KNOWLEDGE MAPS IN PROCESS ENGINEERING DESIGN: A STUDENT’S APPROACH

Abdallah M. Hasna

Abstract: Chemical engineering majors learn to convert raw materials into products; as a result of this specificity, higher education in chemical engineering offers many opportunities and challenges to become more attuned with e-learning and incorporating learning tools. These challenges include providing modern didactic methods in process design courses. In addition instructions in process design courses need to reflect the challenges students may possibly face in industry. In order to instigate a new mode of students thinking in process design we basically need students to switch roles from the existing role of being a student to a practicing engineer’s thinking that requires a global construct. Therefore the main focus may be directed on better communication skills in process design curriculums. This paper proposes the uses of knowledge maps in process design learning as an important aspect of cognition and fundamental constructs of theories in the mind. Given that the construction and reconstruction of meanings by learners requires that they actively seek to integrate newly acquired knowledge with existing knowledge. It’s not surprising that knowledge maps particularly concept maps offer a visual aid to integrate knowledge that would uniquely equip students with a well-structured process for developing active knowledge and the ability to implement critical thinking. Mindful of the limited instructional aides available in chemical process design curriculum this paper describes an approach to introducing students to knowledge maps in process design. The pedagogical basis for this approach is discussed. This work calls for pedagogic re-engineering in process design teaching and learning process by providing students with proficiencies in knowledge mapping tools to enhance communication between design stakeholders to adopt needs based approach over one based on ever increasing consumption. The graphical communication, mapping, process diagrams approach are described, and illustrated with examples i.e. concept map, PBFD, PFD, design logbook notes as an operational framework for conveying complex technical information. The results obtained from using mapping approach are described which demonstrate meaningful learning in written communication.

Keywords: knowledge maps, student development, process engineering and design

1. Introduction
Chemical Engineering education traditionally has had in roots in the 19th century bulk production industry requirements, when economic growth was the main target in development. The past half century chemical engineering education was based on analytic (science) model (Zakowska, 2004). In the early decade of the 21st century we are witnessing chemical engineering education transform towards a holistic and more integrative, multi-disciplinary that is concerned with sustainability. Similarly chemical Engineering class rooms are undergoing major restructuring caused by the rapid progress in information technology. Recent proliferation in computer simulation and modeling makes it simple to introduce Computer Aided Learning (CAL) into everyday teaching practices at chemical engineering. Drawing is the universal language of engineering, in chemical
engineering, as well as in other scientific and technical domains, where one or more materials are physically or chemically transformed, a process is represented in its abstract form (Dobre and Sanchez Marcano, 2007). This topic has been treated previously by a number of chemical engineering educators, however it remains a tricky issue to unpick explicitly. We will begin by providing an explanation of concepts of knowledge map and cognitive map in process design learning and teaching framework, we then describe the concepts of design communication and design communication tool. Finally the context of process engineering design is illustrated by a case study.

2. Learning and Teaching philosophy
Typically, teachers carry a hidden background of beliefs and assumptions that lead them to choose, or accept, certain modes of teaching (Plain, 1998). Similarly, discussion on educational reform into preferable chemical engineering teaching methods has come to dominate academic circles. Traditionally, exam-oriented teaching methods consist of lectures that focus on centralized textbooks common in chemical engineering. The word method describes processes and techniques used by a teacher to communicate information to the student.

Traditional teaching in chemical engineering generally gravitates towards lecture format in comparison with other disciplines such as humanities and social sciences, which lean more toward the discussion format but are by no means the only ones. Similarly, the question of “content verses process” is a topic that perhaps horrifies some and is misunderstood by many others. “If I have a solid technical base, I will automatically be a good teacher”. Some hold the view that teaching is about a way of thinking and doing, rather than subject, and hence teaching method is so much more important than content-subject. Actually, there must be substance, but the tragedy is that in so much teaching the subject is all there is. Without the “process,” without an effective teaching method that takes into consideration the learner, the subject matter becomes of little significance (Butterworth, 1966). Effective aspects of teaching are more important than method (Hanna and McGill, 1985). This discussion further explores the concept of “Good teachers are born and not made”. Affective components which appear to be critical for effective teaching include: Cognitive: mental skills valuing learning; A student-centered orientation; Affective: emotional areas, a belief that students can learn; Physical skills A need to help students learn. The metaphor Leaping from being students to becoming Engineers, uses integrated learning (Rehman and Said, 2005) which relies on three equally important levels of whole student development, structured design experience, guided design experience, and open-ended design experience, which also relates to Bloom’s taxonomy of educational objectives Knowledge, Attitude and Skills. The connection between whole student development and teaching and learning philosophy is also explained Bloom’s taxonomy for details please refer to (Bloom, 1956).
3. Debunking the Stereotype

There are many misconceptions, misapprehension and stereotypes about what engineers are or do in western society (Beder, 1989) and particularly chemical engineers. In support of this view, we call up Fralick et al. (2009) research that found that most of 1,600 middle school students from urban and suburban schools in the southeastern United States drawings of engineers depicted a human, while approximately one-third portrayed no person at all. Similarly, Williams (2004) referred to the image of engineers depicted as spending long hours working alone in a cubicle filled with empty pizza boxes and soda cans, eminently conservative (Mazmanian and Lee, 1975). To the contrary of most cited stereotypes describing chemical engineers as works alone in laboratory or office. In reality, chemical engineering is a social multidisciplinary endeavor according to Byrne and Fitzpatrick (2009). Chemical engineers spend a large part of their day collaborating with teammates. Chemical engineering is a social multidisciplinary endeavor, interacting with engineers from all other disciplines, customers, business managers, etc. The roles of chemical engineers vary from industry to industry but it is generally required that chemical engineers must be able to professionally, communicate project status and results to constituencies at team and client levels including verbally, textually, poster, Process Flow Diagrams (PFD), Piping and Instrumentation Diagrams (P&ID), datasheets, reports, and finally drawings to provide clarity on numerical values and dimensions of design calculations.

4. Design curriculum

Designing is decision making on an alternative course of action. Where decision making is a sequence of stages linked by feedback loops; each stage has alternative solutions or possible courses of action which the next stages are the objects of comparative assessment and choice(Alexander, 1982). Chemical engineering and process engineering are interchangeable terms describing chemical process plants. Chemical engineers are primarily interested in process systems engineering in which the systems approach is employed in the design and operation of chemical processing plants (Huckaba and Monet, 1963). The chemical-process engineer is the link between product design and production. Chemical engineering plants consist of a series of unit operations used to produce a material in large quantities. Process Engineering is concerned with the development of techniques and tools to address the generic manufacturing problems of design, operation and control for the process industries (Perkins, 2002). With that in mind, chemical engineering curriculum should reflect real life industry challenges, since an important goal of the undergraduate curriculum in chemical engineering is to develop the integration, design, and evaluation capabilities of the student (Lewin et al., 2002).
In order to discuss the development of design skills in engineering students using an integrated learning approach, first there is a need to classify these approaches; typically it consists of structured, guided, and open-ended design experiences. For example, we have embedded a number of design communication activities in two engineering design courses to achieve a comprehensive skill set, to replicate an industry environment. These activities include Process Flow Diagrams PFD’s or Piping and Instrumentation Diagrams (P&IDs), straightforward graphical illustrations that in most cases need little explanation. The symbols used by engineers are more or less the same in any language, even if one is unable to read the descriptive text. This discussion delves into components of good teaching practice in chemical engineering design. Why teach knowledge maps in engineering design? Engineering design uses graphics as the language of communication all over the whole world (Zakowska, 2004). The main outcome of teaching communication tools in chemical engineering design is to achieve realization of engineering design practice through hands-on experiences and graphical modeling “Teaching by asking instead of by telling”. Generation of fundamental physical and chemical data (e.g. properties of a new chemical in aqueous/non-aqueous systems) as shown Table 1.

<table>
<thead>
<tr>
<th>Process</th>
<th>Properties</th>
<th>Utility</th>
<th>Safety</th>
<th>Equipment</th>
</tr>
</thead>
<tbody>
<tr>
<td>Extraction</td>
<td>Thermodynamics</td>
<td>Transport and</td>
<td>Process Control</td>
<td>Chemical Reactors</td>
</tr>
<tr>
<td>Absorption</td>
<td>Fluid and Particle</td>
<td>High Pressure Boiler</td>
<td>Construction</td>
<td>Liquid-Solid</td>
</tr>
<tr>
<td>Distillation</td>
<td>Dynamics</td>
<td>Feed Water</td>
<td>Process Safety</td>
<td>Operations Solid-</td>
</tr>
<tr>
<td>Adsorption</td>
<td>Reaction Kinetics</td>
<td>Cooling Water</td>
<td>Sustainability</td>
<td>Solid Operations</td>
</tr>
<tr>
<td>Ion Exchange</td>
<td>Gas and Gas-Liquid</td>
<td>Instrument Air</td>
<td>Waste Management</td>
<td>Heat-tran</td>
</tr>
<tr>
<td>Evaporation</td>
<td>Psychrometry</td>
<td>Plant Air</td>
<td>plant performance</td>
<td>Efficiency</td>
</tr>
<tr>
<td>Cooling</td>
<td></td>
<td>Low Pressure Steam</td>
<td>analysis</td>
<td>Conversion</td>
</tr>
<tr>
<td>Drying</td>
<td></td>
<td>Nitrogen</td>
<td></td>
<td>Process Economics</td>
</tr>
</tbody>
</table>

Table 1: design parameters

Raw material quality that is at specification and consistent is a key requirement in unit operations where raw materials are converted into valuable products. Information on raw materials, products and process data is required for reliable unit operations calculation, i.e. material balances and process diagrams, information on the feed stream properties is required to assess composition, properties and specifications of raw materials in process feed stream include but limited to data shown in Table 2.

<table>
<thead>
<tr>
<th>Component</th>
<th>Molecular Weight</th>
<th>Mass fraction</th>
<th>Specific gravity</th>
<th>Mole flow rate</th>
<th>Density</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Average Molecular Weight</td>
<td>Boiling point</td>
<td>Mass flow rate</td>
<td>Mole Fraction</td>
<td>Pour point</td>
</tr>
</tbody>
</table>

Table 2: stream data

5. Modes of design communication

Using knowledge maps in chemical engineering programs is a potential design communication tool. Often one can reduce a real-world problem to a purely simplified process that provides a picture of the relations, which is often much more revealing than a list of points. Graphical design communications benefit the student by illustrating the problem that chemical engineers may need to solve in an attempt to convert thinking into visual communications to forms a visual bridge between an idea and its creation. Drawings are the written language through which the design ideas are transmitted (Belofsky, 1991).
Process design is central to chemical engineering; consequently, knowledge maps to chemical engineering is what a word processor is to words and writing, as it indicates the general flow of plant processes and equipment. Similarly, there are many different process drawing and mind mapping software tools on the market today. Many engineering companies require their designers to know and use several different CAD software tools. Engineers must be prepared to accommodate the client’s preference of CAD programs. In today’s marketplace, the pipe drafter and designer should learn how to use drawing communications (Parisher and Rhea, 2002).

**Table 2: Assessment Strategy**

<table>
<thead>
<tr>
<th>Assessment Description</th>
<th>Category</th>
<th>Weight</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 Round table discussion</td>
<td>Pen and Paper</td>
<td>5%</td>
</tr>
<tr>
<td>2 Gantt Chart</td>
<td>Task</td>
<td>5%</td>
</tr>
<tr>
<td>3 PFD process flow diagram</td>
<td>Presenta...</td>
<td>5%</td>
</tr>
<tr>
<td>4 Research Seminar</td>
<td>Presentation</td>
<td>5%</td>
</tr>
<tr>
<td>5 Modeling: Hysys, Aspen, Ansys, abaqus, mat lab, solid works</td>
<td>Pen and Paper</td>
<td>10%</td>
</tr>
<tr>
<td>6 Equipment sizing: Mathematical calculations</td>
<td>Report</td>
<td>10%</td>
</tr>
<tr>
<td>7 Design for Assembly: practical, experiment</td>
<td>Mixed Skill</td>
<td>5%</td>
</tr>
<tr>
<td>8 Computer Aided Drawing</td>
<td>Pen and Paper</td>
<td>5%</td>
</tr>
<tr>
<td>9 Individual student design</td>
<td>Presentation</td>
<td>5%</td>
</tr>
<tr>
<td>10 Technical poster</td>
<td>Report</td>
<td>5%</td>
</tr>
<tr>
<td>11 Final individual project: includes literature review</td>
<td>Report</td>
<td>30%</td>
</tr>
<tr>
<td>12 Final project defense: Panel Discussion</td>
<td>Presentation</td>
<td>10%</td>
</tr>
</tbody>
</table>

**Figure 2: Classifications of cognitive maps (Scavarda et al., 2004)**

Typical design communication skills acquired in class activities in these courses include:

- Students learn hand sketches of process, equipment and develop the ability to build a flow sheet for a given chemical process.
- The University of Michigan has some helpful methodologies on problem solving supported by Fogler (2006) companion website. These exercises typically begin with the student writing out the problem statement using any one of knowledge maps listed in Figure 1 to prioritize options. These options can include information on what to solve, and consider why the need to solve the problem.
- Draw and label Knowledge map define and name all variables and/or symbols. Show numerical values of variables if known.
- Identify and name relevant;
- Principles, theories and equations, Systems and subsystems, Dependent and independent variables known’s and unknowns, Inputs and outputs, necessary (missing) information.
- The design parameters listed in Table 1 are some of the key areas required to establish the design and contribute towards the desired attributes of a chemical engineer, an
engineer should be able to: create a concepts (Magee, 2004), use graphics (Boeing, 2003) to define the stated problem.

6. Course Assessment Strategy
Assessing what students learn during a chemical engineering design course is a difficult task. Course assessment is both a teaching method and a set of techniques. Three key parameters spring to mind when preparing available assessment strategy resources, educational background of the students, and allotted teaching time. There are shortcomings with most common assessment methods. Although a written test might assess content or process knowledge, it will not capture or reliably assess the practical and teamwork skills that are built up during a group design project (Hey et al., 2006). We have devised a unique mix of assessments consisting of 12 components as shown Table 3 because student thinking is far more important than content of the curriculum. Each component contributes to the overall assessment in this course. Although some of the components have small weight, each section is compulsory. The assessed components are listed in Table 3. It is important to select the method and structure which will help the learner accomplish their full potential. Discussing the patterns of assessments with students has lead to better learning environment with the students.

Presentations: The presentations were used to serve as a form of progress report. Typically engineers prepare project reports for supervisors, conferences or coworkers, which are reviewed in group settings. This provides advantages of developing confidence in presentation skills.

Final Report preparations: Students were advised that the most effective method to convey their technical information was via sample calculations accompanied with some discussion in support of their calculation methods. Student reports included text drawings, photographs, calculations, graphs, tables, appendices of supporting data. The students developed their reports over the two semesters.

Design notebooks, log books: The students were required to make notes of workshops activity, guest lectures, group activities, tutorials and lectures. Because much of the learning occurred outside class time, progress was monitored via log book. Log books served twofold: it was another form of written communication. It also served as evidence of students’ progress and efforts for assessment purposes; Journal entries described the how, when, by who; why certain decisions were made; data source; it recorded assumptions made; it provided the evidence of work development to safeguard cases of plagiarism.

Provision for student learning Design Studios: Design studios (DS) is an approach that brings the focus back to the learner as the centre of learning with real-life work situations as a part of the training process. In this method, students developed problem-solving skills for lifelong learning, studio-styled learning models have evolved from the master-student relationship of the classical apprenticeship (Armarego and Clarke, 2004). Typical infrastructure required is network access, land line telephones, email access, roundtable and suitable seating. This style of education model is well documented by the following universities McMaster, Canada, Aalborg, Denmark, Delft the Netherlands.
7. Case Study: process description
This section will contribute towards the strategy of changing student's mindset, i.e., the metaphor leaping from being students to becoming engineers. Most industry problems in the engineering world are typically presented as "text problems" and as interdisciplinary. Hence, chemical engineers must be trained and prepared to tackle a problem like process material balance from the description. One simple technique is to find the solution by making a list of what processes are in use. Why do we need to go with the selected process, what chemistry is involved if any? What economics are involved and where will the feed material come from? Is it an ethical purchase? What temperature and pressures are involved? Some of this detail may seem somewhat excessive at this point; however it attempts to simplify the problem at hand. For example, the olefins conversion unit consists of two towers. Deethylenizer: separates unreacted ethylene the tops are moved to recycle the C2. The bottom of this tower feeds the second tower (Depropylenizer), where it produced a polymer grade propylene overhead product and a bottom C4-plus stream that is sent to the purification section. Figure 4 represents simple olefins conversion flowcharts to show the main material routes through the process (lines and arrows) and to depict the main operations (blocks).

8. Discussion
The premise of engineering education is to graduate engineers who can design, and that design thinking is complex (Dym et al., 2005). Knowledge maps allow students to learn the principal of process diagnosis and convert numbers into real output. Engineering education that ignores nonverbal thinking will produce engineers who are dangerously ignorant of the many ways in which the real world differs from the mathematical models constructed in academic minds (Ferguson, 1994). Consequently, previous research has indicated university level teachers assume a certain level of prior knowledge which may or may not be possessed by students (Bunting et al., 2006). Similarly, It is a fair hypothesis that engineers are practical “can-do people,” after all our profession is about the application of science. Hence most engineers tend to think and learn visually, and find drawings are often useful. An important first step in addressing nearly every engineering problem or design is to represent the situation graphically (Wickert, 2005) which plays into Intellectual Quality (IQ) indicators, the descriptors of the distinctive characteristics of authentic intellectual work as high order thinking, deep knowledge, deep understanding, substantive conversation, knowledge as problematic and meta-language (Elgezawy, 2008).
• Dimensioned drawings of equipment
• 3d CAD render drawings of equipment
• Graphs of equipment performance
• Independently gather information to create physical and chemical properties summarized in a data table and present in an individual written report.

Similar methodologies were also reported by Gadala-Maria (Gadala-Maria, 2001) where;
• students worked in groups and reported both orally and in writing on the flow sheet, major pieces of equipment.
• Prepared conclusions and recommendations on a problem with global and societal implications.

Knowledge maps were used to describe a process precisely so that it could be evaluated. Each is useful to convey different types of information. In a domain specific task, these communication skills were used to number streams, list operations/equipment sequence, arrange the process using standard symbols, simplify the process description using a labeled flowsheet, assign algebraic symbols to unknowns (compositions, concentrations, quantities). Typically flowsheets were used as schematic representations to describe the operating details of a chemical process, these details include: arrangement of equipment, interconnections, movement of material, stream connections, stream flows/quantities, stream compositions, operating conditions. A number of basic flowcharts types were used to define the problem: (block diagrams, process flowsheets (or Process Flow Diagram), piping and instrumentation diagrams (PID).

The primary goal of the exercise was to teach design and develop students’ critical thinking skills. One way to achieve this goal was through knowledge maps. Typically, chemical engineers will use any of following tools to define or illustrate any process: Process Flow Diagram (PFD), Piping and instrumentation diagram (P&ID), process description, and dynamic process simulation. Students were given a number of processes to explain details of operation using fundamentals of how the process works, and also to visualize this using a process flow diagram. The purpose of this design exercise was to apply or practice what was learned in other courses, i.e. to join fragmented courses. This weekly one on one session promoted homogeneous learning in which students continuously experienced design practice and gained design skills across the curriculum. In fact, in most cases, we realized that students were learning some of these concepts for the first time. Furthermore, it created a platform to apply the development of teamwork and communication skills in all modes, i.e., written, verbal, and visual communication, were exercised through written reports, and oral presentations.

Embedding knowledge maps in chemical engineering design presented an opportunity for students to work with others on real life problems, collaborate on a team, and convey technical information in written format. It also encouraged team discussions. This was the true test of knowledge, since all educators are interested in teaching critical thinking to their students. This method of teaching avoided the common pitfalls of exam-oriented educational patterns, which yield the inevitable result of teaching just for the sake of testing, better explained with the phrase “teaching to the test.” Thus, true engineering is found in applying known scientific concepts for practical solutions. Accordingly, hands-on practice requires little use of lengthy equations. True creativity is born in common sense; we as engineers gather information about technical data.
9. Conclusion

Our experience with knowledge maps served as a communication tool in this course and presented a number of advantages, namely increased supervision flexibility and assessment accuracy, as students were graded for their method, and not the final numerical value in material and energy balances. Students were required to present their maps during consultation sessions. Similarly, students developed other transferable learning skills, and in particular developed a capacity for independent learning and for communicating instructions and sharing information with colleagues. Students had an opportunity to conduct self-paced instruction and independent study. The presented methods amplified the students’ hands-on skills in engineering design by requiring students to substantiate their ideas in a knowledge map and thus promote students’ awareness of fundamental thermodynamic principles in design concepts. The concept maps enhanced the written quality of the final student presentations and technical report, as it offered simple account of process. It also connected whole student development by providing visualization aids to enable chemical process skill development and learning. Students were observed using it during technical discussions. Students developed their own learning ability. In particular, they developed a capacity for independent learning in self-paced study. The presented method enhanced students’ hands-on skills, stimulated students’ interest in process design and promoted students’ awareness of integrated design concepts. Finally I will end this with a question that has haunted me for many years: Yes we can design instruction, but can we design learning?

10. References


11. Acknowledgements
The author wishes to acknowledge all students, staff and technicians who participated in these two courses, with a special acknowledgement to Mr. Baskaran Pandian and Ms Candida Fernandes for their invaluable assistance.