Interactive, Modular Experiments and Illustrative Examples to Integrate Pharmaceutical Applications in the Chemical Engineering Curriculum and K-12 Outreach Programs

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abstract

Rowan University, in collaboration with the National Science Foundation (NSF) funded Engineering Research Center for Structured Organic Particulate Systems (C-SOPS), continues to develop teaching modules and problem sets to introduce students to engineering concepts in the particle and powder technology of pharmaceutical processing and drug delivery systems. The Center is hosted by Rutgers University and also includes Purdue University, the New Jersey Institute of Technology, and the University of Puerto Rico in Mayagüez. The goal of the Center is to become a national focal point for developing structured organic particulate systems used in pharmaceuticals and their manufacturing processes. Rowan University has partnered as an outreach/education member institution to develop teaching modules for K-12 and college level students. The Rowan University efforts have focused on mobile, hands-on teaching modules, problem sets and illustrative examples. Mobile, self-contained experiments in V-mixing, pneumatic conveying, particulate deagglomeration and segregation, and hopper flow have been designed, constructed and integrated in chemical engineering courses and K-12 outreach efforts. Experiments involving the statistical analysis of pharmaceutical tablet compositions, fluidization of excipients, pharmacokinetics/pharmacodynamics, drug delivery using environmentally sensitive polymers, and strip film drug delivery have been developed and integrated in lower and upper level chemical engineering courses. Illustrative examples to teach life cycle analysis concepts in pharmaceutical processes have also been developed. This work will highlight some of the experiments and educational modules and present methods to integrate them in the engineering curriculum and outreach efforts. The new teaching modules and demonstrations presented here add to the material developed over a five (5) year collaboration with the NSF funded C-SOPS. This collaboration can serve as a model for the development of teaching materials and outreach efforts in engineering education.

The self-contained, mobile educational modules and illustrative examples give students the opportunity to learn technologies important to the pharmaceutical and chemical industries and to apply foundation chemical engineering principles. The completed educational materials will be incorporated into the C-SOPS website for use by Center members and faculty at other schools. This work will serve to expand and strengthen the educational impact of the Center in the region and throughout the country. It also serves to integrate important technologies in the chemical engineering curriculum and enhance the understanding of and interest in engineering among K-12 students.

introduction

For over five (5) years, Rowan University faculty members have been engaged as Educational Outreach Partners with the NSF-sponsored ERC on Structured Organic Particulate Systems hosted by Rutgers University (with member schools: New Jersey Institute of Technology, Purdue University and University of Puerto Rico-Mayaguez). The goal of this educational partnership

has been to develop and disseminate undergraduate materials related to pharmaceutical technology and to seek ways to integrate this into the undergraduate engineering curriculum.[1-3] Pilot testing at Rowan University, including the use of some of the materials in the Freshman Chemical Engineering course at the State University of New York-Stony Brook,[4] has yielded positive assessment results. This work has resulted in the development of classroom problems, laboratory experiments and demonstrations that can be used throughout the undergraduate engineering curriculum and for K-12 outreach. The results have been disseminated through ASEE conference papers, the ASEE Chemical Engineering Division – CHED Summer School for Faculty.[5] Problem sets developed through this work appear in undergraduate engineering textbooks.[6]

Particulate systems can be found in more than 90% of pharmaceutical and chemical processes.[6] Laboratory experiments and demonstrations that include particulate systems is an excellent way to integrate particle technology into the traditional engineering curriculum and familiarize students with this important technology and the pharmaceutical industry. The pharmaceutical industry employs one in eight chemical engineers, second only to the chemical process industry. The expanding role of chemical engineering in pharmaceutical production demands the inclusion of pharma-related concepts in chemical engineering courses throughout the curriculum. Successful curriculum improvement requires a new approach to integrating concepts of batch processing, solid-liquid separation techniques, solid-solid particulate processing, drug formulation and delivery, and technology at the nano-scale. Students must have a solid grasp of chemical engineering fundamentals and the perspective necessary to work successfully side-by-side with pharmacists, pharmacologists, medicinal chemists, and materials chemists in this highly multidisciplinary field. The field of pharmaceutical engineering is quite broad and involves the manufacture of the active pharmaceutical ingredients (API) and drugs in the final dosage form as well as their therapeutic delivery. The interface of pharmaceutical science and chemical engineering is crucial for understanding the basis of structured organic particulate systems (SOPS), a term that describes the multi-component organic system that comprises a drug, nutraceutical, and any medicinal formulation.

The workshop modules highlighted here can be used as part of traditional engineering courses, in specialty topics courses and in K-12 outreach efforts. The team-based interactive approach practiced at Rowan University has been shown to significantly enhance student learning and interest in engineering and technology. The integration of industrial technology in the undergraduate curriculum has served to familiarize students with important industrial applications of concepts learned in the classroom. In addition, the work described here has been an important component of outreach efforts to increase interest in and preparation for engineering studies among K-12 students.[1,3,5-7]

educational modules and demonstrations

Each educational module is self-contained and can be adapted for use in traditional undergraduate chemical engineering courses and K-12 outreach efforts. The modules include interactive team-based activities that promote inquiry and collaborative learning.

The introduction of engineering principles in the first year curriculum is an important aspect of this work. Engaging students and guiding them in the selection of their major is a key element of the Rowan University first year experience. Simple experiments that can be used at the first year level were the focus of modules involving the reverse engineering of asthma drug delivery devices, statistical analysis of pharmaceutical tablets, adhesive properties of bandages, fluidization of excipients, pharmacokinetics/pharmacodynamics of APIs, and strip film drug delivery. Experiments and problem sets on sustainable healthcare practices are currently in development.

first year educational modules

Asthma Drug Delivery Experiment: Through this experiment, students learn about reverse engineering strategies and drug delivery product designs. Student teams conduct a basic quality control analysis on the dosage delivered by various asthma medicine devices. These include an ADVAIR DISKUS®, nasal sprays, and metered dose "rescue" inhalers. The goal is to investigate the transport processes employed by each delivery system, and to ascertain if it is possible to improve the diskus® design. A quality control study on the packaging of powder in the diskus® is also part of this module. This includes a statistical analysis of the mean and standard deviation of the individual doses delivered. Results from experiments involving the diskus® are described here. The complete laboratory procedure and sample results are available through the pharmaceutical knowledge and training website, www.PharmaHUB.org, in the Teaching Resources section.

The ADVAIR DISKUS® is a dry powder inhaler with two active pharmaceutical ingredients (API) prescribed to patients with asthma and chronic obstructive pulmonary disease (COPD). Fluticasone propionate, one of the two, is a corticosteroid, which is used to reduce lung inflammation. Salmeterol, the second ingredient, is a bronchodilator, which relaxes the muscles in the airways to improve breathing.[8] Asthma is the tightening of the airways in the lungs leading to wheezing, shortness of breath, coughing, and a tightening in the chest.[9] The ADVAIR DISKUS® is available in several dosage strengths of both APIs and is prescribed based on a patient's diagnosis.

Reverse engineering of the diskus® was the first part of the experiment. Students reviewed the patient information sheets and operating instructions provided in the diskus® package. This is a good opportunity to introduce students to the regulatory aspects of the pharmaceutical industry, as the package inserts contain other medical information. Students were asked to brainstorm how the device delivers specific amounts each time it is used. After reviewing the operating instructions and a physical inspection of the unit, students discovered that the medicine is released by pressing down the dispensing lever and that the drug is inhaled from the mouthpiece. At this point, students were provided with small tools to dissect the device. They observed that the diskus® opens like a clam shell, and the inside of the diskus is hollow, with several gears that work to release the drug from the folder (Figure **1**).

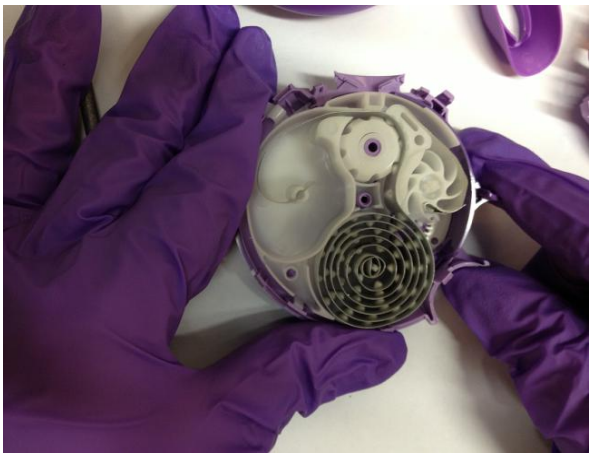

Figure 1. Diskus® internal dispensing mechanism

Based on the initial examination, students are asked to determine how the inhaler works. They ascertain that powder containing blisters are not punctured. Instead, the device is designed to rip the foil strip blister packets open using the lever. Pressing the lever tears the blister pack open, which releases the powder that is inhaled from the mouthpiece. This method protects the integrity of the other doses used on subsequent days. The device tested contained 60 doses. Throughout this experiment, students were encouraged to photograph the diskus® at various stages of disassembly for their laboratory write-up.

The second part of the experiment involves the determination of the mass of drug delivered in each dose. Students must fully disassemble the diskus®, so that the drug blister packet roll is available for analysis (Figure **2**). The individual blister packs were cut open with an Exacto® knife and each dosage carefully placed onto weighing paper with a spatula. Table 1 shows data for ten samples with a mass mean of 12.8 mg and a standard deviation of 0.281 mg. Data analysis can include a box-and-whisker plot to determine any outliers.

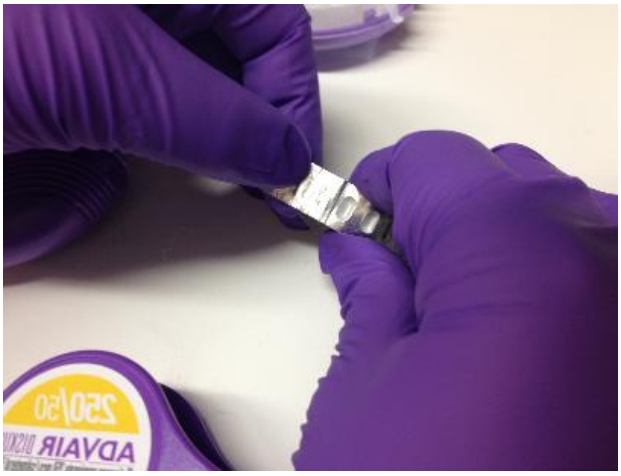

Figure 2. Individual blister from the drug dispensing mechanism in diskus®

Table 1. Analysis of individual dosage amounts in the diskus®

Diskhaler Trial	Mass (g)
1	0.0130
2	0.0130
3	0.0127
4	0.0132
5	0.0126
6	0.0123
7	0.0130
8	0.0129
9	0.0124
10	0.0130
Mean	0.0128
Std. Dev.	2.81E-04

Students were asked to speculate how the mass of the drug dose relates to the actual dosage of the APIs. The Advair dry powder inhaler, as described on the product label, contains lactose in addition to the two active ingredients, fluticasone propionate and salmeterol. Lactose is used to enhance the API aerosolisation and delivery to the lungs.[10] It is inexpensive, relatively tasteless and benign to humans in most cases (unless allergic).The diskus® used in this experiment contained 0.250 mg fluticasone propionate and 0.050 mg salmeterol, for a total of 0.30 mg of API. The remainder, 12.5 mg, is the excipient lactose. This experiment can also include comparisons with the other two drug delivery devices, a nasal spray and a meter dose inhaler (MDI). Students quickly identified the differences in drug delivery mechanisms and ascertained that the diskus® is the most accurate delivery method. A complete discussion of the mechanism and statistical comparison of the three devices can be found in the laboratory write-up on www.PharmaHUB.org, Teaching Resources Section.

The Bandage Comparison Experiment: This experiment allows students to compare the absorption, adhesion and tensile strength properties of three types of wound bandages. Students are familiarized with material properties and material science testing equipment. Adhesive bandages are used for minor surface wounds. One side of the bandage is coated with adhesive material that sticks to the skin. Bandages have a non-adhesive absorbent pad attached to the adhesive side, which helps absorb fluid (blood) that may excrete from the wound. In some cases, this pad will be medicated with an antiseptic solution. The Band-Aid® brand bandage is one of the most popular and commonly sold bandage brands.

In this experiment, student teams compared two generic store brands of bandages to Band-Aid® brand bandages. The comparison is based on three characteristics; adhesion, absorbency and tensile strength. Sample results are presented here. The complete laboratory procedure and sample results are available through the pharmaceutical knowledge and training website, www.PharmaHUB.org, Teaching Resources Section.

Bandages were first prepared for measurement by removing the absorbent pad. Another group of bandages were cut into rectangular pieces with an equal amount of adhesive material on either side of the absorbent pad. Students recorded the length and width of each bandage.

Absorption measurements involve determination of the equilibrium mass of water absorbed by the gauze pad. Students measured the amount of water absorbed by the absorbent pad. Next, a viscous fluid (42% glycerol by volume), approximating the viscosity of human blood was used. Results obtained are shown in Table 2.

Table 2 . Data obtained from absorption experiment

Water Runs			
Brand	CVS® - sheer	CVS® - plastic	Band-Aid®
Average Area (in^2)	0.434	0.443	0.585
Average Initial Weight (g)	0.083	0.081	0.103
Average Final Weight (g)	0.320	0.305	0.292
Average Water Absorbed (mL)	0.237	0.223	0.189
Average Absorption (mL/in^2)	0.601	0.541	0.331
42% Glycerol/Water Runs			
Brand	CVS® - sheer	CVS® - plastic	Band-Aid®
Average Area (in^2)	0.533	0.510	0.644
Average Initial Weight (g)	0.082	0.079	0.103
Average Final Weight (g)	0.334	0.324	0.293
Average Water Absorbed (mL)	0.252	0.245	0.189
Average Absorption (mL/in^2)	0.474	0.481	0.294

Based on this study, the bandage with the maximum absorption rate was the CVS® sheer brand for the water runs, and the CVS® plastic brand for the 42% (v) glycerol runs. For both sets of experiments, the Band-Aid® brand had the lowest average absorption. Thus, the Band-Aid® brand was the least absorbent of the bandages tested. Fluid viscosity appears to affect the absorption rate of the bandages. The data indicate that fluid absorption rate decreases with increasing fluid viscosity. Students were asked to explain these results

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A force testing apparatus was used to evaluate bandage adhesion to porcine skin, a standard model for human skin. The bandage was adhered to the porcine skin so one piece of adhesive side was connected to the skin, while the other was attached to the force test system (

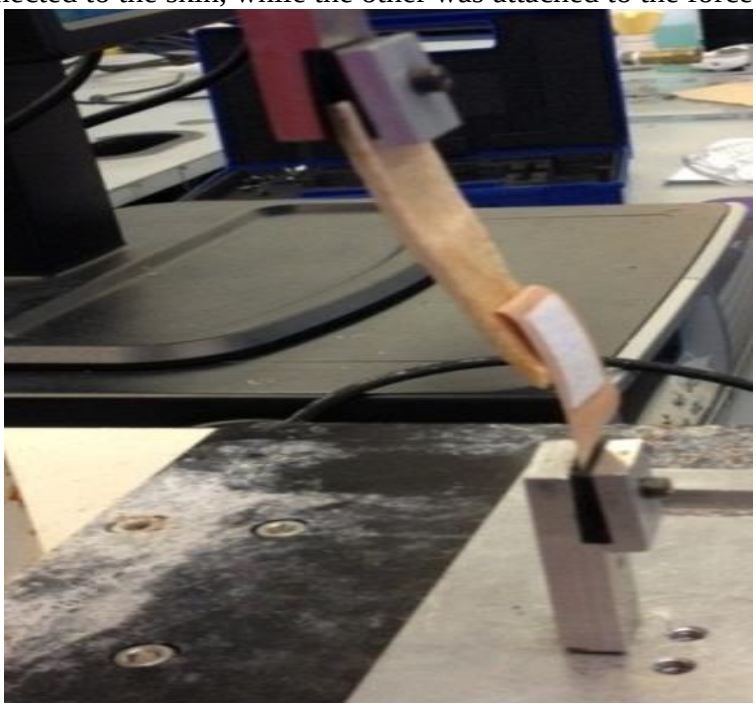


Figure 3). The testing apparatus operated at an upward rate of 20 mm/min and data were collected until the bandage became completely detached from the porcine skin.

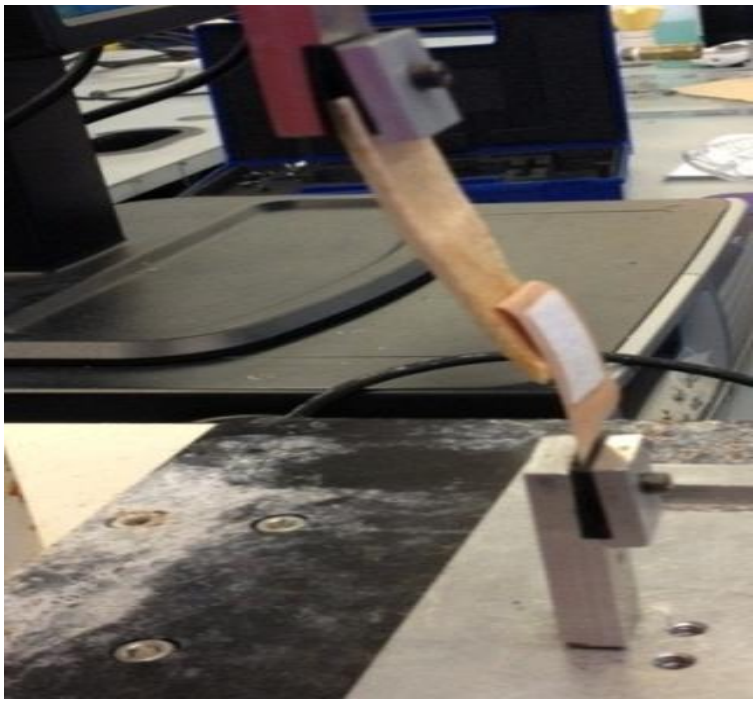


Figure 3. Adhesive bandage attached to the porcine skin in testing apparatus

Students collected adhesion testing data and developed plots of normalized length vs. force (N) for each of the bandage brands (Figure **4** and 5). Students observed and documented trends in the data (e.g., a certain length where the force reaches a maximum, general shape of the data, etc.).

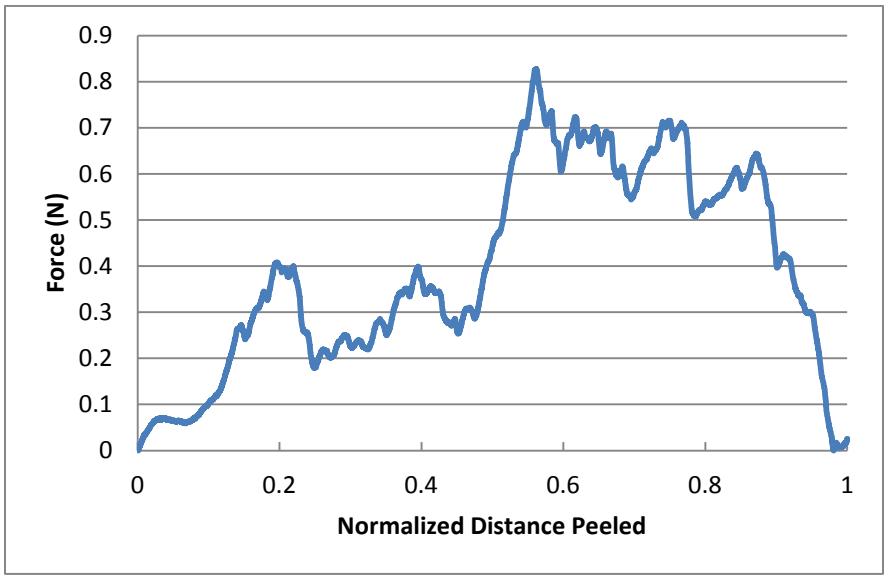


Figure 4. Adhesion properties of the CVS® brand sheer bandage

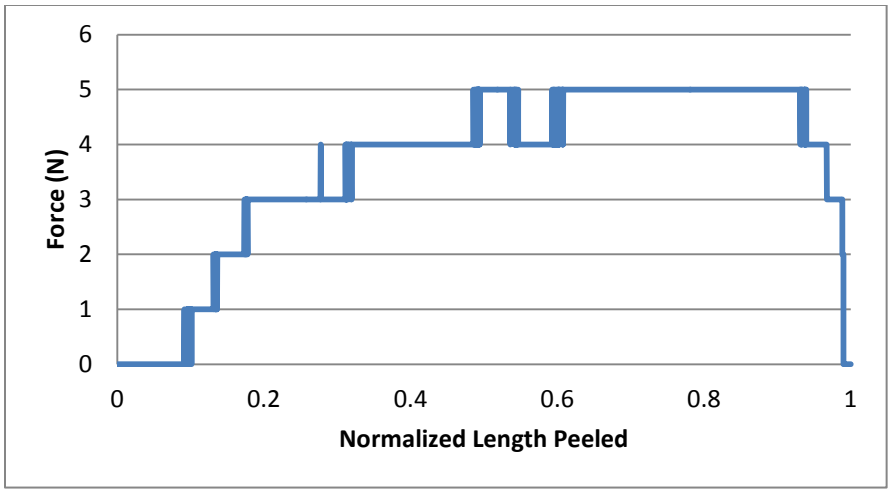


Figure 5. Adhesion properties of the CVS® brand sheer bandage

The graphs obtained show that from the start of experimentation, the force required to peel the bandage increases until it reaches a maximum around a normalized peel length of 0.5 to 0.6. Once this maximum is reached, the force required slowly decreases until a normalized peel length of roughly 0.9 is achieved, subsequently the force required significantly decreases until the bandage is completely removed from the skin.

The tensile strength is measured by moving the adhesive strip at an upward rate of 20 mm/min until completely torn. Typical results of a stress (N/cm^2) vs. strain study are shown in Figure **6**.

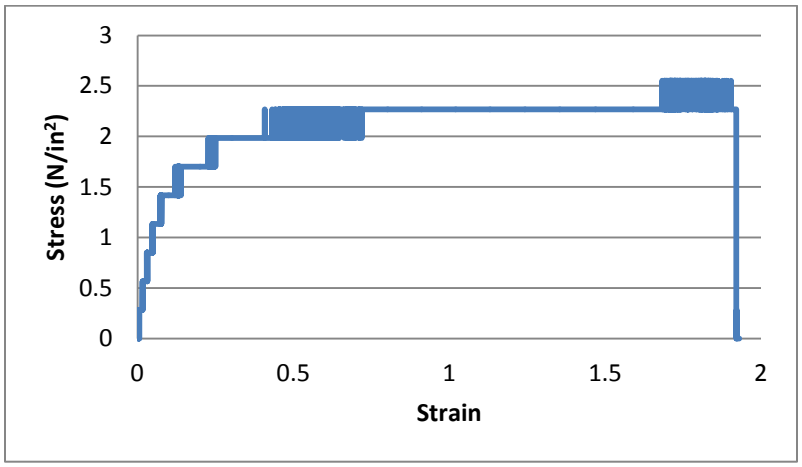


Figure 6. Tensile testing results for the CVS® sheer brand bandage

Students can observe the elastic portion of the material at the beginning of the experiment when a linear stress-strain relationship applies. The modulus of elasticity can be calculated from the slope of the curve in this region. Students can determine the yield point and when rupture occurs. They were asked to compare this stress-strain relationship to literature data for other materials. In addition, adhesion, absorption and tensile properties of other bandage brands can be compared.

upper level educational modules

v-mixing technology module: V- mixers are tumbling mixers widely used in the pharmaceutical, food and chemical process industries to mix powders and particulates.[11, 12] These mixers rotate along a horizontal axis to mix their contents. Figure 7 shows a bench scale polycarbonate v-mixer used for demonstrations. The figure shows the initial set-up with two different colored polymer spheres and the mixed spheres at the conclusion of a mixing experiment. These demonstrations are highly visible, colorful and are highly effective in engaging students in K-12 outreach programs. As part of this work, four of these v-mixers have been designed and constructed. They are operated with a pneumatic motor allowing for variable rotation speeds. This work has been documented and design and construction manuals have been developed and disseminated.[5, 13]

Figure 7: Laboratory scale demonstration V-mixer

V-mixing is introduced with a demonstration of this type and students can speculate on and discuss the variables that impact particulate/powder mixing quality. These qualitative discussions offer critical and analytical thinking opportunities for K-12 students. They can also serve to launch v-mixing investigations for engineering students. For the latter students, a detailed discussion of V-mixing and the convective and shear mixing involved in the process follows. Figures 8 a and b are schematics of the polycarbonate V-mixer assembly and the V-mixer stand designed and constructed for a wide range of applications and mixer loads. As the Figure 8 b shows, the V-mixer rests on a rotating stand. Thus, no torque is directly applied on the V-mixer. The pneumatic motor is connected directly to the v-mixer stand.

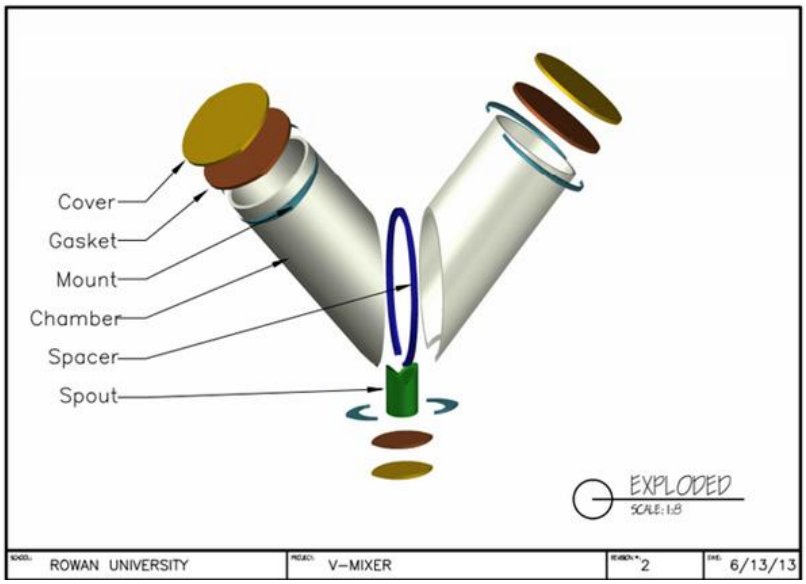


Figure 8 a: V-mixer assembly

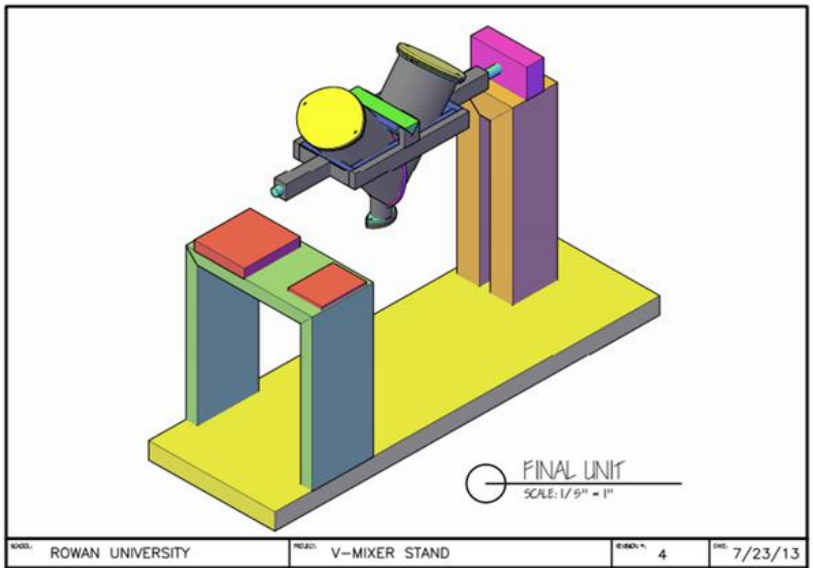


Figure 8 b: V-mixer with rotating stand

The V-mixer shown in Figures 8 a and b was used to study particulate mixing. Students used sugar, table salt and kosher salt (NaCl) for the mixing studies. Samples were taken using an adapted spatula and sample salt concentrations were obtained using conductivity readings from a solution of the sample in deionized (DI) water. Students calibrated the electroconductivity meter using standards with known salt concentrations. They also obtained a calibration relating air pressure to the rotational speed for their V-mixer assemblies. The calibration curve is shown in Figure 9. As the figure indicates, there is no significant difference in calibration for V-mixer loadings ranging from 500 g to 2500 g.

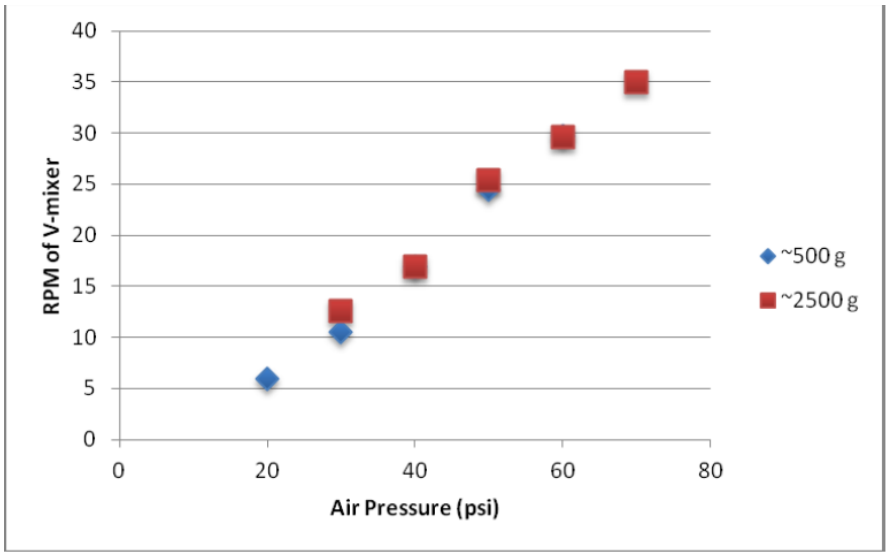
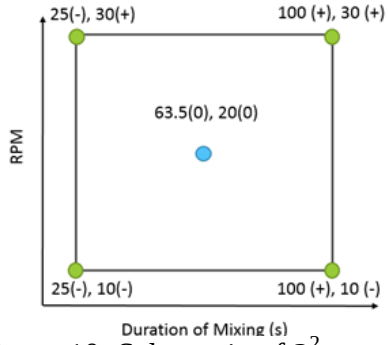


Figure 9: Rotational speed as a function of air pressure calibration

Particulate loadings were 80% sugar and 20% NaCl (by weight) to simulate the active ingredient (salicylic acid) and excipient content in a standard aspirin tablet. A V-mixer loading volume of 50% was used for all experiments. This educational module was multifunctional in that it familiarized students with V-mixing technology and its use in the pharmaceutical industry while introducing them to experimental design and advanced statistical techniques. Figure 10 is a schematic of the 2^2 factorial experimental design and the experimental conditions used by students to investigate the effect of rotational speed and experiment duration on mixing quality.



Experimental Design Conditions

Duration of Mixing (s)	RPM
100 (+)	30(+)
25(-)	10(-)
100(+)	10(-)
25(-)	30(+)
63.5(0)	20(0)

Figure 10: Schematic of 2^2 experimental design and experimental conditions

Mixing quality was measured by computing the difference between measured sample salt concentrations and the results of ideal mixing (20% (w) salt). Figure 11 is a pareto diagram showing the effect of rotational speed and experiment duration on mixing quality. The vertical blue line on the diagram is the minimum significant factor effect (MSFE). Bars on the plot that extend beyond the MSFE indicate a statistically significant variable.

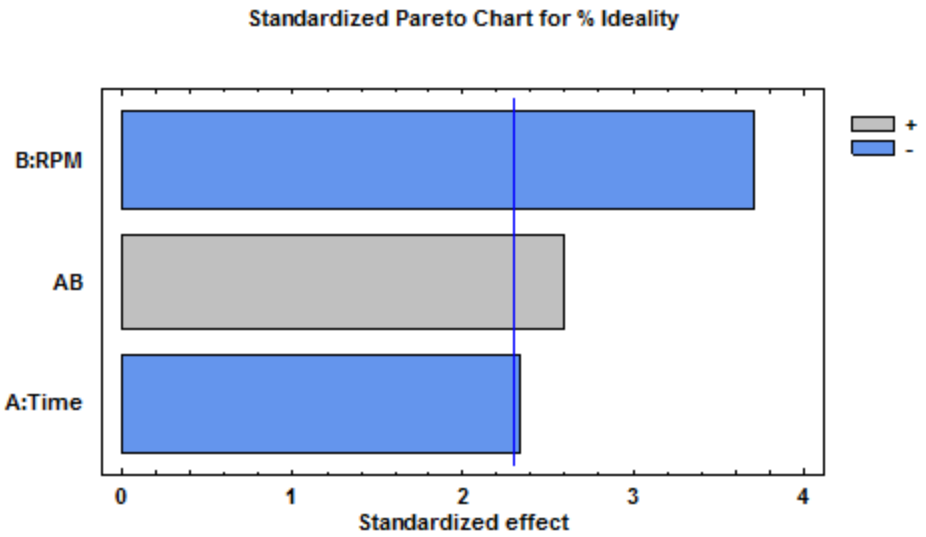


Figure 11: Pareto diagram for table salt results (90% confidence level)

These preliminary results indicate that the interaction between rotational speed and experiment duration enhances mixing quality while each variable, independently, has the potential to decrease mixing quality. These results indicate that it is possible to "over-mix" particulate systems.[11-15] Once the particulates are thoroughly mixed, additional mixing can result in segregation and a decrease in mixing quality. Students were asked to discuss this phenomenon and conduct a literature search to better understand the material which was then discussed in a subsequent class meeting. The V-mixer designed and constructed for this work can be used for a wide range of particulate systems. Table 3 is an ANOVA table showing the effect of salt type (different densities and particle sizes) and number of revolutions in V-mixing experiments.

Table 2: Analysis of variance for mixing quality- (90% confidence level)

Source	*Sum of Squares*	*df*	*Mean Square*	*F-Ratio*	*P-Value*
MAIN EFFECTS					
A:Revolutions	430.858	4	107.714	3.13	0.0248
B:Salt	116.518	1	116.518	3.39	0.0731
INTERACTIONS					
AB	140.424	4	35.1059	1.02	0.4084
RESIDUAL	1376.03	40	34.4007		
TOTAL (CORRECTED)	2265.81	49			

The V-mixer educational module can be used in a wide range of courses and laboratories. As part of this work, it has been used as a unit operations laboratory experiment. In addition to learning basic principles in V-mixing and pharmaceutical applications, students learned experimental design and advanced statistical data analysis techniques.

particle deagglomeration: This module is currently under development. Students will be exposed to an important aspect of particle technology. The module begins with a detailed discussion of the different types of particle agglomerates and models for particle deagglomeration.[16-18] Particle deagglomeration is generally accomplished by flowing agglomerates in a stream of air. Particulate agglomerates are introduced in the system, exposed to air flow and subsequently collected. The flow Reynolds number is a key variable in determining the resulting degree of deagglomeration. A bench scale deagglomerator is being designed to investigate the effect of air Reynolds number and particle properties on extent of deagglomeration. This unit will be used for undergraduate research as well as for class and laboratory demonstrations.

Figure 12 is a schematic of a stepwise deagglomeration mechanism that is proposed for the unit currently being designed.

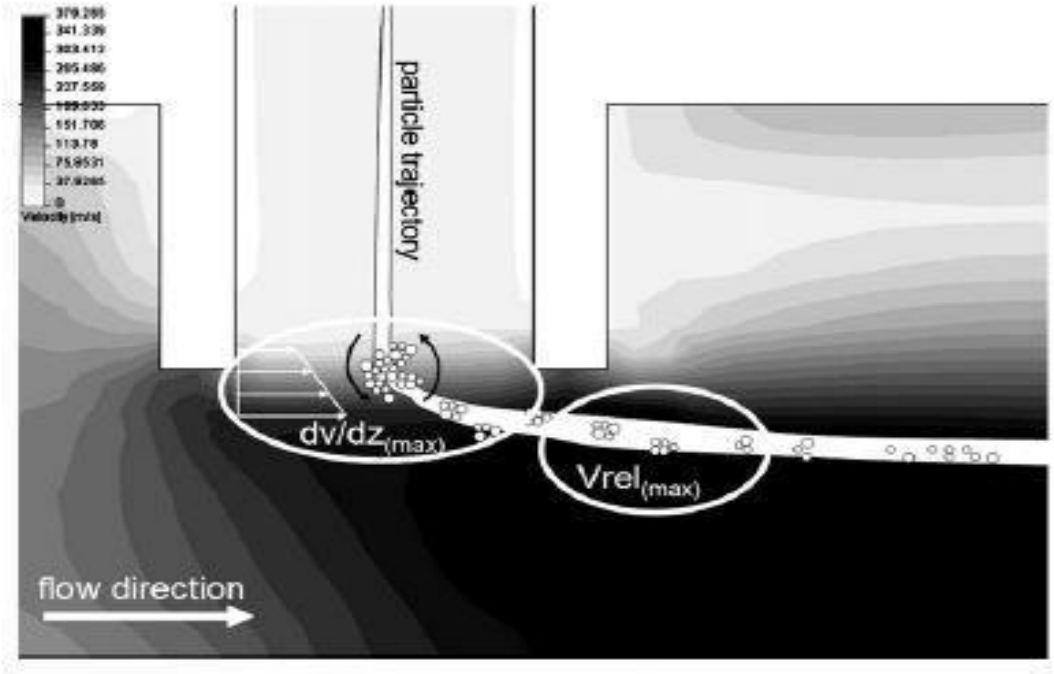


Figure 12: Step-by-step deagglomeration in dry powder disperser "deagglomerator" [19]

Figure 13 is a schematic of the proposed deagglomerator with increasing diameter in the particle collection zone. The proposed design has distinct particle collection zones of specific diameters. This will provide zones of specific Reynolds number where particles can be collected and studied.

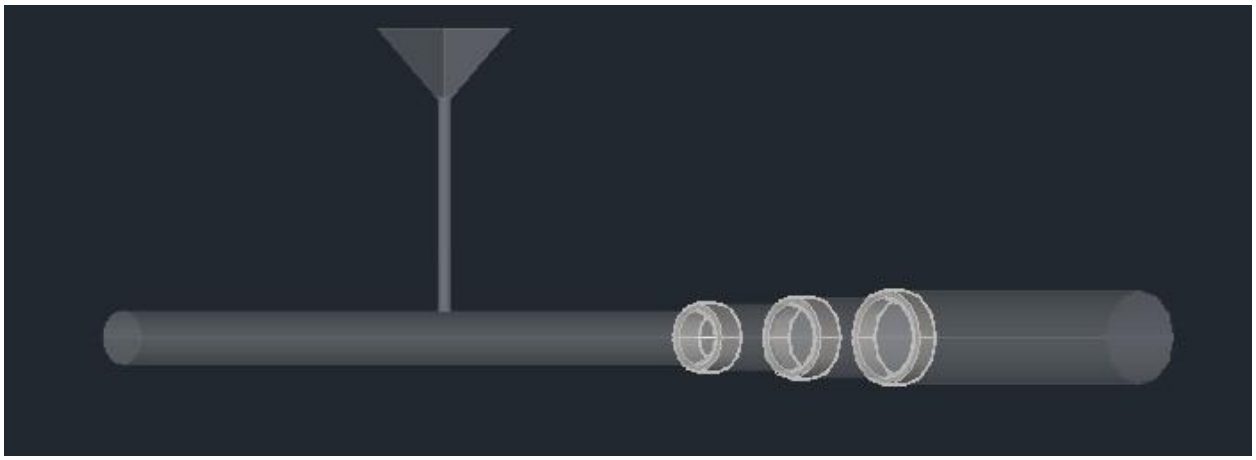


Figure 13: Proposed particle deagglomerator with vertical particulate introduction and distinct particle collection zones

The proposed particle deagglomerator is highly visual and will allow for a hands-on approach to the study of a highly complex property of particulates.

pH-sensitive hydrogel characterization: Chemical engineers contribute to the design of controlled drug delivery systems which deliver a drug at a desired rate to a desired location in the body. The experiment presented here is one of a series in which students design, prepare, and characterize pH-responsive hydrogels for oral drug delivery. For this experiment, students prepare pH-responsive hydrogels based on p(MMA-EG) and characterize the network structure of the swollen hydrogel through mesh size modeling in different pH environments. Students can optimize the hydrogel for oral drug delivery by varying its structure. They identify important design variables, practice translating quantitative laboratory measurements into data used in design evaluation, and learn aspects of polymer characterization, which can be applied to other areas of material science and engineering.

Mesh size is determined from correlations using existing tensile and experimental density data to characterize how the gels respond to pH variations.

The swelling ratio, Q is found from Equation 1.

$$Q = \frac{\text{volume of swollen gel}}{\text{volume of dry polymer}} \quad \textbf{(1)}$$

The tensile modulus is related to the tensile stress and the equilibrium polymer volume fraction as given by Equation 2

$$\frac{\tau}{\alpha - \alpha^{-2}} = G\, v_{2,s}^{-1/3} \quad (2)$$

where G is the tensile modulus, α is the elongation, τ is the tensile stress, and $v_{2,s}$ is the equilibrium polymer volume fraction in the gel (1/Q). G can be found from the slope of a plot of τ vs. $v_{2,s}^{-1/3}(\alpha-\alpha^{-2})$ using experimental data.[22]

The molecular weight between crosslinks is related to the tensile modulus by Equation 3

$$\frac{}{} = RT\rho_{2,r}\left(\frac{}{} \quad \frac{}{} \quad \frac{}{}\right)^{1/3} \tag{3}$$

where T is temperature, M_e is the effective molecular weight between crosslinks, M_n is the molecular weight of the linear polymer chains of copolymer, v_{2r} is the polymer volume fraction after crosslinking but before swelling (relaxed state, 1/q), and $\rho_{2,r}$ is density of polymer.

Equation 4 is used to determine the mesh size, ζ

$$\zeta = \left(\frac{}{}\right)^{1/2} {}_{l} v_{2,s}^{-1/3} \tag{4}$$

where $^{C}{}_{n}$ is the Flory polymer character ratio, l is the carbon-carbon double bond length (1.54 Å), and M_o is the molecular weight of the repeating units making up the polymer chains.

In the experiment described, students synthesized pH sensitive hydrogels by photo-polymerization of a monomer solution containing the photo-initiator dimethoxy propyl acetophenone, the cross-linker, poly (ethylene glycol) methacrylate and monomers methacrylic acid, and poly (ethylene glycol) (n) monomethyl ether monomethacrylate, as described by Tuesca.[23] The gels were cut into uniform disks, using an aluminum cutter with a diameter of 15.88 mm, as shown in Figure 14, and were placed in a freeze dryer for two days.

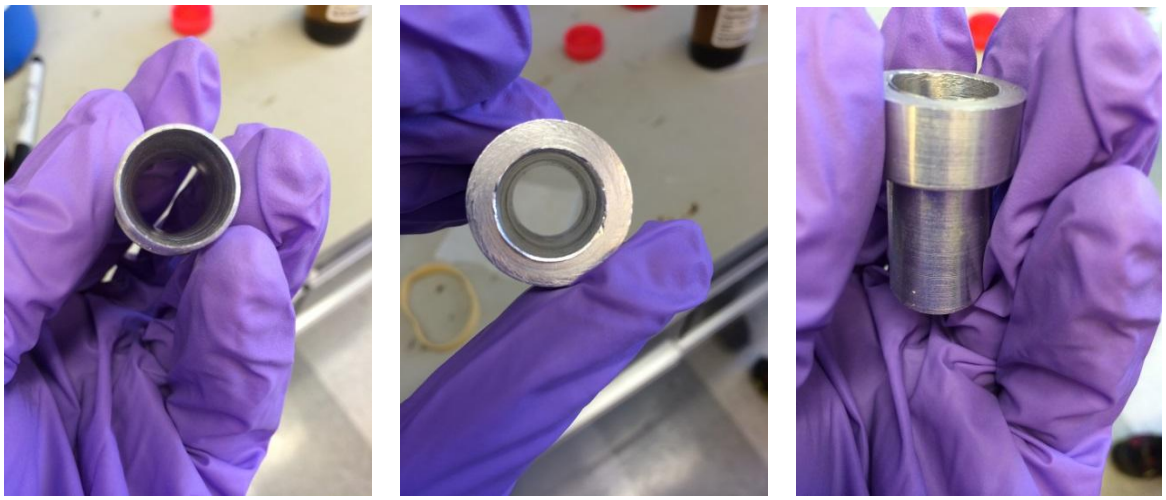


Figure 74. 2x3 hydrogel disk cutter apparatus.

The procedure of Farrell et al.[22, 24] was used for tensile testing, and the density of non-swollen and swollen gels was measured using a density determination kit. The swollen gels were made by placing dry disks in a phosphate buffer solution at a specified pH.

The mesh size is expected to increase with decreasing monomer and crosslinking agent concentrations. Sample data obtained from student experiments are shown in Figures 15 and 16. Using a polymer formulation of 40% monomer and 0.4% crosslinker, the mesh size is greater at a neutral pH than at an acidic pH. The mesh size of the swollen polymer increases with decreasing monomer concentration.

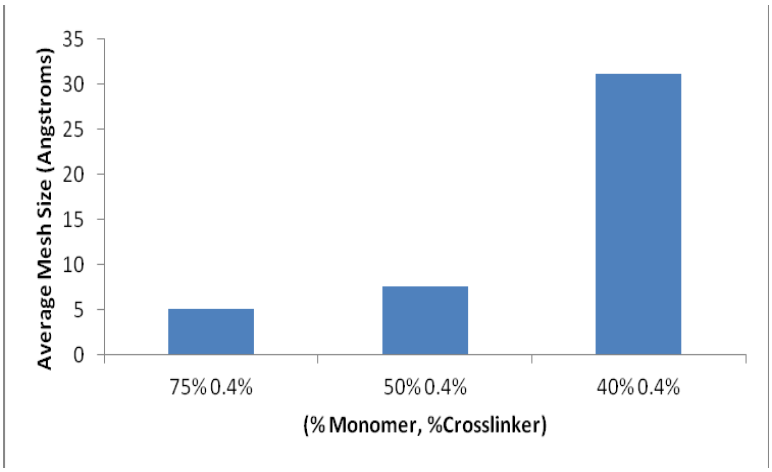


Figure 15. Effect of environmental pH on mesh size

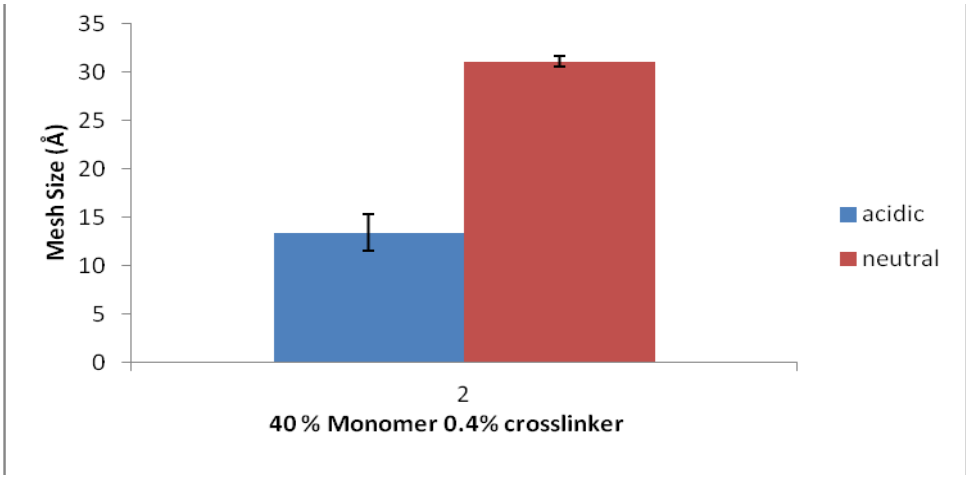


Figure 16. Effect of monomer concentration on mesh size at 0.4% crosslinker concentration and neutral pH.

This experiment is one of a series that introduce students to structure-property relationships in pH sensitive hydrogels for oral insulin delivery. Students learn how to perform density determination experiments and mesh size modeling, and how mesh size relates to the swelling characteristics of the gels. This experiment allows students to develop skills specific to drug

delivery and biomaterials, as well as skills in data acquisition and analysis and engineering design.

summary

The Rowan University educational outreach partner model can serve as a template for other collaborations to bring research into the undergraduate classroom. Self-contained educational modules and laboratory demonstrations designed to integrate particle technology, with applications in the pharmaceutical and other industries, into the undergraduate engineering curriculum were developed. Many of the experiments and demonstrations presented here can also be used in K-12 outreach programs. The modules are highly versatile and can be used to introduce students to a technology and to teach engineering and data analysis concepts. The teaching modules and techniques developed allow for interactive and hands-on learning in a team-based environment. These approaches are known to enhance learning and to engage students in engineering and technology. They provide students with the tools and conceptual foundation to understand basic particle/powder technology and fundamental engineering concepts. The main focus of this work was pharmaceutical technology but the concepts introduced apply to a wide range of industries. The integration of technology modules into traditional engineering courses is an excellent way to familiarize students with important industries and technologies without adding courses to the engineering curriculum.

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