ChE survey

# TEACHING COLLOID AND SURFACE PHENOMENA —1995—

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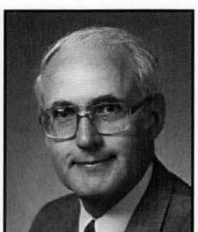
Variety. Variety in topic, in emphasis, and in approach—that's what we found from a 1995 survey of how colloids and surface phenomena is taught today. This is really not surprising, though, because of the variety in the topic itself: surfaces and interfaces; surfaces separate any two phases. So the applications can be gas-liquid, gas-solid, liquid-liquid, liquid-solid, and solid-solid boundaries. The materials that reside in fluid surfaces—surfactants—represent unique species with interesting behaviors such as micellization, liquid crystals, cosurfactants, and/or microemulsions. Applications abound. Surface phenomena is an integral part of water and waste-water treatment, physical separations, catalysis, polymer production, mineral processing, ceramics, and biomedical systems. Surface phenomena has growing applications in mass transfer, fluid mechanics, heat transfer, homogeneous phase separations, and reaction engineering.

So, how is this material taught to today's professionals? Rarely! In our survey, sent to 180 chemical engineering departments in the United States and Canada, only nineteen schools reported that they teach at least one course. Five schools teach two or more courses (Princeton, Carnegie-Mellon University, University of Washington, University of Minnesota, and McMaster Unitersity). Except for a required junior-level course in a ceramic engineering program, only eleven schools offer this as a senior elective.

In this paper we will illustrate how the courses are taught, with an emphasis on context and with varying emphasis on the content (properties, phenomena, theory, practical and experimental). Ideas will be presented on how to demonstrate and measure the phenomena. Resources will be given. Methods for teaching courses will be summarized, and we will close by giving ideas about future developments.



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## CONTEXT: CORE FUNDAMENTALS

Sometimes surface phenomena is presented in the context of environmental engineering, biomedical engineering, particle processing, catalysis, ceramic or materials engineering; sometimes the central theory of surface phenomena is given with little discussion of applications. Some instructors focus on the theory, some blend applications with theory, and a few use the applications as the focus, with the theory being learned for the purpose of designing a device or a process.

Part of the difficulty in offering an applications approach is the lack of available design data. Some instructors bring in applications through research and consulting. Those that offer courses focusing on the context independent fundamentals include Radke(14), Israelachvili(19), Jacobson(20a), DiMilla(20b), Prieve(20e), Evans(75a,75b), Saville(105a), Russel(105b), Miller(110), Ploehn(116), Slattery(128), Zollars(143), Thies(144), and Berg(145b).* Others place more emphasis on adsorption at gas-solid surfaces (Fort(139)) and on catalysis (Ko(20c)). Some instructors work in the context of

* *Numbers in parentheses are the numbers assigned to entries in the "Summary of Responses" list appearing in the Appendix to this article.*

solid processing (whether it be transportation, separation, or reaction): Scheiner(3), Tiller(45), Chiang(102b), and Nicholson(159c), and on coating: Tallmadge(38). Some instructors describe a variety of applications that are not focused on any particular industry or unit operations: Wasan(49), Bike(73), Phule(102a), Botsaris(134), and Woods(159b). A few instructors focus on polymers: Anderson(20d) and Pelton(159a). Ratner(145a) has some biomedical applications while environmental applications are given by Dold, et al.(159d).

**In this paper we will illustrate how the courses are taught, with an emphasis on context and with varying emphasis on the content (properties, phenomena, theory, practical and experimental). Ideas will be presented on how to demonstrate and measure the phenomena. Resources will be given. Methods for teaching courses will be summarized, and we will close by giving ideas about future developments.**

## SURFACE PROPERTIES, THEORY, SURFACE PHENOMENA, PRACTICAL APPLICATIONS

Being able to measure surface properties is seen as a key by many instructors. It helps measure the required data . . . and the process of measuring the data helps the understanding of the phenomena. Some instructors provide a laboratory course to complement the theoretical courses, while others blend the laboratory experiments into the theory course. One course uses the laboratory to drive the learning. Some teachers emphasize the experimental methods in this courses, and others place little emphasis on how to measure properties. Some use demonstrations of measurement techniques or of the phenomena.

To capture more of the flavor of the courses presented, we classify the approaches according to six extremes. These are based on how much emphasis seems to be placed on

1. *The theory of surface and colloidal properties (e.g., surface tension) called "theory-property." Instructors here would provide mathematical descriptions and derivations.*
2. *The properties and the theory/application of how to measure (e.g., surface tension and how to measure) called "description-measurement properties." With this approach, instructors might describe the theory, correlations, and methods to experimentally measure surface tension.*
3. *The measurement of surface properties (e.g., experimental measurement of surface tension via Wilhelmy plate) called "measurement-properties." Teachers might demonstrate how to experimentally measure the property, they might ask students to estimate values for the surface tension from experimental data, or students might perform a laboratory.*
4. *The theory of the behavior of surfaces and colloidal systems (e.g., theoretical definition, estimation, and modeling of surface tension) called "theory-behavior." Professors might provide mathematical descriptions and derivations.*
5. *Modeling and understanding the behavior of surfaces and colloidal systems (e.g., surface tension variation and Marangoni behavior) called "description-behavior." Instructors in this course would emphasize the phenomena that occur because of surface tension: wetting, Marangoni behavior, capillarity, and fingering. They might illustrate the practical applications, such as breakup of drops, prilling for fertilizer production, drop size in emulsion polymerizers, gas bubble diameters in aeration basins, and ink-jet printing.*
6. *The applications of the behavior (e.g., explain the faulty performance of a solvent extraction unit because the wrong phase is the dispersed phase) called "application-behavior." This course could be presented by lecture, demonstration, videotapes, or labs. Instructors might expect numerical calculations of the practical applications; this usually requires the addition of engineering practice (such as information about mixing characteristics and the dependence of drop size on the Weber number).*

In general, rarely are courses or texts given that are strictly "theory-properties." Many texts (and courses) are blends of theory of behavior combined with theory and description of measurement techniques for properties. For example, Hiemenz's book[1] is about half and half of these combinations. Applications are listed occasionally, but are not emphasized (hence, we would code or describe courses given with this approach as being "theory, behavior, properties"). Contrast this with the Evans and Wennerstrom text.[2] They place introductory emphasis on experimental measurement of the properties

## TABLE 1
**Experiments**

| *Topic* | *Elaboration* | *Labs* | *Demonstrations* |
|---|---|---|---|
| Surface tension measurements | DuNouy ring | Jacobson(20a); Berg(145b) | Fort(139); Wasan(49) |
| | Wilhelmy plate | Zollars(143); Berg(145b) | Fort(139); Woods(159b); Wasan(49) |
| | Drop weight | Zollars(143); Berg(145b) | |
| | Sessile drop | Berg(145b) | |
| | Maximum bubble pressure | Zollars(143) | |
| Surface pressure of insoluble monolayers | | Myristic acid, Berg(145b) | Fort(139); Jacobson(20a) |
| Equilibrium contact angles | Equilibrium for liquids | on polymers, Jacobson(20a) | Fort(139); Woods(159b); Wasan(49) |
| | Wetting properties | plasma-treated polypropylene Berg(145b) | |
| | Dynamic advancing/retreating | Zollars(143); Berg(145b) | |
| Coefficient of friction | | Jacobson(20a) | |
| Particle size measurement | By photo counting | — | Woods(159b) |
| | By Coulter counter | Jacobson(20a) | Woods(159b) |
| | By centrifugation | Zollars(143); Berg (145b) | |
| | By QELS | Zollars(143) | |
| | By sedimentation | Berg(145b) | |
| Particle/surface characterization | By SEM | Partch(24) | Jacobson(20a) |
| | By TGA | Partch(24) | |
| | By ESCA | — | Ratner(159a) |
| | By STM | Jacobson(20a) | |
| | By TEM | Partch(24) | |
| Particle preparation | Submicron spherical silica particles | Partch(24) | |
| | Coating w/polymers via in-situ polymerization | Partch(24) | |
| Molar mass of polymers | Light scattering | Zollars(143) | |
| Electrophoretic mobility | — | Jacobson(20a); Zollars(143) | |
| Electrophoresis | — | Dold(159d); Berg(145b) | |
| Surface viscosity | Of monolayer via deep channel | Berg(145b); Wasan(49) | |
| Viscosity | Effect of particulates on | Zollars(143) | |
| CMC determinations | By surface tension | Jacobson(20a) | |
| | By conductance | Jacobson(20a); Berg(145b) | |
| | By dye titration | Berg(145b) | |
| Surface adsorption or surface area determination by BET | — | Jacobson(20a); Berg(145b) | |
| Adsorption from solution | — | Jacobson(20a); Berg(145b) | |
| Colloid stability | Jar test for clay removal | Jacobson(20a); Dold(159d); Berg(145b) | |
| | and electrolyte addition | Berg(145b) | |
| Soap bubbles | Drainage, equilibrium angles | Berg(145b) | |
| | Stability | — | Wasan(49) |
| Flotation | Separation by preferential wetting | Berg(145b) | |
| Emulsions | Preparation and testing, HLB | Berg(145b) | |
| | Stability | — | Wasan(49) |
| Deep bed filtration | — | Dold(159d) | |
| Surface filtration | — | Dold(159d) | |
| Marangoni effects | During mass transfer via Schlieren optics | Berg(145b) | |
| Solubilization of dyes by aqueous surfactants | — | Jacobson(20a) | |
| Adsorptive bubble fractionation of dye | — | Jacobson(20a); Berg(145b) | |
| Scanning tunnel microscopy | — | Jacobson(20a) | |

and focus more on the phenomena and some applications (code, theory-behavior).

Given the limitations of this classification, we have tried to illustrate where most of the courses reside. This is based on our knowledge of the texts and the descriptions, course outlines, and exams submitted by the respondees to our questionnaire.

More theoretical courses seem to be offered by Prieve(20e), Saville(105a), Russel(105b), and Slattery(128). A mix of theory, behavior description, and property measurements seems to be given by Radke(14), Israelachvili(19), DeMilla(20b), Anderson(20d), Ploehn(116), Fort(139), and Thies(144). Slightly more emphasis on behavior description is used by Ko(20c), Bike(73), Evans(75a,b), Miller(110), Berg(145b), and Pelton(159a), while slightly more emphasis on instrumentation and measurement is given by Zollars(143) and Ratner(145a). Heavier emphasis on phenomena and application is given by Phule(102a), Botsaris(134), Shaeiwitz(149), Wasan(49), and Nicholson(159c). Increased emphasis on practical applications is given in courses by Tiller(45), Chiang(102b), and Woods(159b). A blend of practical application and experimental measurement is given by Dold, *et al.*(159d), and laboratory courses are given by Berg (145b), Jacobson(20a), Nicholson(159c), and Partch(24).

## LABORATORIES, DEMONSTRATIONS

Laboratories are offered as separate courses to complement other courses: Jacobson(20a). Others have a required laboratory component where the student teams must complete some experiments: Berg(145b) and Zollars(143). This is a mixture of property measurement and phenomena demonstrations. The list of experiments is given in Table 1. Other programs (Evans(75a,b)) use laboratory experiments and demonstrations as side enrichment via CD ROM or other media. Some teachers emphasize analytical instruments and have combinations of theory, demonstrations, and laboratory visits: Zollars(143) and Ratner(145a), while others have demonstrations and perhaps visits to laboratories: Wasan(49), Fort(139), Berg(145b), and Woods(159b). Some demonstrations that instructors have used are given in Table 2.

**TABLE 2**
**Demonstrations**

| *Concepts* | *Demonstrations* | *Used by . . .* |
|---|---|---|
| Young-LaPlace equation | • Uneven sized soap bubbles on ends of a tube | Berg(145b); Woods(159b) |
| Surface tension | • Equilibrium angles for intersecting soap films | Berg(145b); Woods(159b) |
| | • Floating loop of string on water with soap touching center of loop | Woods(159b) |
| | • Floating razor blade | Nikolov and Wasan(49) |
| | • Demonstrations from C.V. Boys | Berg(145b) |
| Contact angles | • Soldering of copper pipe | Woods(159b) |
| | • Mixing cocoa in milk | Woods(159b) |
| | • Oil spill cleanup and "herders" | Woods(159b) |
| | • Spreading from liquid lenses and solid crystals | Fort(139) |
| | • Wave damping effect caused by spread films | Fort(139) |
| | • Ethanol, water, water plus 10x CMC value of surfactant on glass of overhead projector | Nikolov and Wasan(49) |
| | • Floating needle or razor blade plus soap touches surface | Nikolov and Wasan(49) |
| Marangoni behavior | • Water plus drops of ethanol | Nikolov and Wasan(49) |
| Phase separation | • Slide with water and polydispersed clay particles | Nikolov and Wasan(49) |
| | • Gold sol plus 2% gelatin plus salt addition; vary sequence of addition | Lyklema |
| Structure in suspensions | • Monodispersed, highly charged latex suspension; shine layer through slide to show inner structure | Nikolov and Wasan(49) |
| Characteristics of emulsions | • Oil/water and water/oil emulsions in office supply device | Nikolov and Wasan(49) |
| Radii of curvature | • Glass of water and model of surface with normals | Woods(159b) |
| Surfactants | • Film balance and LB films | Fort(139); Berg(145b) |
| Particle interactions in colloidal suspensions | • Particle structure formation in colloidal suspensions quantified by light diffraction | Wasan(49) |
| Film rheology | • Interference colors produced during the drainage of vertical foam film. Each color indicates the local film thickness. | Wasan(49) |
| Wetting and spreading of oil at air/water surface | • Interference patterns in reflected light produced from the crude oil layer at air/water interface. | Wasan(49) |

## RESOURCES

Many instructors have created their own notes. Table 3 lists the major texts used. In addition, some excellent videotapes are available; they are listed in Table 4. Theo Overbeek's lectures, videotapes, problems, and answers provide another rich source of information and have been used by Botsaris(134), Pelton(159a), and Woods(159b).

The American Filtration Society has been so concerned about the lack of undergraduate courses in the areas of particle processing that over the past five years they have held educational workshop-conferences to bring together academia and industry to design texts in four topics: particle science (particle characterization and surface phenomena); flow through porous media; particle fluid mechanics and transportation; and fluid-particle separations. Some background is given by Ennis, Green, and Davies.[3] Two sets of notes have been completed by the unique combination of industrialists and academicians: Particle Science (or Surface Engineering) and Flow Through Porous Media. In 1996, the notes on Fluid-Particle Separations should be available. For more details, contact S. Chiang(102a).

The University of Minnesota has and is preparing a series of modules, distributed on MAC-based computers and eventually on CD ROM. The modules developed so far are on forces (4 modules) and micelles (1 module). Complementing these will be laboratories, demonstrations, and problems that will allow one to use the material via problem-based or cooperative learning. The general overall themes of the modules are surfaces, colloids, polymers, forces, fluids, and heat transfer. The material is similar to a series of books being developed by Evans and Davis (System Mechanics of Interfaces). The team developing this approach includes Karl Smith, an international authority on cooperative and problem-based learning.

## TEACHING APPROACHES

Although the lecture currently is the preferred instructional style, there are some interesting and novel teaching approaches. Three schools use initial interest surveys and modify the curriculum to match the student's interests: Bike(73), Ploehn(116), and Ko(20c). Self-study is used by Slattery(128). Others bring active learning into the classroom through cooperative learning activities, "guided-design," and in-class problem solving: Chiang(102b), Shaeiwitz(149), and Woods(159b). Woods, for example, shifted from lectures to the Osterman feedback lecture system with a resulting increase in both student's marks in the course and student ratings of the course. In this format, the 50-minute lecture is divided into two 20-minute mini-lectures separated by a 10-minute cooperative calculation or discussion activity. During this time, the instructor circulates through the class to monitor how well the students have understood the

**TABLE 3**
**Texts Used**

*Text (# of respondees using the text)*

| | | |
|---|---|---|
| • Own Notes (7) | • Hunter[6] (1) | • Edwards, et al.[10] (2) |
| • Hiemenz[1] (4) | • Woodruff and Delchar[7] (1) | • Shaw[11] (1) |
| • Russel, Saville, and Schowalter[4] (3) | • Miller and Neogi[8] (1) | • Adamson[12] (1) |
| • Evans and Wennerstrom[2] (2) | • Everett[9] (1) | • Walls[13] (1) |
| • Israelachvili[5] (2) | | • Slattery[14] (1) |

**TABLE 4**
**Videotapes**

| *Topic* | *Application* | *For more...* |
|---|---|---|
| Trefethan's "Surface Tension in Fluid Mechanics" | Surface tension and Marangoni | Encyclopedia Britannica |
| Shell research | Maragoni behavior | Woods(159b) |
| Shell carburetor | Stability | — |
| Shell electrostatic explosions | Electrostatic behavior | Woods(159b) |
| Berg research | Marangoni roll cells; side and top views | Berg(145b); Woods(159b) |
| Hickman research | Vapor recoil; Marangoni | Palmer(111); Woods(159b) |
| Brimacombe research | Marangoni | Woods(159b) |
| Wasan research | Coalescence | Wasan(49) |
| | Particle-particle impact on coalescence | Wasan(49) |
| | Computer simulation of coalescence and separations | Wasan(49) |
| Woods research | Coalescence | Woods(159b) |
| Hartland | Coalescence | — |

material. If comprehension is lacking, the instructor can then use the following 20-minute period to elaborate and correct misconceptions. Pelton(159a) uses selected published papers as the driving mechanism for student learning, while the approach used by Dold, *et al.*(159d) is to identify a piece of equipment to be designed, provide the students with a sample of the feed, and ask them to measure the pertinent properties and use the information to complete the equipment selection and design. Nicholson(159c) uses two plant visits, laboratories, and self-directed learning in his approach, and Wasan(49) uses video-conferencing. Several approaches use an industrial "process" for a focal point; Scheiner(3) uses the Bayer process; and Dold, *et al.*,(159d) use an industrial waste-water treatment process. The resources being produced by the team at the University of Minnesota (Evans,75) will be of great assistance to help us move to active, cooperative learning.

## IDEAS ABOUT FUTURE TRENDS

Our hope is that surface phenomena will become a mainstream, curricular requirement for all programs. In reviewing the AIChE conference programming trends, we note that in the 1960s, surface phenomena tended to have about three sessions per conference. They were attended by researchers dedicated to this specialized topic. At the 1995 Miami Beach meeting, however, surface phenomena papers were presented in about 30% of the conference sessions. Indeed, all physical systems studied by engineers have surfaces and boundaries. The more we learn about those surfaces, the better will be our ability to predict what happens as material passes through, reacts, or interacts with the surface. What still remains to be done is to develop surface phenomena as a cohesive, core fundamental subject for our undergraduate programs.

Of all the courses currently given, only Nicholson's(159c) is required at the junior level. His course is characterized as having plant visits, laboratory measurements, and practical applications. Things that we might do to bring surface phenomena into the mainstream of undergraduate chemical engineering and to recruit students for our graduate programs might include:

1. *Using surface phenomena as the topic for communication courses and projects.*
2. *Including surface phenomena projects and activities in the laboratory program, as is done at Clarkson.*
3. *Developing a course on the practical engineering applications of surface phenomena or surface engineering and make this required in the junior year. This will need the practical applications flavor that is broad; it also needs data to allow us to do practical problems.*

## SUMMARY

The responses to the survey (sent to about 180 chemical engineering departments) reveal that about twenty schools currently give at least one course in colloid and surface phenomena; five schools offer two or more courses. The courses tend to focus on the foundational theory; a few courses include applications, and some teach surface phenomena in courses on the environment, particle processing, separations, and mineral processing.

Surface properties and their measurement is an important theme for many respondents. Imaginative combinations of laboratory courses and demonstrations enrich some of the programs. The breadth of the subject is reflected in the many different approaches taken in teaching it. The rich set of practical applications of surface phenomena is illustrated by the wide range of examination questions and problems assignments used.

There is no dominant and popular text. Most instructors use their own set of notes (or textbooks that they have written). A rich variety of films, videotapes, demonstrations, and self-study tapes are available. A new development is the computer modules being developed by the University of Minnesota and the course notes prepared on "particle science" by the American Filtration Society.

In methods of teaching the course, most use a lecture format with active learning; cooperative learning approaches are used in several schools.

Extensive cross-referencing has been used in presenting the results so that those interested can follow up on some of the many ideas used.

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## *APPENDIX*

# *Summary of Responses*

The number indicates the University as listed in the 1995 Index of Schools in the AIChE Faculty Directory
*Key: J-Junior Required; S-Senior course; SL-Senior Lab; SE-Senior Elective; G-Graduate; AG-Advanced Graduate*

3. Alabama, B.J. Scheiner, *Hydrometallurgy* (S,G) ***Text:*** own notes, half on hydrometallurgy and half on surface phenomena. Integrates the ideas around the Bayer process. ***Style:*** lecture, question, pass out activities to get students to think about why things happen.

14. California, Berkeley, C.J. Radke, *Applied Surface and Colloid Chemistry* (G) ***Text:*** own notes, capillary hydrostatics and dynamics, capillary thermodynamics, colloids and electrical phenomena. ***Style:*** lecture

19. California, Santa Barbara, J. Israelachvili, *Colloids and Surfaces* ***Text:*** Israelachvili

20a. Carnegie Mellon University, A.N. Jacobson, *Experimental Colloid and Surface Science* (SE,G) ***Text:*** Hiemenz; laboratory complements lecture course with experimental techniques. Complete 9 out of 12 experiments plus demonstrations in film balance and SEM. ***Style:*** laboratory

20b. Carnegie Mellon University, P. DiMilla, *Physical Chemistry of Colloids and Surfaces*

20c. Carnegie Mellon University, E. Ko, *Surfaces and Adhesion* (G) ***Text:*** Woodruff and Delchar; gas-solid interactions with half on principles and half on experimental techniques. ***Style:*** surveys students ahead of time and then sets the course content; replaced exams with review paper or a research proposal with oral presentations.

20d. Carnegie Mellon University, J. Anderson, *Physical Chemistry of Macromolecules* (SE,G) ***Text:*** Young and Lovell; general concepts, chemical synthesis of polymers, polymers in solution and bulk polymers. ***Style:*** lecture

20e. Carnegie Mellon University, D. Prieve, *Colloid Science* (G) ***Text:*** Russel, et al.; light and its application to colloids, Brownian motion, diffusion in a force field (sedimentation), flocculation, electrostatics, double-layer forces, electrodynamics of continua, slow Brownian flocculation, electrokinetic phenomena. ***Style:*** lecture

24. Clarkson, R. Partch (SL) Lab: preparation and characterization of aerosols

38 Drexel, J. Tallmadge, *Interfacial Phenomena* (SE) ***Text:*** own notes; half on fundamentals of basic phenomena, half on coating and two-phase flow. ***Style:*** lecture

45a. Houston, F. Tiller, *Theory and Practice of Solid-Liquid Separation* (SE,G) ***Text:*** own notes on the theory and practice of solid/liquid separation, particle characterization, flocculation, slurry properties, cake formation. ***Style:*** lecture

49. Illinois Institute of Technology, D.T. Wasan, *Interfacial and Colloidal Phenomena with Applications* (SE,G) ***Text:*** Edwards, et al.; surface tension, contact angles, adhesion, wetting and spreading; adsorption and micellization; surface rheology, colloid stability; thin liquid films and emulsions and foams; rheology of dispersions and electrophoresis and electrokinetic phenomena. ***Style:*** video-conferencing with demonstrations, videotapes and three or four labs.

73. U. Michigan, S. Bike, *Colloids and Surfaces* (G) ***Text:*** Hunter; thermodynamics of surfaces, preparation and characterization of colloids, electrochemical double layer, van der Waals forces, DLVO, polymeric stabilization and flocculation, transport, association colloids, applications; ***Style:*** interest survey, class presentations, critical review of articles and emphasis on applications

75a. Minnesota, F. Evans, *Colloidal Domain* (G) ***Text:*** Evans and Wennerstrom; solutes and solvents, monolayers, double layer, micelles, forces in colloidal systems, bilayers, polymers, colloidal stability, colloidal sols, phase equilibria, macro and microemulsions. ***Style:*** lecture, unique computer modules

75b. Minnesota, F. Evans, *Fundamentals of Surface Phenomena* (G) ***Text:*** Evans and Wennerstrom

102a. Pittsburgh, P.P. Phule, *Principles of Surfaces and Colloids* (SE,G) ***Text:*** own notes; particulate surface and interfacial area; surface tensions, energy; wetting, adhesion, adsorption, gas-solid, liquid solid; forces between particles and DLVO; processing fine particles/emulsions; polycrystalline materials; experimental techniques of surface analysis ***Style:*** lecture with interdisciplinary focus that attracts materials science, chemical engineering, chemistry, physics, and pharmacy students; take-home exam

102b. Pittsburgh, S. Chiang, *Fluid Particle Processing and Separation* (SE,G) ***Text:*** own notes; about a third on particle characterization and surface phenomena ***Style:*** lecture plus cooperative learning plus project

105a. Princeton, D.A. Saville, *Colloidal Dispersions I* (G) ***Text:*** Russel, et al.; experimental foundations and theory ***Style:*** lecture with tutorials

105b. Princeton, W. Russel, *Colloidal Dispersions II* (G) ***Text:*** Russel, et al.; experimental foundations and theory ***Style:*** lecture with tutorials

110. Rice, C. Miller, *Interfacial Phenomena* (G) ***Text:*** Miller and Neogi; half on fundamentals of interfacial tension, contact angles and surfactants together, and half on flow and transport at interfaces with a little on colloidal stability ***Style:*** lecture, term paper

116. South Carolina, H.J. Ploehn *Colloids and Interfaces* (SE,G) ***Text:*** Israelachvili and Everett; historical perspectives, interfacial thermodynamics, capillarity and wetting, adsorption and monolayers, surface, micelles and self-assembly; intermolecular forces; colloidal stability; Brownian motion; radiation scattering techniques; transport phenomena; phase behavior of concentrated systems ***Style:*** interest survey, lecture with projects, and oral presentations

128. Texas A&M, J.C. Slattery, *Advanced Interfacial Phenomena* (AG) ***Text:*** Slattery ***Style:*** self-study

134. Tufts, G.D. Botsaris, *Surface and Colloid Chemistry* (SE,G) ***Text:*** Shaw plus notes; I Fundamentals - attractive and repulsive forces between particles, electrokinetics, stability and flocculation, surfactants, micellization and adsorption, wetting, curved interfaces, nucleation, capillarity and surface tension gradients; II Applications - emulsions, concentrated suspensions and slurries, separation processes, drying of coatings, and foams ***Style:*** lecture plus series of fascinating practical-case problems; Overbeek's videotapes available

139 Vanderbilt, T. Fort, *Surfaces and Adsorption* (SE,G) ***Text:*** own notes; adsorption, wetting, detergency, flow through porous media. ***Style:*** lecture enriched by films and slides from past research; demonstrations of experimental methods of measuring surface tension and contact angle, the film balance, and techniques for making Langmuir Blodgett films, spreading from liquid lenses and solid crystals and wave damping effects of spread films; videotapes

143. Washington State, R. Zollars, *Interfacial Phenomena* (SE,G) ***Text:*** Hiemenz; emphasis on molecular basis for interfacial forces and the macroscopic phenomena that result and on the latest analytical techniques (QELS, Proton correlation spectroscopy; field flow fractionation; STM and AFM); basic concepts and measurements; molar mass; sedimentation and diffusion; solution thermodynamics; viscosity and light scattering; interfacial phenomena; surface tension; adsorption from solution; adsorption by a solid surface; surfactant structures; colloidal phenomena; flocculation, electrostatic and electrokinetic behavior ***Style:*** lecture with significant laboratory group work

144. Washington U., C. Thies, *Principles of Surface and Colloid Chemistry* (S) ***Text:*** Hiemenz; nomenclature, powder technology, sedimentation and diffusion equilibrium; viscosity; osmometry; light scattering; surface tension; porosimetry; adsorption from solution; adsorption at gas-solid surfaces and surface area determinations; electrical double layer and flocculation phenomena ***Style:*** lecture

145a. U. Washington, B.D. Ratner, *Surface Analysis* (SE,G) ***Text*** Walls; practical course on how to measure the nature of solid surfaces with emphasis on ESCA and how to interpret and quantify data ***Style:*** lecture plus real-world data that the students analyze (a ladybug's wing in 1995); surfaces, energy interactions with matter, vacuum systems, ESCA, SIMS, contact angles, auger apectroscopy, scanning, tunnelling microscopy, SEM, TEM, EDXA, vibrational spectroscopies (IR, SERS, IETS, EELS), applications in biomedical and microelectronics ***Style:*** lecture plus student projects and visit to instrumental lab

145b. U. Washington, J.C. Berg, *Surface and Colloid Science Laboratory* (SE,G) ***Text*** own notes "Surface and Colloid Science"; capillarity, capillary hydrostatics; solid-liquid interactions; interfacial thermodynamics (adsorption, self-assembly); colloids; electrical properties of interfaces (double layers, DLVO, kinetics of aggregation, electrokinetics) capillary hydrodynamics (Marangoni effects, Gibbs elasticity) ***Style:*** lectures, small demonstrations; laboratories with self-complete handouts; over twenty experiments available with each student (working in pairs) doing four experiments; videotapes

145c. U. Washington, B. Rogers, *Surface Science*

149. West Virginia, J.A. Shaeiwitz, *Interfacial Phenomena* (SE,G) ***Text*** Hiemenz; intermolecular and interparticle forces, interfacial tension, wetting, adsorption, colloids and sedimentation, sedimentation versus diffusion, colloid thermodynamics; viscosity of suspensions; charged interfaces, double layers, DLVO, coagulation kinetics; stabilization and flocculation by polymers; electrokinetic phenomena; application to particle pollution control; surfactants; micellization; emulsions, microemulsions; detergency; surfactant adsorption and applications; surfactant-based separations ***Style:*** lecture plus active learning plus project; emphasis on problem solving; applications

159a. McMaster, R. Pelton, *Polymer Colloids* (G) ***Text:*** Hunter, and Evans and Wennerstrom; colloid stability; colloid (latex) characterization; surface chemistry (surface tension, thermodynamics of interfaces and capillarity); surfactants (characterization and properties) ***Style:*** assigns published papers as the mechanism for learning; students orally present summaries of findings

159b. McMaster, D. Woods, *Colloids, Surfaces, and Unit Operations* (SE,G) ***Text:*** own notes; when is surface phenomena important (particle characterization, thin films and surfactants), surface tension with two surfaces, interactions of three surfaces, variation in surface tension with temperature, pressure and concentration; attractive forces between surfaces, adsorption, adsorption of ions; implications for two surfaces DLVO and rate; adsorption of polymers ***Style:*** problem-based with Osterman feedback lecture with in-class problem solving; applications oriented; demonstrations, videotapes

159c. McMaster, P. Nicholson, *Materials Processing I*(J) ***Text:*** Adamson plus own notes; introduces powders and powder-liquid systems and applies fundamentals to mineral processing and slip synthesis; comminution, grinding theory, and methods of powder synthesis; particle statistics, measurement of particle size and surface area; mixing and packing of particles; surface chemistry of suspensions; flocculation, deflocculation and ion-exchange; oxide structure and surface charge; clays, ion-exchange, suspension stability, dilatancy, thixotropy and EDP; mineral flotation and elutriation, and process mass balances ***Style:*** cooperative self-directed learning and active learning with lectures; two plant trips, experimental laboratories

159d. McMaster, P. Dold, A. Robertson, D. Woods *Environmental Laboratories* (G) ***Text:*** own notes; student teams do five experiments to provide data to size/design water or waste water treatment facility; Topics - flow measurement, coagulation/flocculation, activated sludge, rotary vacuum filtration (surface filtration) and deep bed filtration ***Style:*** mini-lecture introduction; samples supplied and students learn theory on a need-to-know basis; run experiments, interpret data, and size equipment ❐