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Designing the New Global Chemical Engineer

Universities around the world are tackling different pieces of the teaching puzzle to transform students into ideal chemical engineers.

Teaching the principles of chemical engineering to produce the ultimate product — the well-rounded chemical engineer — is one of the most innovative and continually evolving challenges. Universities have to teach the science as well as the art, figuring out ways to engage students and teach them how to use the principles versus simply applying a procedure to arrive at a solution. The following are examples and challenges of universities that are modernizing their curriculum to produce the type of chemical engineer the world and industry need in the new millenium.

Back to the basics

With so many different technology areas emerging within chemical engineering, how much university preparation is necessary for students to be able to work in industry and to meet a company's objectives? Dr. S. Ganeshan, President of the Indian Institute of Chemical Engineers, addresses this question from both the academic and industrial points of view through his positions as an adjunct professor at the Indian Institute of Technology, Bombay, and as general manager at Toyo Engineering India Ltd.

In the 1967 movie "The Graduate," Benjamin Braddock is advised to take up a career in plastics: "That's the future, son." Plastics, after all, define us and the modern world. However, chemical engineering may look very different in the near future, instead transformed by the emerging new environment that requires technology specialization.

Ganeshan explains that chemical engineering is different from other engineering disciplines because the design and analysis occur on processes instead of products. "The uniqueness of chemical engineering is that, unlike the other branches of engineering that are all derived exclusively from physics, it is the only discipline that also leverages the unique powers of chemistry to solve engineering problems. Chemical engineering is the only discipline that manipulates material at the molecular and atomic levels. A student of chemical engineering needs to spend a lot more time building the basics, which will include large dollops of chemistry. Of all engineering streams, chemical engineering has the most in common with such new sciences as biotechnology and nanotechnology. Chemical engineers are best positioned to exploit these sciences, for the betterment of life."

Ganeshan also says that in the past, engineering was ahead of the basic science and it was very often necessary to explain why a particular process performed as it did. Engineering was highly empirical. Today, however, science is ahead of the engineering. Hence, chemical engineers need to be provided with the necessary tools to enable rigorous analysis of processes, regardless of the science. With the necessary tools, the chemical engineer then has the wherewithal to apply them to the emerging fields. This, Ganeshan believes, should be introduced at the graduate level. Otherwise, exposing students to the emerging fields without equiping them with a basic toolkit will not be productive.

"Today the stress is more on the new engineering, which is not a bad thing in itself, but unfortunately it is coming at the cost of basic knowledge. This is the pitfall that we need to avoid. We need to stress basic engineering and chemistry," Ganeshan urges.

The new chemical engineering has come full circle. It was developed from chemistry, became more "engineering," and now it returns with a focus on chemistry — in particular, surface chemistry, electrochemistry, colloidal and interfacial chemistry, and biochemistry and enzyme chemistry, he notes.

"Chemistry defines us. It is our claim to exclusivity. It is why we are different. It is why we are. We must ensure a firm foundation in the basics at the undergraduate level and leave specialization to the graduate degree. We must say to the young chemical engineer, 'Go back to the basics, son.'"

Cooperative problem-based learning and "inventioneering"

How to teach the basics is another piece of the puzzle that has been considered by faculty at Bucknell Univ. A "best practices" approach has been utilized to help prepare chemical engineering students in their first course of the curriculum, material and energy balances. Professors Tim Raymond and Michael Hanyak have incorporated an active, cooperative, problem-based learning (PBL) environment into the course.

The course consists of five two-

week projects where students work in teams to complete problems covering a range of materials and, simultaneously, practice teamwork and professional skills. Additionally, each project involves a complex laboratory experiment and use of process simulation software.

"Our goal regarding teaching and learning has always been for the instructors to be a 'guide by the side' rather than a 'sage on the stage,'" says Raymond. "One of the many goals of our course is to teach to all the students and all of their many preferred learning styles, while providing them the guidance and support they need to succeed. This includes communication and presentation skills, teamwork skills, laboratory experience, etc."

Previously, the course taught basic material content with no lab component; work and homework were completed with problems assigned from the textbook. The new course takes a problem-based, minimal-lecture approach, incorporating team-based labs and projects, supplemental materials, independent learning, and field trips. This format teaches typical mass and energy balance content while providing a support network and addressing teamwork skills and different learning styles.

A two-hour class held three times per week involves a mini-lecture that discusses key concepts and a class activity to study example problems. Students are given projects that involve a complex laboratory experiment and the use of process simulation software. Students rotate through all four team problems and see each problem by the end of the course. The labs and field trips offer hands-on and real-world applications, and student presentations develop communication skills.

Raymond explains that "you can't do it all in class, so the approach is learning by doing." The course focuses on application with guidance and feedback. Each student is accountable and keeps individual documentation in a journal. Exams are used to confirm the students' learning.

In some traditional chemical engineering curriculums, the mass and energy balances course has been used to "weed" students out of the program. "I believe it is a serious mistake to attempt to 'weed out' students through an intentionally difficult or overly intense course," replies Raymond. "Students admitted into the university and college of engineering are there because they have already proven (via high school classes, SATs, etc.) their ability to perform well in math and science. It is our goal to turn them into engineers," he says.

"Much of the competitiveness of the United States in the future global markets will rely on not simply our math and science skills, but rather on our ability to think critically, creatively and outside the box, and to work in interdisciplinary teams that often include non-engineers. By giving a 'weed-out' course, we would be losing many great students who may not grasp the abstract and mathematical concepts immediately, but who otherwise have much to offer our discipline in terms of creativity and global thinking. Students learn through a variety of methods, and to 'weed' them out based on learning styles (or any other method) before giving all students a chance to demonstrate what they have to offer would be a serious mistake."

In a comparison of the traditional versus PBL approaches using the same content, exam scores indicated better retention and deeper learning of the material by students in PBL classes. In addition, the independent learning and teamwork skills the students gained better prepared them for future courses and industry.

Using the concept of PBL as the foundation, Paul Sides, professor at Carnegie Mellon Univ., conceived an experiment for his transport laboratory course that allows students to own their results — invention-based learning, or inventioneering, as he calls it.

Sides hypothesized that through an opportunity to invent, students would be able to generate ideas for products or processes, they would be able to generate a working prototype or demonstration in six weeks, and they would learn more because they owned the project in a way qualitatively different from assignments of the past. The focus of the experiment was to provide students with the opportunity to invent, analyze, realize, and document new products and processes, motivate them to use and assimilate the knowledge to which they had been exposed, seek the knowledge they needed, and learn how invention connects to the commercial world.

When the concept was announced to the junior-level class, Sides says that no groans greeted the news and several students visibly awakened. One even wanted to know who owns the intellectual property. This was the first indicator that ownership had been conceived, he says.

"The ownership aspect of the project worked wonders. The students were several times more engaged and active than in previous years, where the experiment was open-ended but they were given the problem," says Sides. "Students are full of creative ideas — more than I knew or guessed. When I gave them the assignment to invent something, I had a few ideas in reserve in the expectation that some groups would falter when asked to be original. None of my reserve ideas were necessary. The most enjoyable time of my previous year was the half hour I spent with each group, where we heard their ideas and batted them around with the students. Learning was occurring in an environment that was equal parts real and academic."

Each team was required to invent a

product or process based on a principle of momentum, heat, or mass transfer. The team had to demonstrate a working prototype within the six weeks remaining in the semester. They were also required to make a poster that described the idea, the technical underpinnings, prior art, and an assessment of how well it works. In addition, each team had a budget of $1,000 to spend on its invention.

"The overall goal was actualization of concepts of transport phenomena. The students showed much ingenuity, but they had to be reminded continually that what they had learned in class might be relevant to their designs. The gulf between principles of engineering and their thinking processes with regard to their inventions remained wider than I wanted all the way to their poster presentations. Making sure they bring their academic toolbox more directly to bear on their thinking will be the main thrust when we teach the class again this spring," adds Sides.

"Students invented and realized their inventions with far more enthusiasm than for past assignments. We found a formula for engaging the students and will be repeating the project in subsequent years," he reports.

Software integration

As computer technology has advanced, so have software computational and modeling capabilities. In addition, companies rely on modeling software to maximize their resources and profits. Thus, a new challenge is raised that Professor Anthony Dixon, of Worcester Polytechnic Institute (WPI), has encountered and explored.

"I think one of the major challenges we have to face is how to teach the applied mathematics that chemical engineering students need for their engineering work. I remain convinced that this is best done by engineers in the context of the application, but a challenge to us as educators is how much to teach of the traditional analytical approaches versus using new software-based approaches, such as COMSOL. Furthermore, if we use software, how do we get students to use it intelligently and critically, and not as a black box?"

Dixon incorporated the COMSOL software package into a course in mathematical modeling for chemical engineers. This led to three questions: Are the students getting the appropriate background to use the software? Are the students effectively being taught how to use the software? And are the students being taught to be informed and critical users of computer packages?

Dixon explains that engineering students need to learn how to formulate mathematical models of physical situations, how to obtain useful solutions to the model equations, and how to correctly interpret and present the results. For chemical engineers, the second step in this sequence frequently involves the solution of ordinary or partial differential equations describing transport phenomena and/or reacting systems. This has traditionally been accomplished by analytical methods, such as Laplace transforms or Fourier series expansion in eigenfunctions.

When, how much, and what type of computing should be included in the undergraduate chemical engineering curriculum are ongoing matters of interest. "It is essential that students not lose sight of the physical and chemical phenomena being modeled, the assumptions behind the mathematical models, or the need to verify and validate the computational methods applied to the problem," explains Dixon.

Similar concerns have been raised regarding the use of process simulation software to carry out the extensive material and energy balances for a process design. "Successful implementation of these advanced computer tools may require a refocusing of course objectives and skills taught, and a restructuring of the curriculum. In addition, the tendency of students to accept computational results as being true must be guarded against. It is important to teach students to examine computer output critically and to question the results of their efforts," he continues.

To implement the software program into the mathematical modeling course, instruction took place in a computer lab and was based on a "watch and do" method where the instructor solved a demonstration problem and then students undertook a worksheet problem on their own with the instructor's help. The students also used the program for homework exercises and an "in-lab" exam, in which they solved a problem similar to one of their homework assignments, under reasonable time constraints. Some limited background theory in the finite-element method was provided in the form of lectures and handouts, in parallel with the software lab sessions.

A statistical analysis of student responses to end-of-course survey questions and exam questions was performed. Dixon reports that "the students appear to be learning how to operate the COMSOL program quite satisfactorily. But their skills in setting up problems and in becoming discriminating users of the technology are less well developed, and will motivate some changes in the curriculum for the next offering."

Teaching soft skills

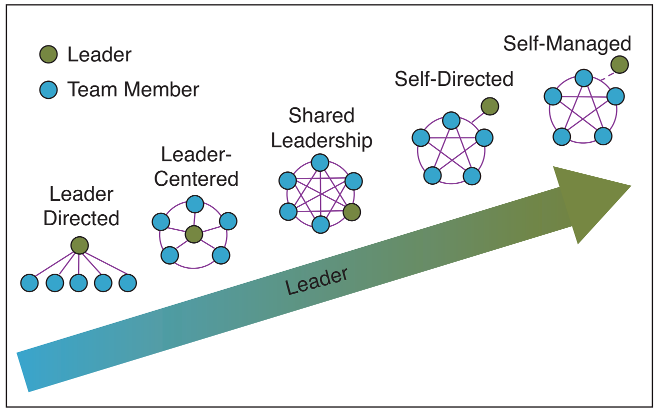
The chemical engineering environment has become global and one that demands both technical competencies and soft skills. But, do universities really need to teach conflict resolution, teamwork, leadership, etc.?

Professor Laureano Jiménez, of the Univ. Rovira i Virgili (Tarragona, Spain), believes that they do. In addition to technical knowledge and management competence, chemical engineers need to possess social skills. These skills need to include teamwork, cooperation, creativity, innovation, communication, cultural diversity, leadership, decision-making, and organizational development. They must be versatile and customer-oriented, he explains.

An educational module was developed and implemented to transition first-year chemical engineering students into a comprehensive project-based learning environment. All first-year students participate in an integrated design project with fourth-year students. In partnership with Dow Chemical, a set of short training courses was designed to support the development of various competencies (Figure 1).

"In the new educational system, student teams grow from leader-directed teams in the first semester of the first academic year to self-directed or empowered teams in the fifth year of the curriculum. In this empowerment journey, fourth-year students play a key role acting as facilitative leaders of first-year and second-year project teams, adjusting their facilitative leadership role according to the team development stage," explains Jiménez.

"The core of the competency-based educational model is client orientation. The need to satisfy clients and to adapt to their changing needs triggers the development of competencies related to the transformation of the individual students (versatility, entrepreneurship and innovation, systems-oriented thinking, etc.), of the organization (facilitative leadership, teamwork and cooperation), and of the institution (organizational development and performance, and organizational leadership)."



■ Short training courses were designed so that students' teamwork abilities led to the development of self-managed teams. Image courtesy of Dow Chemical.

Jiménez defines five essential soft skills that an engineer needs:

• *Teamwork* — contributes to effective team output by cooperation, participation, and a commitment to share vision and goals

• *Leadership* — influences and guides others toward identifying and achieving a vision and goals; provides purpose and direction; motivates and enthuses

• *Communication* — communicates effectively with all people, is able to deal with controversial dialogue, and presents and facilitates varieties of material and meetings

• *Cultural diversity* — deals effectively with conflicts and facilitates reconciliation caused by cultural diversity, based on understanding differences in cultures, norms and value systems

• *Organizational development and performance* — contributes effectively to increasing organizational performance by knowledge about relevant technologies (*i.e.*, strategy deployment, etc.) and their implementation.

"The first-year students' evaluation shows that the module helps them: (1) to identify what they need to accomplish to gain future employment as chemical engineers; (2) to understand what an integrated design project consists of and what the benefits of teamwork are; and (3) to realize that the integrated project and the related teamwork are great opportunities to acquire the competencies that are essential in today's workplace," says Jiménez.

Jiménez summarizes the integrated project as both project-based learning and cooperative learning — created by learning how to learn, integrating and dispersing knowledge, and developing social skills. This is what companies want and look for.

Preliminary results show that student attendance has increased, the dropout rate has decreased, and more professors act as facilitators in the classroom, as the academic staff had to improve their performance as well. The training in nontechnical capabilities helps students to set the pattern to become life-long learners. The open-ended problems and lack of information force students to understand the principles of different unit operations, be active in determining the information that is needed to solve a problem and to seek it out.

Jiménez says the message to take home is that "students remember 20% of what we explain, 50% of what they do in the lab, and 100% of the soft skills." CEP

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