Integrating Chemical Engineering as a Vehicle to Enhance High School Science Instruction

Deran Hanesian, Levelle Burr-Alexander, Howard Kimmel,
Joseph Kisutcza, Reginald P. T. Tomkins

The Otto H. York Department of Chemical Engineering
The Center for Pre-College Programs
New Jersey Institute of Technology
Newark, New Jersey 07102

Abstract

The National Science Education Standards (NSES) support the teaching of engineering and technology principles and design within the traditional science content areas. However, teachers are inadequately prepared to teach these principles of engineering. In addition, most science textbooks lack activities and problems that use engineering principles.

There is an urgent need for in-service training of science teachers that include programs to increase their knowledge of engineering principles and to provide these teachers with the means of introducing engineering principles and design in their classrooms. The relationship between the subjects of chemical engineering and chemistry provides a vehicle to readily enhance currently available curriculum materials, and create connections between the science used in engineering applications in the real world and standards-based science. It can also provide content that fits the instructional classroom needs of high school science teachers.

We have developed an approach to utilize chemical concepts to introduce high school students to the principles of chemical engineering through their teachers. The design of a chemical manufacturing plant forms a viable basis for introducing chemical engineering principles into the high school science classroom. A relevant chemical process, such as the manufacture of Aspirin, is selected. After an overview of the various components of the plant, key components are selected to illustrate relevant scientific concepts in the chemical engineering operations.

Summer institutes, with hands-on workshops, are designed to familiarize the teachers with this approach, along with the appropriate chemical engineering principles and suggested methods for integrating these principles into their classroom instruction. The course is scheduled for eight full days during the first two weeks of July. Teachers are recruited from the New York-New Jersey Metropolitan area through mailings and the Mid-Atlantic region through electronic list serves. In order to be selected, teachers must be teaching high school chemistry, physics, physical science,

or any equivalent course in which they would be able to utilize the material in their classrooms. Otherwise, they are accepted on a first come, first served basis until the desired limit of 15 is reached. Teachers are given a stipend. Throughout the course, the topics in chemical engineering principles are related to the science concepts that are familiar to the teachers.

Introduction and Background

Most high school science teachers are not familiar with the application of science concepts to the practical world of engineering. Hence, there is an urgent need for in-service training for science teachers that include programs to increase their knowledge of engineering principles and to provide those teachers with the means of introducing engineering principles and design in their classrooms. The relationship between the subjects of Chemical Engineering and Chemistry provides a vehicle to readily enhance currently available curriculum materials, and create connections between the science used in engineering applications in the real world and standards–based science. It can also provide content that fits the instructional classroom needs of high school science teachers.

The Pre-Engineering Instructional and Outreach Program (PrE-IOP) is designed to integrate and implement engineering and design principles into middle and high school science curricula[1]. We developed an approach to utilize chemical concepts to introduce high school students to principles of chemical engineering that was first piloted in a summer institute in 2002. This summer institute used a classical format based on the Chemical Engineering Curriculum to introduce the science principles used in chemical engineering[1]. Feedback from the teachers and experience quickly taught us that a different approach was needed to make the material more meaningful to the teachers and their students. One of the suggestions made by the teachers was to take a real process and show how chemical engineers use science principles to develop the process technology for the manufacture of a commonly available and well-known product. Since the typical plant involves multi-step processes, an overview of processes, in general, and chemical processes, in particular, starts with the examination of what a process is. To understand the overall concept of a process, simple processes are explored which take place in well-known systems, such as an automobile and its process units, the engine, starting the engine, cooling system, and the heater-air conditioner (summer and winter). The key components of the automobile are shown as a process flow diagram. A brief overview of this process flow diagram is given in about 15 minutes.

We then develop the concept of a chemical process and how a chemist prepares a new product in the laboratory and how a chemical engineer must take these chemistry concepts and relate them to large-scale production facilities. A short discussion of a simple example of a process given by Solen and Harb[2] is used for this purpose.

The human body allows for the further analysis of the characteristics of a complex chemical process and discussion of sub-processes within the overall process. A more extensive interactive discussion with the teachers using the human digestive system is used. An analysis of the digestion system is made and the basic principles of process control are introduced relating to everyday experiences the students have with their bodies. These concepts, which will be of interest to a high school student, provide the opportunity to look at both physical and chemical processes. The teachers work in groups of two and draw the process flow diagram of the human digestive system. Our concept of the flow diagram of the human digestive system is given to them for comparison after their effort is complete.

In all cases, we look at the entire process of the chosen product from start to finish. Throughout the course, the teachers are divided into groups of two and cooperative learning techniques are used with “hands-on” activities. The teachers are given a notebook with many details for their use as a reference. During the eight days of the program, simplified overviews are presented in class.

The Manufacture of Acetylsalicylic Acid (Aspirin)

We are then ready to look at the manufacture of a well-known product, such as the pharmaceutical, Aspirin. The chemical engineer must create a large-scale flow process with recycle of unreacted reactants, solvents, and their recovery. They must be concerned with the disposal of large quantities of undesirable by-products and waste, pollution abatement and prevention and an operating plant that runs for 24 hours per day, 365 days per year with periodic shutdowns for scheduled maintenance.

Using the Aspirin manufacturing plant, the module focuses on those science concepts taught in high school that are relevant to chemical engineering principles. For relevant processes, different process units are used and the chemical and physical concepts that are involved are identified and related to chemical engineering principles and practices. Diverse topics such as heat transfer, mass transfer, chemical reaction and separations technology are introduced and related to scientific concepts. For example, an overall system material balance based upon stoichiometry must be made. During the discussion of process variables, mass, volume, flow rate, chemical composition (mass fraction and mole fraction), pressure and temperature concepts and relationships are discussed and applied in material balances. The different phases of matter and the ideal gas law come into play. After an overview of the Aspirin process, key components of the manufacturing process of Aspirin are selected to illustrate relevant chemical and physical principles to the Unit Operations.

Process Technology

Acetylsalicylic Acid (Aspirin) is produced in a two-step process by the Schmitt modification of the Kolbe synthesis. Currently, there are many approaches to producing Aspirin. Any chemical process is composed of three principle components. These are:

- Pre-Reaction Physical Preparation Steps
- Reaction Steps
- Post Reaction Physical Separation Steps

The production of Acetylsalicylic Acid is discussed in these three process components, outlining the scientific principles and their related chemical engineering principles. These principles are tabulated for the various Unit Operations used in the Aspirin Process and are given to the teachers.

The key components of the process selected for discussion are:

- the **Heat Exchanger** used to heat the 50% Caustic Soda (NaOH) solution entering the **Mixer**
- the **Mixer** used for contact of the Caustic Soda with Phenol
- the **Dissolution Vessel**
- the Acetylsalicylic Acid **Reactor**
- the separation technology with a focus on the **Crystallization Vessel** and the solvent recovery **Distillation Columns.**

In any discussion of chemical engineering processes, material balances must be considered. **What will be the capacity of the chemical process?** This question is generally known as the design basis. **How do you determine the design basis?** The desired capacity of any production facility is generally determined by a detailed market analysis and what fraction of the potential market one can expect to capture. **How is Aspirin used and by whom?** We assume that largely human beings consume Aspirin. Hence, we assume that there is a direct relationship between the Population of the United States and the amount of Aspirin produced in the United States. The teachers are issued the necessary data and asked to predict the Aspirin requirements in the year of 2025. Once the Aspirin requirements are known, the teachers decide on what percent of this capacity will be produced in the new facility that they will design. Thus, they will know how much Acetylsalicylic Acid (Aspirin) must be produced each year.

Starting with the amount of Acetylsalicylic Acid to be produced each year in the new facility, the teachers back calculate, using stoichiometric principles, the annual needs of all raw material Feed Streams and Products Streams. For simplicity, they assume 100 percent conversion in each reactor and 100 percent yield in each step of the process. Once the annual flow rates are known, they will be able to calculate the hourly flow rates for all parts of the process and begin the design of the specific process units. Similarly, energy balances can be made on each process unit to determine the energy requirements but this exercise is not performed. To provide tools for the teachers to use in the classroom for visualization of the overall stoichiometric chemical process material balances, the Multimedia Module "Material and Energy Balance" developed at the University of Michigan and obtained from CACHE Corporation was used for "hands-on" experience[3].

Energy and Energy Balances

Discussion of a chemical plant requires consideration of energy and energy balances of the process. The First Law of Thermodynamics for closed and open systems is applied to simple problems involving non-reactive and reactive energy balances, heat effects, phase changes, heats of reaction, mixing and solution. The chemistry concepts of thermochemistry, calorimetry, chemical bonds and structure, chemical and physical equilibrium, solutions, chemical reactions, work, and heat are applied to single and multi component systems. Principles of physics, such as vectors, motion, momentum, dynamics, friction, kinetic and potential energy, conversion of work to energy and vice versa, velocity, acceleration, torque, power and gravity are also important in the plant and are discussed. A few thermodynamic cycles including the Carnot engine are discussed to show the relationship of work and heat. Vapor-Liquid, Liquid-Liquid, Solid-Liquid, Solid-Vapor, and chemical reaction equilibrium concepts are also important processes in the manufacturing plant and are discussed. In the Thermodynamics area "hands-on" experiments are performed. The classic "drinking bird" experiment[4] is performed and work is discussed. This demonstation is ideal for the high school classroom. The first and second laws of thermodynamics are discussed using the power plant cycle. An experiment is used to demonstrate the maximum work done to show the concept of reversible and irreversible work.[5] To demonstrate the different modes of energy transfer, an experiment on measuring heat transfer was adopted from a freshman chemical engineering course.[6]

Heat Exchanger

There are many questions that must be answered before the heat exchanger is designed. First, the inlet and outlet temperatures of the Caustic soda must be chosen. Then the proper heating medium is picked and the type of heat exchanger suitable for heat transfer is chosen. Once these questions are answered, the First Law of Thermodynamics is applied and the quantity of heat that is transferred is calculated. When the quantity of heat that must be transferred is calculated the teachers are ready to design the heat exchanger. Throughout the discussion, the teachers see the concepts of enthalpy, kinetic energy, potential energy, heat and work used in the First Law of Thermodynamics. They also realize the importance of temperatures, flow rates and heat capacity in the quantity of heat used. To design the heat exchanger, the teachers are introduced to the concept of an Overall Heat Transfer Coefficient and the temperature driving force and the analogy to Ohm's Law. The type of heat exchanger to be used, heat exchanger area and the logarithmic mean temperature driving force are also discussed. Working in teams of two the teachers are guided through the calculations until the area is determined. Once the area is known, a discussion follows about the geometric details of an actual physical heat exchanger with pictures. The calculation exercise is followed by a "hands-on" laboratory experiment with a Coffee Cup Calorimeter. The simplified discussion of Energy, Energy Balances and Heat Exchanger design takes about one and one half days with chemistry and physics principles, with which the teachers are familiar, constantly related to the chemical engineering principles needed.

The Fluid Dynamics of the Mixer in the Aspirin Process

In Step 1 of the Kolbe-Schmitt synthesis of the two-step Aspirin process, Phenol is mixed with the hot 50 % by weight Caustic Soda (NaOH) to produce the salt, Sodium Phenolate, and water as the first step in the preparation of Salicylic Acid. The addition of the Phenol and hot NaOH is essentially an acid-base reaction and in large vessels, requires good mixing to enable the two phases to contact each other and the reaction to Sodium Phenolate to be as rapid as possible. Good mixing requires good agitation and a well-designed vessel. **What is agitation? What is mixing?** Agitation and its objective good mixing are perhaps one of the oldest and most common operations in chemical engineering practice in the chemical and other processing industries. Agitation can be defined as the forcing of a fluid material by some mechanical means, usually a motor driven agitator, to flow in a circulatory or other pattern in a vessel. Mixing, on the other hand, means taking two separate phases, such as the Phenol and hot Caustic Soda, and making them randomly distribute through one another.

The discussion of agitation and good mixing in a large plant vessel is different from agitation and good mixing in a small laboratory flask. The teachers soon see the problem of chemical engineering, which is given little thought by the chemist in the laboratory. The teachers are introduced to the flow patterns in a large vessel, the problem of a vortex and baffles, and types of impellors. The dimensionless Power Number, which is needed to determine the agitator power requirements, is based on the basic physics concepts of force and lever arm to produce a torque and the agitator revolutions per unit time. The dimensionless modified Reynolds Number, which is needed to develop adequate flow patterns in the vessel and the use of both of these dimensionless numbers for scale-up to a large vessel is discussed. The teachers become aware of the basic scientific principles needed for good mixer design. They realize the importance of fluid physical properties of density and viscosity and the importance of the physical concept of rotational motion and angular velocity. They also realize the importance of good empirical experience in chemical and mechanical engineering design.

Dissolution of Disodium Salicylate in the Dissolving Vessel

The dry Disodium Salicylate, $Na_2C_7H_4O_3$, salt (some of the literature references refer to it as Sodium Salicylate, $NaC_7H_5O_3$) is flushed with water from the Autoclave to the Dissolver. More water is added to the Dissolver to complete the dissolution of the salt to form a solution. In addition, activated carbon is added to remove any color in the solution by the process of adsorption. The teachers are asked, **what is dissolution? What is a solution?.** To learn about dissolution, we must understand the underlying scientific principles of solubility and solutions. **What is solubility?** Solutions are homogeneous mixtures of two or more substances, and can occur in the solid, liquid or gas phases. In this case, we are interested in the solution of Disodium Salicylate, the solute, in water, the solvent. The quantitative description of solutions is concentration in any of the many various units. **What is solubility?** Solubility is defined as the concentration of a saturated solution, in which the solute can no longer dissolve. A solution in which the concentration is less than the solubility is called an unsaturated solution. One with a greater concentration than the solubility is supersaturated. The teachers very quickly see the concepts that they teach their students being applied in the dissolution process.

The solution process is complex and depends upon the chemical and physical concepts of solute-solute, solvent-solvent and solute-solvent attractive forces and the change in the disorder, which occurs with good agitation and mixing. The process of a solute dissolving in a solvent can be exothermic or endothermic. The solubility of a solid solute in a liquid solvent is temperature dependent. Pressure has very little effect on the solubility of a solid in a liquid. Whenever, a solute is brought into contact with a solvent, the attractive forces of the solvent, which are enhanced by the thermal motion of the solute particles, cause the structure of the solid solute particles to break apart and to disperse the ions or molecules from its surface into the solvent. This is analogous to the vaporization of a liquid into a gas. Thus, these ions or molecules enter the solvent and form a solution of the solute in the solvent. The teachers are introduced to the application of the concepts of diffusion and mass transfer, which is analogous to Ohm's law, a science principle that is familiar to them. Mass transfer involves a concentration driving force and a resistance, or its reciprocal, conductivity, which is given by the empirical mass transfer coefficient. The teachers realize the analogy between heat and mass transfer and the application of basic chemical and physical concepts, since both the heat transfer and the mass transfer coefficients are presented to them in the context of the resistance in Ohm's Law.

From these basic scientific concepts, they see that there are many chemical engineering concepts in the dissolution process. One is good agitation and mixing, which involves concepts of fluid dynamics. A second is heat transfer, which results from the energy effects. The third important concept is mass transfer. Following the discussion on dissolution, the teachers perform a "hands-on" experiment in the dissolution of a lollypop.

The Acetylsalicylic Acid (Aspirin) Reactor in Step 2 of the Aspirin Production Process

In Step 2 of the Kolbe-Schmitt synthesis, Acetylsalicylic Acid is prepared by the reaction of Salicylic Acid with Acetic Anhydride. Salicylic Acid is in crystalline form and Acetic Anhydride is a liquid. In order for the reaction to proceed with good molecular contact between reactants, a mutually suitable solvent such as Toluene is used. We also previously discussed that every chemical process consists to the pre-reaction physical preparation steps, chemical reaction steps and the post-reaction physical separation steps. Although it is important to optimize the design of a chemical reactor, it is the optimization of the entire process, particularly the post-reaction physical separation steps that can decide on the economic feasibility of the chemical process. However, the post-reaction physical separation steps depend on the effectiveness of the chemical reaction steps. The teachers soon realize the importance of the reaction steps in the overall process economics.

For the chemical reaction steps, chemical kinetics and chemical reactor design are the important aspects of producing almost every industrial chemical. In fact, it is primarily the knowledge of chemical kinetics and chemical reactor design that distinguishes the Chemical Engineer from other engineers. The reactions may be either homogeneous of heterogeneous. The selection of the type of chemical reactor and its design to enable the safest and most efficient operation can result in the success or failure of a chemical plant. Therefore, for the Chemical Engineer, the knowledge of chemical kinetics and chemical reactor design is of paramount importance.

The teachers are introduced to Chemical Reactor Design. The Chemist working with the same chemical reactions that a chemical engineer is working with does not encounter the problem of reactions in large reactors. For example, the mixing in a small laboratory flask is much more rapid then the mixing in a large chemical reactor. There are other factors that are important. The Chemist is interested in reaction time to achieve a desired conversion of reactants. So is the Chemical Engineer. However, the Chemical Engineer is as much interested in **batch cycle time** because it is the total time to complete one batch cycle in a chemical reactor that will determine the production rate of your product. It takes time to fill a large vessel, heat it to reaction temperature and then following the reaction, cool, empty and clean the tank. These operations involve the basic concepts used in fluid flow and heat transfer and the related chemical concepts. Various types of industrial reactors are discussed. The teachers are shown how the concepts of reaction rate law, concentrations of reactants and the Arrhenius equation, which they teach in their courses, is used by the chemical engineers to design a reactor.

Following the discussion of reactor design, the teachers perform a "hands-on" experiment to study the rate of progress of a chemical reaction by boiling potatoes of about the same size for different boiling times, cutting the potato in half and noting the diameter of the uncooked part and its relation to the original diameter of the potato. Hence, the progress of the reaction, or conversion of the reactant, can be followed.

Post Reaction Physical Separation Techniques - Crystallization of Acetylsalicylic Acid

The Acetylsalicylic Acid is in solution and the reactor contents are transferred to cooling tanks to recover the Acetylsalicylic Acid by crystallization. The teachers are asked, **what is crystallization?** We have seen already that crystallization is the reverse process of dissolution. **What happens during the crystallization process?** Crystallization is the formation of solid particles within a homogeneous phase. Crystallization occurs by the formation of solid crystals from a liquid solution, which, in this case, is the deposition of Acetylsalicylic Acid (Aspirin) crystals from the liquid contents of the Acetylsalicylic Acid Reactor that are fed to the Crystallizer. This latter process is very important commercially because of the large number of materials, which are sold in the crystalline form. When a solution is cooled, it first reaches saturation, its solubility limit. At this point, further cooling will result in crystal formation. These crystals are pure after washing. Thus, crystallization affords a good, practical method of obtaining pure chemical substances, which after washing and drying are ready for packaging and the market. The teachers recognize the application of the concepts of solution and solubility that they teach.

In a crystallization process, yield, purity, sizes and shapes are important. One chemical compound will crystallize in one crystal structure or it can crystallize in two or more different classes depending upon the conditions of crystallization. For example when Sodium Chloride, ordinary table salt, is crystallized from water it forms a cubic structure. Acetylsalicylic Acid forms white crystals, which are commonly monoclinic needles, when crystallized from water. It can also be a white powder. From an organic solvent, like isoamyl alcohol, flat platlets are formed. Crystal structure is very important for many products. There are seven classes of crystals that are taught in basic courses. These are cubic, tetragonal, orthorhombic, hexagonal, monoclinic, triclinic system and trigonal. The scientific concept of the solubility of a material with temperature is of paramount importance. As the mother liquor solution, as it is called, is cooled, equilibrium is reached when the solution becomes saturated or reaches its solubility limit for the temperature. Many times a solution is cooled to its solubility limit for the temperature and no crystals will appear with further cooling. The resulting solution is called supersaturated. Chemical engineers in the design of a crystallization process apply all all of these basic scientific concepts, which are taught in science courses.

Whenever crystallization occurs in any homogeneous mixture, a new solid phase is formed. It is important to understand the mechanisms by which crystals form and grow. These basic scientific concepts are important in designing and operating crystallizers. There has been a great deal of experimental and theoretical work done by scientists and engineers to understand crystallization. The process of crystallization consists of the basic scientific steps of nucleus formation and crystal growth. Together, these two steps determine the crystal size distribution (CSD) in a crystallizer. When a solution is free of all solid particles, nucleus formation must first occur and then crystal growth can begin. The driving force for nucleation and the growth steps to occur is supersaturation and these two steps cannot occur in a saturated or undersaturated solution.

Crystallization theory is complex. There are three important forms of nucleation and the rate of nucleation has its base in the theory of chemical kinetics. The thermodynamic differences between small and large crystals are important. A small crystal has a significantly larger amount of surface energy per unit mass than a large crystal. Hence, a small crystal has greater solubility than a large crystal. Since ordinary solubility applies to large crystals, in a supersaturated solution a small crystal can be at equilibrium, its solubility limit. If a larger crystal is also present, the larger crystal grows and the smaller crystal dissolves. Hence, the effect of particle size is important in crystallization.

Crystal growth is a diffusion process and depends on the solid surface on which it grows. The solute molecules or ions in solution reach the solid surface by diffusion as they move through the liquid phase. Hence mass transfer is an important concept in crystallization. The mass transfer coefficient is important in this step. When the molecules or ions reach the crystal surface, they must be accepted into the crystal lattice. This reaction occurs at the surface at a finite rate. The overall process is one of two steps, diffusion to the surface and acceptance into the crystal lattice. Throughout the discussion of the crystallization process, the teachers recognize important basic scientific concepts that they teach in their courses and the application of these concepts by chemical engineers. A simple experiment to crystallize sugar is given to the teachers for their classroom and laboratory use, but is not performed by the teachers in class.

Post Reaction Physical Separation Techniques - Distillation

In the production of Aspirin, the mother liquor leaving the crystallizer contains toluene, acetic anhydride, and acetic acid. How are these materials to be separated and recovered for recycle to the process for reuse? The most common method of separating liquids is distillation. The teachers are asked, **what is distillation?** The simplest system has a single stage, the boiler and the condenser. We have all performed this simple distillation in the chemistry laboratory. Unfortunately, distillation in a large chemical plant is more complex and is very energy intensive, especially for separations of compounds with similar boiling points. The chemical industry relies heavily on this separation technology.

What is distillation? We know that all chemical compounds in the liquid phase will exert a vapor pressure at a given temperature and any two chemicals in the liquid phase will have individual boiling points at a given pressure. We know that at normal, standard pressure of 760 mm of Hg, the normal boiling point is reported. The difference in boiling point, or vapor pressure is the basis of the separation technique that we call distillation. If two compounds have a wide difference in boiling point at a given pressure, the vapor pressure will be widely different, and the relative volatility will be large. Hence, for this case, distillation will be simple and very useful as a separating technique. Conversely, if two liquids boil at near the same temperature at a given pressure, the vapor pressures will be similar, the relative volatility will be small and separation by distillation will be more difficult. **What is relative volatility?** In simple concepts, it is the ratio of the vapor pressures of two compounds at the same temperature. Thus, if we have two liquid compounds at a given temperature, their respective vapor pressures will be P_A^o and P_B^o. The relative volatility of component A with respect to component B will thus be $\boldsymbol{\alpha_{AB} = P_A^o / P_B^o}$**.** We also know that when the molecules of two liquids are relatively similar, about the same size, and there are no complicated effects when they are dissolved in each other, such as molecular association, chemical reaction, etc., the mixture is ideal. Under these conditions, Raoult's Law and Dalton's Law apply. When the relative volatility is equal to 1.0**,** separation by distillation is not possible and a requirement for distillation is that the relative volatility must be greater than 1.0. The closer the relative volatility is to 1.0, the more difficult will be the separation by distillation. The teachers quickly realize that the important concepts of vapor pressure, and its variation with temperature, Raoult's Law, Dalton's Law, which they teach, are needed by chemical engineers to design distillation systems on a large scale. Different types of large-scale distillation columns are discussed.

Evaluation

The evaluation included teacher feedback on the workshop itself, and assessment of impact on the teachers' classrooms.

The overall ratings of the workshop by the teachers were a unanimous excellent. During the course evaluation, some interesting comments were made. The teachers enjoyed

- The activities related to chemistry or the curriculum and the application of chemical engineering
- The demonstrations, Lab tours and the discussions
- The intimate contact between the Faculty and the High School Teachers
- Being made aware of the scale-up process from chemistry to the plant scale
- Breaking down a complex process into small steps (Unit Operations), the visualization of components in a plant and to be able to recognize them.

Some of the teachers found the mathematics, which is very important for the chemical engineer, somewhat difficult to follow, particularly for distillation. The teachers feel that they will modify their science courses based upon what they learned in this workshop. A unanimous recommendation was to include more "hands-on" activities that the teachers can take back to their students. This transfer of information will allow their students to do more "hands-on", problem-based learning such as drawing the flow diagrams with the computer and to perform more experiments related to the chemical processes. During the course, the teachers understood the basic concepts taught in a simplified manner as indicated by the questions asked during their interaction with the faculty. At the end of the course, the teachers were asked to write a plan on how they will incorporate the material presented in their classroom.

The likely-hood of classroom implementation by the teachers was measured by post-workshop surveys. Follow-up in the classroom is now taking place. The primary post-workshop instrument was a "Readiness to Teach" survey developed for all professional development programs offered through PrE-IOP. The survey is meant to ascertain the teachers' confidence that they will be able to teach the topics discussed in the workshop. There are four possible choices for each topic:

1. I would have to start from scratch.

2. I would need more training to teach the topic.
3. I would have to look at my notes.
4. I could teach a lesson on the topic tomorrow.

For most of the topics, the teachers indicated that they would have to look at their notes, or could teach a lesson on the topic tomorrow. Response number 2 was selected by some participants on only three topics “mass transfer”, “process dynamics and control”, and “process and plant design”. This is not surprising since these are topics not normally included in the high school curriculum. It also suggests that we should try alternative approaches to these topics in future workshops. Surprisingly, all participants indicated that they “could teach a lesson tomorrow” on “Thermodynamics”. This could be due in part to our approach which is qualitative, rather than mathematical, and the discussions are always in terms of real-world applications.

Summary

By focusing on these six examples of unit operations in the Aspirin manufacturing process the teachers realize the relevant scientific concepts that they teach to their students and how these concepts are used in the design of Chemical Engineering Unit Operations. These materials provide discussion subjects in their classroom of practical applications of the basic scientific concepts that the students are learning and these materials aid in addressing the state content standards. Most important, is the focus on teaching the pre-engineering skills of design and problem solving needed to convey the skills and knowledge required for successful admission to undergraduate engineering education programs. The summer institutes, with “hands-on” workshops are designed to familiarize the teachers with this approach along with the appropriate chemical engineering principles, and suggested methods for integrating the basic concepts and their application into their classroom instruction.

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DERAN HANESIAN received his B. ChE. and Ph.D. in Chemical Engineering degrees from Cornell University in 1952 and 1961 respectively. He was employed at DuPont and then started teaching at NJIT in 1963 and served as Chairman of the Department of Chemical Engineering, Chemistry and Environmental Science from 1975-1988. He is the recipient of numerous awards and in October 2000, he was designated in the inaugural group of five **MASTER TEACHERS** at NJIT. He is a Fellow and Emeritus Member (52 years) in the American Institute of Chemical Engineers and a Fellow and Life Member in the American Society of Engineering Education.

LEVELLE BURR-ALEXANDER is the Project Manager for Instruction for the Pre-Engineering Instructional and Outreach Program and serves as the NJ Affiliate Director for Project Lead The Way®. She has degrees in Chemistry and Biomedical Engineering, and is currently completing her Ed. D. in Curriculum Development and Systemic Change. Ms. Burr-Alexander has nearly two decades of experience in curriculum development and implementation of educational programs for educators and students in science, mathematics and technology.

HOWARD KIMMEL is Professor of Chemical Engineering and Executive Director of the Center for Pre-College Programs at New Jersey Institute of Technology. He has spent the past twenty-five years designing and implementing professional development programs and curricula for K-12 teachers in science and technology. At the college level, he collaborates on projects exploring teaching methodologies and assessment strategies in first year college courses in the sciences, engineering, and computer science.

JOSEPH KISUTCZA received his BS in ChE from Newark College of Engineering in 1972 and his MS in ChE from NJIT in 1979. He has 35 years of industrial experience in both process design and development areas. He has worked for CE Lummus and Givaudan-Roure. He has been an Instructor for the senior design course and other senior classes at NJIT since 1997.

REGINALD P. T. TOMKINS is Professor of Chemical Engineering at New Jersey Institute of Technology. Dr. Tomkins has extensive experience teacher training and curriculum development for secondary school science and technology courses, as well as at the university level. In addition, he is direction of the ChIME (Chemical Industry for Minorities in Engineering) summer program for 7th and 8th grade students, and is co-director of the New Jersey Chemistry Olympics.