in creating products, equipment, processes, instruments, machines, structures, etc. The results benefit humanity but are mainly driven by profit. Design is essentially a problem solving exercise that results in new, alternative, or improved solutions. Proven techniques form the body of engineering design science, but creativity and innovation are necessary for advancement. Engineering design involves a team of engineers from different disciplines. Each discipline has its own specialized design applications demanded by their respective professions. At our university, a structured and integrated design engineering program is not available. Instead, each department has each own design subjects, which serve as the capstone courses for their respective undergraduate students.

The need to establish a design engineering program may seem to be obvious but not when other priorities exist. Thus, the thinking was that the individual undergraduate design courses of each discipline are sufficient to meet the demand for design engineers. Also, the market for design engineers is not well-developed in our country. However, design engineering will be essential to the manufacturing and related industries in the coming years. For competitiveness in the manufacturing and industrial sectors, design engineering is especially necessary.

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1. Background

This paper is the result of about two decades of effort to institute a chemical engineering design option at the graduate and undergraduate levels. It also reflects the changes design engineering has undergone through the years.

1.1 Initial Proposal

In 1987, the UPD Department of Chemical Engineering conducted a revision of its curriculum at the undergraduate level. Three options of specialization were included: environmental engineering, biochemical engineering, and process/equipment design. These were also adapted as areas of research in the masters program. The first two areas were successfully implemented while the design option did not prosper. The reason cited was that the design course (plant design for chemical engineers) requires all the principles in chemical engineering so that no new subjects have to be offered. In 1994, the department instituted the doctoral program in chemical engineering. Once more, the design option was proposed to be included in the masters and doctoral programs. Again, the difficulty in implementing the design option arose with similar reasons as before being cited. We can analyze the situation in the following manner: The plant design course at the undergraduate level is a capstone course that serves as a training subject where the students integrate everything that they have learned. If we extend that thinking to the graduate level, then new ideas are difficult to germinate. The author kept on analyzing the situation using the concept of paradigms.

1.2 Activities of the Author on Paradigms

In 1988, the National Research Council of the USA issued a report on the frontiers of chemical engineering, in which the paradigm of chemical engineering was described. (Committee, 1988) This stimulated the author to think about the application of paradigms in his profession and related interests. It took him about seven years to accomplish something concrete. Having analyzed the paradigm of chemical engineering, he thought about initiating new strategies in other areas of interest, such as in education, biotechnology, environment, energy, design engineering, etc. The result was an activity called "probing paradigms". For the next several years, probing the paradigm of engineering design was part of the activities of the author.

1.3 Activities of the Author on Design

For about three decades since the 1980's, the author has been conducting activities related to design. As a practical experiment, he designed and fabricated equipment used in fermentation technology and biotechnology. He was also involved in the design of conventional and non-conventional wastewater treatment plants. He offered graduate and undergraduate courses on special topics, subjects that mirrored the then current developments in engineering design science, employing at the same time the result of his work on paradigms. The final result of the activity is the topic of this paper.

2. Concept of Paradigms and Probing Paradigms

2.1 What is a Paradigm?

The term paradigm comes from "paradeigma", a Greek word derived from "paradeiknynai" that means "to show side by side". Originally a scientific term, it now refers to a model, a theory, a map, a perception, an assumption, or a frame of reference. (Covey, 1989) Based on a supplement to the Oxford dictionary (Burchfield, 1972), the word has various usages, the context of which often has to be explained. The term sometimes becomes a source of confusion and controversy if the usage is improperly conveyed. In a more general sense, paradigm refers to the way how man perceives, understands, or interprets the world not in the usual terms of what he sees visually. Therefore, the paradigms in the mind of different people may be different. A simple way of understanding paradigm is to see it as a map. We are all aware that the map is not the "territory" but rather it is a representation of the territory. (Covey, 1989)

2.2 Determining Paradigms

Each profession has its own paradigm—a collection of knowledge that the practitioners agree to guide their work. (Kuhn, 1970) For chemical engineering, its paradigm refers to the methods of solving problems systematically. (Committee, 1988) Tracing and examining the history of a profession is the first step in determining its paradigm. We can note how new ideas, theories, themes, and theses, developed into new point of views and alternative directions (as paradigm shifts). The professional organizations provide useful information based on the practices of the members. Proceedings of conferences certainly record useful perspective and outlook.

The development of the curriculum parallels the developments in actual practice. There may be some differences initially, but unification of ideas usually follows. Natural feedback occurs. Data for the determination of the paradigm are reflected in textbooks, reference books, trade books, equipment catalogues, newsletters, the patent literature, etc. Anecdotes, speeches, memoirs, biographies, reflections, contemplations and reviews are excellent sources too. The paradigm of a profession certainly is affected by current events and the prevailing conditions of the world. (Jose, 2013)

2.3 Probing Paradigms (Jose, 2013)

After a detailed study and examination of the paradigm of chemical engineering (that took several years), the author noticed that new ideas (related to chemical engineering) were coming out of his mind. He viewed it as the result of analyzing and investigating the paradigm of his profession. He later called the process as "probing paradigms", which meant a total understanding of every aspect of the paradigm. It is equivalent to uncovering insights, observing perspectives, finding new points of view, discovering outlooks, observing attitudes, and many others. The thesaurus can provide many synonyms of the word "probe", such as contemplate, muse, ponder, brood, mull over, cogitate, ruminate, investigate, study, examine thoroughly, etc.

Many new thoughts and ideas come out of our mind after the probing. The author then came up with a method of generating ideas, which is discussed next.

2.4 Generating Ideas

The method of generating ideas consists of the following: (a) analysis of paradigms, (b) systematic organization of ideas, (c) mapping of these ideas in one's mind, and (d) connecting ideas to form new ideas. (Jose, 2013). These ideas are basically stored in different parts of the brain. Referring to the spreading activation theory and connectionist's theory from cognitive science, connecting two ideas will result in a new idea that could become an innovation. (Plsek, 1997) The connection of ideas can be done both actively (while awake or in the beta state) or passively (while asleep or in the alpha state). While awake we can use mind maps or concepts maps to organize the ideas or use the computer and consciously organize them in the mind. Passively, we lead our mind into the alpha state with recorded information fed using an earphone. We can also explain the process by considering that our brain is a neural network computer consisting of two layers (conscious and subconscious mind). By inputting the information, the neural network computer learns and processes the information and produces outputs in terms of new ideas. The new ideas are inputted again for evaluation and for choosing the good ones. (Jose, 2013)

3. Developments Leading to the Proposal on the Institution of the Design Option

As mentioned earlier, the original proposal referred only to the graduate and undergraduate programs in chemical engineering. This section describes the two-decade journey of the author that led to the proposal to institute a design engineering program at our university. Each engineering discipline has specialized design courses usually taken up at the undergraduate level. The knowledge from all disciplines constitutes design science. It has evolved and advanced together with the emerging technologies. Advances in electronics, computer technology, and artificial intelligence have fostered robotics and computer-aided design and manufacture. We should keep in mind the diversity of design engineering: It is concerned with materials, processes, machines, tools, instruments, gadgets, personal products, appliances, structures, plants, etc. These could be a good argument for an interdisciplinary program, but other matters have to be considered. With every new idea and concept, appropriate changes in design engineering occur. More complications occur due to globalization and borderless economies. The accumulated knowledge is now the basis of the program to be instituted.

3.1 Practical experiences of the author on design

In the late 1980's, the author's interest was on equipment design based on his specialization in fermentation technology. Providing low cost but efficient equipment for the country's industry was one of his objectives. The examples he chose were the rotary shaker and the autoclave. He noted the intricacies and the need for the expertise of mechanical and electrical engineers. In design, collaboration among disciplines is necessary. Also, there should be close correspondence among the user, the designer, and the fabricator. Later, the author was involved in the design of a commercial-scale wastewater treatment plant.

He encountered difficulties in the preparation of the process and instrumentation diagram (P&ID), since it required the collaboration among chemical, mechanical, and instrumentation engineers. Here again teamwork was necessary.

3.2 Advanced Plant Design

The author continued offering design engineering courses at the graduate level in the form of special topics in the absence of a program in design engineering. In effect, experimental courses were offered.

This was in the early 90's. The courses were based on equipment and plant design in chemical engineering, which was mostly about conventional design. However, a book by Donald Woods (1995) provided a more practical approach to chemical engineering design. It presented the big picture of the engineering profession. Along with many processes and examples, he explained the following: why mass and energy balance is necessary, why and how to apply thermodynamics, why and how to use fluid mechanics and heat transfer. He also introduced simplified P&ID. Recent books have modified their approach. (Sinnott and Towler, 2009)

3.3 Developments in design in the US in the 80's

The United States has traditionally been the leader in engineering design and has influenced other countries, for example, Japan. However, in the mid-1980's, severe readjustments occurred in large companies due to depressed economic conditions. Company takeover became the trend. Downsizing and personnel layoffs were inevitable. The best qualified engineering designers were retired. This resulted in the loss of competitiveness of the US in the world market. (Mansfield, 1993) Other countries particularly those in Asia took advantage of the situation and became tiger economies. The situation underscores the importance of design in maintaining competitiveness. But today, the US is rebounding back, with new emerging design principles and applications.

3.4 Engineering Design, the Environment, Sustainability, and Globalization

The revolution in environmental protection has had a profound effect in engineering design. With the implementation of the Environmental Protection Act (particularly in the US), companies had to treat the effluents, which was costly. To offset the cost, companies implemented pollution prevention practices, process improvement, or process redesign. Due to heightened environmental awareness, corresponding principles were incorporated in the design and processes ran more efficiently. (Freeman, 1995) In the 1990's, design for environment was introduced for creating eco-efficient products and processes. (Fiskel, 1996) Closely related to the environment is sustainability (from sustainable development) of design, which connects the technologically possible with the ecologically necessary. (Vezzoli and Manzini, 2008) Globalization is the trend today. Here, financial markets are integrated, deregulated, and liberalized worldwide, which sometimes can lead to financial crisis. It certainly has an impact on design engineering.

3.5 From Bulk Commodity Chemicals to Chemical Products

The specialty chemical industry took shape only in the 1970's at about the same time "advanced materials" and "electronic chemicals" were being reassessed. When Charles Kline presented a paper on the emerging industry, it was criticized severely. (Smith, 1988) But today, chemical products have become dominant over the bulk chemical industries. Many chemical companies design and manufacture high-priced specialty chemical products such as electronics, cosmetics, and pharmaceuticals. Few highly-efficient companies now manufacture bulk commodity chemicals using high technologies and few workers. Competition is very stiff and only the most robust survive. (Cussler and Moggridge, 2001) The trend has affected design practices.

4. The Development of the Proposal for the Engineering Design Course

Comprehending and integrating all the information in Section 4 to come up with some new ideas is not an easy task. By 1998, the author's work on paradigms had progressed to a point where he was then able to apply the principles. The activity was facilitated by the author's offering of special courses about engineering design to formulate the program presented in this paper. In probing the paradigms, all the information about chemical engineering and engineering design are systematically plotted in the mind. This required consistent awareness of the organization of the information. With practice the activity becomes automatic. The probing took about ten years for chemical engineering and about five years for engineering design.

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5.1 Initial Activities and Probing Paradigms

The author spent about ten years to develop the technique of probing paradigms, as applied to chemical engineering, biotechnology, energy, environment, and design. By probing the paradigms of chemical engineering and engineering design, he was able to find the reason for the continued failure in offering the design option. The paradigm of chemical engineering design is congruent to the paradigm of chemical engineering itself. We need a different paradigm and must have a paradigm shift. Design is a natural part of chemical engineering (as in all engineering disciplines) and an important part of its paradigm. The conventional concept of chemical engineering design consists of selecting an appropriate process, specifying and sizing equipment, optimizing the process; and setting up a feasibility study. Undergraduate students take this course, which is called plant design. The course is a capstone course where the student applies all the principles he/she had studied in the previous years, or in other words, the paradigm has been built in his/her mind. In this manner, the philosophy or the paradigm of plant design fits with the chemical engineering paradigm. It becomes indistinguishable with the regular chemical engineering paradigm. The instructors (including the author) also had the same line of thinking. As a result, when the design option was introduced in the graduate program, it became a mere extension of chemical engineering. The sight and focus of the real objective of the design option were lost.

5.2 Further Results of Probing Paradigms

After five years of offering the special topics and special problems courses based on the then current issues and available reference materials (and probing paradigms), the author came out with the following idea: To design a new product, we need a new process, and new equipment may be needed. The term "new product" was the missing term. In chemical engineering, we seldom refer to product design. Product design usually falls under mechanical or industrial engineering design. This is partly because chemical engineering traditionally deals with bulk commodity chemicals. This was the real key: We need the paradigm of product design in chemical engineering. We have to probe the paradigm of engineering design. A quick way of doing this is to scan the books available in design. Most of the books are for mechanical or industrial engineering focusing on the products related to those professions. Very few were discussing chemical products. This is expected because the above-mentioned fields seldom apply chemistry. A book, Engineering Design, a Materials and Processing Approach by Dieter, (1999) considers chemistry and materials as part of design. Hence, he knows the paradigms of chemistry, material science, and process design. The situation became clear: We have to adapt the design paradigms of different engineering disciplines (mechanical, civil, electrical, industrial, metallurgical, etc.) to chemical engineering design. Another way of looking at this is we have to use the paradigm of total engineering design in designing a new product. The author was now able to solve the dilemma of instituting the design option after the probing.

The program should include three aspects: (a) product, process, and equipment design for a new or retrofitted process, (b) clean technologies and pollution prevention, and (c) innovation, creativity, and invention. This program clearly advocates a balance between economics and environmental protection. Prepared adequately, a non-polluting process is more economic. We can achieve these by retrofitting an existing process or by designing an entirely new process. We need creativity and innovation to do this.

5.4 Action taken

The program has finally been completed by 2005 but was not implemented for the UPD Department of Chemical Engineering because its scope has expanded beyond that of chemical engineering. With this development, the author instead pushed for the application for the entire college, as a design engineering option in the graduate program. Under this program, the principles from different disciplines will be applied with the total design engineering concept.

5. The graduate programs in engineering at our university

The college of engineering has an established graduate program. It partners with local and international universities, industries, government agencies and international agencies in the area of engineering education, research and development, as well as extension services, all towards advancing knowledge and meeting social responsibility. The college offers 21 graduate programs that are at par with graduate programs offered in engineering schools in other countries.

5.1 Graduate Programs of Each Department

The College consists of two institutes and six departments: The Institute of Civil Engineering (ICE), the Electrical and Electronics Engineering Institute (EEEI), the Department of Chemical Engineering (DChE) and the Department of Mining, Metallurgical, and Mining Engineering (DMMME) offer MS and PhD programs. The Department of Geodetic Engineering (DGE) and the Department of Industrial Engineering and Operations Research (DIE/OR) offer Diploma and MS degree programs. The Department of Computer Science (DCS) and the Department of Mechanical Engineering (DME) offer only the Masters Program.

5.2 Environmental Engineering Program

The Environmental Engineering (EnE) Graduate Program was established in 1973. Since its institution, it has collaborated with the World Health Organization, United Nations Development Programme, and several foreign universities. It is a trans-disciplinary and multi-departmental research and academic unit of the college of engineering intended to provide advanced environmental engineering studies. The participating departments are DChE, DCE, DGE, DIE/OR, DME, and DMMME. EnE maintains an active linkage with international organizations, university and industry networks in the Southeast Asian region, Europe and Australia. The areas of specialization include biological and chemical wastewater treatment, natural treatment systems, hazardous waste treatment and disposal, environmental impact assessment, environmental database management, industrial pollution studies, air and wáter quality monitoring and assessment, and solid and hazardous waste management.

5.3 Energy Engineering

The Energy Engineering (EgyE) Program at the UPD College of Engineering was instituted in 1983 with the objective of training specialists who will (a) develop indigenous sources of energy, (b) improve the efficiency of energy utilization, and (c) introduce appropriate energy technologies.

The program is multidisciplinary with lecturers and thesis/dissertation advisers from among the faculty of the different departments of the college. The curriculum was revised in 2009 to provide a responsive and comprehensive knowledge base that will enhance the expertise of researchers, engineers, and scientists. This is particularly useful in (a) developing and managing applied energy technologies, (b) developing analytical tools for energy planning, (c) effectively transmitting critical technical and policy-oriented knowledge to support institutions, and (d) meeting the demands of the dynamic and complex character of an evolving energy sector within a competitive and market-based framework. The program aims to be a pro-active contributor to the country's progress toward energy security and sustainable development. Its mission is to engage in energy research and development of regional and national relevance, to produce solutions-oriented leaders in the energy sector, and to provide expert advice on energy issues of regional and national interest.

6. The Proposed Design Engineering Option in the Graduate Program

The institution of the option follows the procedure by which the environmental and energy engineering programs were planned and instituted. The experience of the College in these programs will insure success of the endeavor. The details will still have to be ironed out by the program committee. Basically, the framework has been setup. Each department will offer specialized courses (featuring state-of-the-art developments) for their own students as well as those from other departments. The proposed program consists of three core courses and specific offerings of each department and institute. In line with the structure of the EnE and EgyE programs, research activities and collaboration with local and foreign institutions will be part of the regular activities of the design engineering option. Connections with non-engineering disciplines such as physics, chemistry, food science, biotechnology, marine science, psychology, etc. will be pursued to foster the development of new ideas.

6.1 Principles of Design Engineering

Design engineering has now a coherent body of knowledge – an engineering design science, embodied by the book of Eder and Hosnedl. (2008) The purpose of the book is to "propose and justify a valid, formalized general model of design procedure, especially to innovative design engineering, that is prescribing a procedure for designing technical systems presented for use in engineering design practice". This book is an excellent reference material for our program. Appropriate and relevant references will be used. Some topics in the course are:

A. Engineering design process, systems, and models
B. Information, knowledge, data
C. Engineering design process and its structure
D. Knowledge related to engineering design processes
E. Factors and models of design situation
F. Specialized engineering design sciences
G. Specialized theories of technical systems
H. Design methods and support for engineering design
I. Materials selection
J. Economics of Design
K. Case studies

6.2 Innovation and Creativity in Engineering Design

Design engineering has to be dynamic and it always needs fresh ideas. Problem solving is a major aspect of design. Innovation and creativity is always needed to generate new ideas. Many techniques on creativity and innovation exist. We can choose and apply those that are suitable for our purposes. The course also features the technique using probing paradigms for idea generation and evaluation. Some topics in the course are:

A. Theories of creativity and innovation related to design engineering
B. Educational concepts for design and innovation
C. Perspectives of design and innovation in socio-technical processes
D. Creative problem solving techniques
E. Survey of techniques of creativity and innovation/Methods of generating ideas
F. Imagination, visualization, and communication
G. Examples, applications, exercises, projects

6.3 Design for Environment and Sustainability

The course provides a logical and practical tool to support the design process. The methodologies and tools integrate environmental requirements into product development. Strategies and guidelines highlight environmental awareness in design. The book by Vezzoli and Manzini (2008) provides suitable framework. Fiksel (2001) updates the development in design for environment. Allen and Shonnard (2001) provides pollution prevention techniques and the concept of green engineering. El-halwagi (2012) details how to achieve sustainable design by applying process integration. Stasinopoulos, et al. (2009) discusses an integrated approach to sustainable engineering. Some of the topics in the course are:

A. Principles of design for environment
B. Guidelines for environmental sustainability
C. Product life cycle design and management
D. System design for eco-efficiency
E. Methods and tools to evaluate the environmental impact of products
F. Environmentally-aware product design
G. Green Chemistry and clean energy
H. Pollution Prevention
I. Process Integration: Heat Exchange: Heat and Mass exchange
J. Case studies in the practice of design for environment

6.4 Implementation at the Departmental Level

Each department or institute (including collaboration) will offer specialized courses and advances in design engineering. Some possible courses are:

- DChE: Chemical Product Design Process Intensification
- ICE: Design of Structures

- DCS: Advanced Software Design
- DME: Advanced Machine Design
- EnE: Design for Environment and Sustainability
- DMMME: Design for Sustainable Materials
- EgyE: Design for Sustainable Energy
- DGE: Design related to Geographical Positioning System.
- DIE/OR: Advanced Product Design
  Human Factors in Design
- IEEE: Design of Advanced Computer systems
- DCS/IEEE/DME: Robotics, Automation, and Computer-aided Manufactuing

7. Conclusion

Oftentimes, when we try to find answers to our questions, we encounter difficulties because of familiarity to what we already have. In curriculum development, finding new avenues and strategies is also difficult for the same reason. Instituting a chemical engineering design option in the masters program was the initial objective and was met with problems in implementation. The activity was carried out at the same time the author started his work in probing paradigms. The solution to the design problem was coupled to the technique in generating ideas. The completion of the technique also led to the solution of the design dilemma.

The solution to the problem discussed may be obvious to some experts in the field of design engineering. The proposed program may even be identical to those existing elsewhere. The important point is how the objective was attained. The technique used in this paper is thus recommended for similar situations, and in formulating teaching strategies in general.

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