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History of Polymer Education—USA

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ABSTRACT

Prior to 1940 there was little or no education directed toward polymer chemistry. With the contributions of Carothers and others that transformed the practice of polymers into a science–and the leadership of Herman Mark and others in formal graduate and postgraduate education–polymer education took root but rapid expansion and general acceptance by more traditionally oriented academic institutions was slowed by many barriers. Only since 1974 has there been a concerted effort to include education in the basic concepts of polymer chemistry into the undergraduate curriculum. Emphasis is on the development of polymer education in the United States.

INTRODUCTION

Polymers and polymer chemistry are important in yesterday's, today's and tomorrow's societies. As natural materials, they have been integral in man's earliest survival as clothing from animal hides and hair; as building materials from wood, plant fibers, and animal hides; and as food. Polymers were crucial to the development of man as the ink and paper of great documents and the recording of knowledge, the building materials of cities, etc.

Today the importance of polymers can be appreciated by considering a number of factors. The polymer industry employs over 800,000

people claiming parity with the total metal-based industry [1]. The annual production of synthetic polymeric materials in the United States is over 20 million tons, representing about 85 kg of synthetic polymers for every man, woman, and child at an average annual cost of about $3000 per family of five. It is difficult to imagine our society devoid of polyester skirts, nylon rugs, rubber tires, rayon socks, etc. Natural polymers, such as wool and paper and other cellulose materials, are also important. In medicine we are focusing on solving the mysteries of thought, recognition, and reproduction, as well as the use of polymers in synthetic limbs, organs, and blood.

Tomorrow offers new frontiers in all major areas of macromolecular science with new building materials, automobiles and other vehicles consisting mostly of polymeric materials, polymeric spaceship wrappings, new synthetic organs, further unraveling of biomacromolecules, etc. A greater focus will be placed on the use of natural, regenerable polymers as stockpiles of nonregenerable feedstocks diminish.

Polymer chemistry is also important because 1) it serves as a basis of many related industries as ceramics, textiles, and leather; 2) its principles are applicable to materials in general; and 3) its principles are vital to biochemistry and medicine.

Even with the great importance of polymers, a deficiency exists in the education of our chemists and chemical engineers regarding polymer science, particularly with respect to their formal, academic training. This disparity can be readily illustrated by considering 1) the fraction of chemists engaged in polymer science (40 to 60% of all professional chemists) compared to the fraction of polymer chemists in academics (3 to 5%), 2) the proportion of academic time spent on polymer or polymer related topics (about 1 to 5%) compared to other topics, and 3) the fraction of support for (academic) polymer or polymer-related research (about 5% of total grant support).

The development of polymer education in the United States will be traced using specific examples to illustrate general trends to show how we got to where we are and to note that rectification of the disparity between the importance of polymer science and its place in academics is occurring. Many great men contributed to the growth of polymer science including polymer education. In this brief paper, not all of those individuals or centers of learning which made significant contributions can be noted.

Polymers are large molecules, often called macromolecules, bound by covalent bonds. The transmittal of both the general and specific properties that contribute especially to the understanding of large molecules and their synthesis is polymer education. Informally, education occurs mainly through the written word–journals, books–visually–laboratory demonstrations, movies, slide presentations–and the spoken word–classroom presentations, short courses, seminars, lecture series, and discussion groups. Education occurs both informally by discussion of research problems or solutions with fellow workers, reading the latest monograph and formally by attending

classes, lecture series, etc. While elements of all of the above will be considered, emphasis will be placed on the academic aspects of polymer chemistry.

Finally, the importance of polymer education cannot be separated from its importance in industry and the "real world," yet unfortunately this is what has and often continues to be done.

Prior to 1940 there was little or no education directed toward polymer chemistry. With the contributions of Carothers and others that transformed the practice of polymers into a science, and with the leadership of Herman Mark and others (informal graduate and postgraduate), polymer education took root but rapid expansion and general acceptance by more traditionally oriented academic institutions was slowed by many barriers. Only since 1974 has there been a concerted effort to include education in the basic concepts of polymer chemistry into the undergraduate curriculum. Emphasis in this report will be placed on the development of polymer education in the United States.

WHY?

One theme that is dealt with in the following sections concerns "why" polymer science has not enjoyed a healthy acceptance by academia in general. Following is a brief scenario summarizing aspects which will be considered later in greater detail.

First, the scientific basis of polymer science was developed relatively recently, beginning to coalesce about 1940.

Second, polymer science was largely founded, developed, and expanded in academic institutions where there still exists a high demand for those trained in polymer science, accentuating the void of polymer chemists in academia. The latter may be related to one of Charles Darwin's two major directives related to evolution. The first principle involves survival of the fittest. The second principle, and one commonly omitted, concerns acceptance by others. Thus, if a society refuses to accept an idea or person, the idea's or person's chances for survival (and evolution) are diminished. Further, society tends to accept its "own kind." Thus, organic chemists beget organic chemists, analytical chemists beget analytical chemists, and polymer chemists beget polymer chemists. But, where are the polymer chemists?–not in academic institutions. Further, we teach what we are most comfortable and most familiar with. Again, since most academic chemists have had no industrial experience, their "chance at becoming familiar, comfortable, knowledgeable in polymer chemistry is almost nil."

Third, some chemists in industry and academia claim that training in the basics of polymer chemistry is not essential since polymer chemistry and chemists working with polymers have done so well without formal training in polymer chemistry and that "on the job"

training is sufficient. I fully agree with those who claim that a general, broadly based training in the elements of all of chemistry is important, but believe that those basic elements must include elements basic to polymer chemistry. Also, because polymer science is still growing so rapidly, some will argue that the basic elements and ideas of polymer science are still changing and not well developed. The counter is that all of science is rapidly changing, including ideas concerning gases, yet this does not prevent us from covering in detail, with our students, the ideal gas theory and applications. Furthermore, the basic principles of polymer chemistry have been rather well developed since the 1950s. For instance, standard kinetics related to free radical polymerization is the most studied in all of science, yet how often is it covered in undergraduate physical chemistry and graduate kinetics courses?

HISTORICAL–THE EARLY YEARS TO 1938– THE AGE OF EMPIRICISM

The key word in the early years of polymer science is empiricism. Thus, Simon in 1839 made polystyrene but it was not until ca. 1937 with the recognization that high purity monomers were necessary that the synthesis of industrially "satisfactory" polystyrene was achieved.

Much of the early development of science, including polymer chemistry in the United States, focused on "application" of natural materials to our needs–cotton, flax, rubber, cottonseed oil, linseed oil, wool, and wood.

Devoe and Raynolds (now a division of the Celenese Corp.) has been making paint in New York since about 1754, a decade prior to our independence. It may have been the oldest corporation in the United States.

The first successful factory was a cotton mill, under Samuel Slater, which began to produce on December 21, 1790. In 1814 the world's first factory to convert raw cotton into cloth by power machinery within the walls of one building was erected in Waltham, Massachusetts by the Boston Manufacturing Co. Lowell, Massachusetts, now the home of Lowell University which is a center of polymer education, was the first American mill city; it employed the Pawtucket Falls of the Merrimack River for power. Charles Goodyear's discovery of the vulcanization of rubber in 1839 was one of the most perplexing and exasperating, yet important tales in United States history.

The first synthetic polymer utilized on a large commercial scale was Bakelite produced by Leo Baekeland, one of many foreign-born scientists who helped create American technology. By 1909 he demonstrated a number of Bakelite articles to members of the recently formed Chemists Club of New York.

The beginnings of polymer education in the United States are

unclear at best because, as with most sciences, polymer chemistry emerged and grew from a number of sciences–science and art associated with fabrics and textiles (making of boat sails, sheets, clothing), coatings (oil based), adhesives (rosins, glues) and rubbers. For instance, a course in paint technology was started in 1906 at North Dakota State University. Other courses in textiles, coatings, and cellulosic materials were also being taught prior to 1920. These early courses were quite applied and might be referred to as courses in technology and not science if such a distinction can in fact be made (technology is applied science). Considerable subject matter now termed polymer chemistry was contained in a course designated colloid chemistry at the University of Delaware by E. O. Kraemer as early as 1941. This was followed by the first courses taught under titles involving polymer chemistry taught in 1944 by G. E. Landt in the Chemical Engineering Department and in 1945 by H. M. Spurlin in the Chemistry Department. John Delmonte taught courses in plastics at Armour Institute of Technology in 1937-1939 and expanded these efforts to courses in the Plastics Industries Technical Institute (1940-1950). Paul O. Powers taught courses in plastics under the auspices of Pennsylvania State College of Franklin and Marshall College (1939-1944) and published the first book for use in colleges (Synthetic Resins and Rubbers, Wiley, New York, 1943). Ray Seymour offered a course in polymer chemistry at the University of Chattanooga in 1945.

The early focus of polymer-related educated was also largely empirical.

DEVELOPING YEARS: 1940-1974

The vast majority of ventures into polymer education focused on graduate and postgraduate education. This emphasis was largely to remain until the 1970s. Early progress was delayed because of World War II.

It took a midwestern bred and reared chemist, Wallace H. Carothers, to assist the world to begin to recognize the potential of synthetic polymers, to begin to build the scientific bases for polymers, and to signal a break from the empirical practice of polymer chemistry to the science of polymers. Carothers directed the research group for DuPont and on October 27, 1938 publically announced a synthetic (first made by Julian Hill) product which, for the first time in the history of the chemical industry, had properties superior to natural fibers. The product was nylon.

The science of polymer chemistry had been born an infant when most of its brother and sister disciplines of chemistry were already mature adults.

In the early to mid 1940s polymer chemistry was "raised" to the status of optional material for certain courses in chemistry. Polymer

chemistry was generally considered to be within the realm of organic chemistry and only a few ventured the inclusion of polymer topics in physical chemistry and fewer still considered it beyond these two areas. Even with the inclusion of several pages or a chapter on polymers in a number of the organic textbooks (such as The Chemistry of Organic Compounds by Conant and Blatt, Macmillan, New York, 1933, 1939, 1947, 1952), it was generally neglected.

A few "staunch believers" did give polymer chemistry a realistic portion of class time, and these "adventurers" were generally well rewarded with a stream of good, interested graduate students. Carl Marvel relates "At Illinois I did work in polymer chemistry and I always spent approximately four to six weeks on synthetic polymer chemistry as part of the second semester of organic chemistry which I taught, and that was started along about 1940...."

Though there were numerous early courses dealing with the emperical and applied nature of polymers in textiles, paints, rubbers, wood, etc., the first formal course in polymer chemistry was probably one associated with Herman Mark given at the Polytechnic Institute of Brooklyn shortly after he arrived from Germany via Vienna and Canada in 1940.

Much of the early formal polymer education centered about "Brooklyn Poly" (now the Polytechnic Institute of New York). By the middle 1940s the Polytechnic had attracted a number of outstanding "polymer" chemists (Herbert Morawitz, Turner Alfrey, Paul Doty, Bruno Zimm, Kurt Stern, A. McLaren, Fred Eirich, and Charles Overberger) under the directroship of Herman Mark. A program of graduate study leading to MS and PhD degrees with a major in polymer chemistry was developed, undoubtedly the first such program in the United States. Course offerings were:

Introduction to Polymer Chemistry (Mark)
Polymerization Kinetics (Alfrey)
Solution Properties of High Polymers (Eirich)
Organic Polymer Chemistry (Overberger)
Chemistry of Proteins (McLaren)

Several approaches were taken to aid the dissemination of fundamental information from academia to industry and the reverse. One approach aimed largely at how to best solve research problems involved utilizing the so-called "Gibson Island Research Conferences" which were founded by Neil Gordon of the Johns Hopkins University with Summer Conferences in 1931, moving to Gibson Island about 1933 or 1934. The Gibson Island Conferences were an ideal trading post for the transfer of information and discussion of trends, results, etc. by the foremost polymer scientist of that era. In each of the first few summers there was a conference on "Synthetic Resins" (really on polymers) chairmanned by Emmet Reid. These conferences have expanded into the framework of the "Gordon Research Conferences," numbering today about 100 conferences per year, many dealing with aspects of polymer chemistry.

Another approach involved "Brooklyn Poly" which was surrounded by numerous other academic institutions and industrial organizations. The developing team of scientists at "Brooklyn Poly" concerned with polymer chemistry began to investigate means to advance polymer chemistry within the greater community. Thus there began a "weekly" polymer seminar which was to attract industrial and academic chemists from the surrounding greater New York City Metropolitan area. The lectures were given by graduate students, faculty, and visiting scientists from many different countries. The Saturday seminars were a welcome change of pace since, because of the war, most chemists had to work on Saturdays. Also, they were free. There was also a Thursday night series. From the interest generated in these seminars grew symposia held on Saturday mornings dealing with advances in polymer research and polymer "clinics" held during the academic vacation for industrial researchers. Thus was being formed a necessary, critical bridge between academia and industry–a bridge, I am sad to say, which has not been kept in good repair nor enlarged to handle the greater volume of "polymer" travel.

Along with the need to "spread the news" of polymer science was the increasing need to develop an adequate vehicle which would focus on the dissemination of generated experimental results in polymer chemistry. In 1940 Drs. Maurits Dekker and E. S. Proskauer of Interscience Publishers consented to begin the publication of a series of monographs on polymer chemistry, High Polymers, with H. Mark and G. S. Whitby as editors. The response was so positive that in 1946 the publication of the Journal of Polymer Science under the editorship of H. Mark and P. M. Doty began. The contribution by Herman Mark to polymer education is clearly seen in the growth of both literary series as the backbones of polymer literature in the world. The Journal of Polymer Science is the most popular journal of polymer science today. It has subdivided many times and "fathered" such journals as the Journal of Applied Polymer Science. [Today there exists two additional primary United States based polymer journal groupings: Macromolecules (ACS) and the Journal of Macromolecular Science with its several divisions (Dekker); and two major ACS divisionally sponsored volumes, Polymer Preprints and Organic Coatings and Plastics Chemistry. Additionally there are numerous other polymer related journals such as Polymer News, SPE Journal, Plastics, Plastics Industry, Textiles, Modern Coatings, Polymer Engineering, Plastics Technology, Plastics World, and Modern Plastics which also add to the healthy contribution by the United States to the polymer literature.]

While a number of introductory or comprehensive texts dealing with polymer chemistry were written, the most influential was probably Paul J. Flory's textbook Principles of Polymer Chemistry, published in 1954. No prior knowledge of polymers was assumed, with particular chapters directed at the beginner. It also contained much information useful to the experienced investigator. A wealth of experimental data was included to illustrate the applicability of the

presented concepts and conclusions. Admittedly missing are topics related to the mechanical properties of polymers and to the application of polymers in industry–i.e., fabrication, synthesis, etc. Even so, Flory's text is a landmark book in science, possibly on the level of Linus Pauling's Nature of the Chemical Bond.

Much informal postgraduate education involved reading books written by those within a particular research area. Such early (pre-1953) books include T. Alfrey, J. Bohrer, and H. Mark, Copolymerization (Interscience, 1952); C. Ellis, The Chemistry of Synthetic Resins; T. Alfrey, Mechanical Behavior of High Polymers (Interscience, 1948); R. Boundy and R. Boyer Styrene–Its Polymers, Copolymers, and Derivatives (Reinhold, 1952); H. Mark and H. Tobolsky, Physical Chemistry of High Polymeric Systems (Interscience, 1950); C. Bawn, The Chemistry of High Polymers (Interscience, 1948); G. D. Alelio, Fundamental Principles of Polymerization (Wiley, 1952); R. Houwink (ed.), Elastomers and Plastomers (Elsevier, 1948); R. Burk and O. Grummitt (eds.), High Molecular Weight Organic Compounds (Interscience, 1949); and A. Schmidt and C. Marlies, Principles of High-Polymer Theory and Practice (McGraw-Hill, 1948).

Many of the editors and authors of these books and numerous research and review journal articles were from industry and represent a continued, critical commitment and investment by industry in postgraduate education. Others are from outside the United States, emphasizing the necessary cross-fertilization of scientist and scientific knowledge critical in the development of a science.

One of the initial national ACS symposia on "Instruction in Polymer Chemistry" was held at the 134th ACS meeting in Chicago, 1958, under the sponsorship of the Divisions of Polymer Chemistry and Chemical Education with William Krigbaum, Duke University, as chairman (partially reproduced in Ref. 1). Speakers included Frank Mayo, Stanford Research Institution ("Contributions of Vinyl Polymerization to Organic Chemistry"); Charles Price, University of Pennsylvania ("Geometry of Giant Molecules"); John Ferry, University of Wisconsin ("Polymer Chemistry in the Elementary Physical Chemistry Course"); Fred Billmeyer, University of Delaware ("A Graduate Curriculum in Polymer Chemistry"); John Kice, University of South Carolina ("Polymer Chemistry Instruction in Small Colleges and Universities"); George Butler, University of Florida ("A Polymer Chemistry Course Based on Theoretical Principles"); Thomas Ferrington, College of Wooster ("Kinetics of Polymer Formation by Free Radical Mechanism"); C. K. Bump, J. D. Cotman, and E. Merz on their experience in teaching polymer chemistry in industry; Charles Overberger, course offerings at Polytechnic Institute of Brooklyn; and Maurice Morton describing the polymer program at the University of Akron. The locations are noted to illustrate that by the 1950s there was already a broadly based academic supporting cast and interest in polymer chemistry and the titles are noted to show that the topics considered in 1958 are still considered vital today.

In 1919 the Division of Rubber Chemistry (then classified as a

section) was organized as the ACS's ninth division. In the early 1920s the Scientific Section of the Paint Manufacturers of the United States and the National Varnish Manufacturers Association provided the impetus for bringing paint chemists together to discuss mutual problems and to provide a forum where papers could be presented and discussed. The first of these meetings occurred in June 1922 in Washington, D.C., and was organized by Henry Gardner. After a second meeting (1923) the subject of affiliation with the ACS was considered with H. A. Gardner appointed as a committee of one to confer with ACS officers. On October 20, 1923, W. T. Pearce sent to the ACS Secretary Parsons a petition with about 100 signatures. On December 21, 1923, Pearce was notified that he had been appointed secretary and Gardner was chairman of the section, eventually called the Paint and Varnish Division, currently known as the Division of Organic Coatings and Plastics Chemistry. Other polymer-related divisions formed including the Divisions of Colloid and Surface Chemistry; Biological Chemistry; and Cellulose, Paper, and Textile.

The ACS High Polymer Forum, similar to today's Macromolecular Secretariat, with the help of C. S. Fuller and A. C. Elm, began meeting at the 1946 Atlantic City ACS meeting. Through the efforts of the Polymer Forum; the Division of Paint, Varnish, and Plastics Chemistry; and others, in 1948 a group of university and industry chemists petitioned the American Chemical Society to establish a separate division of Polymer Chemistry. After a probation period of 3 years the Division of Polymer Chemistry was formed, which today is the second largest division in the ACS.

Compared to more classical areas of chemistry there was little formal education and research related to polymer chemistry to the late 1950s although there existed several individual groups who were conducting important pioneering work including Carl Marvel and F. T. Wall at the University of Illinois; Peter Debye and Paul Flory at Cornell; Ray Seymour at the University of Houston and elsewhere; Malcolm Dole at Northwestern University; James Long, Ray Myers, and Al Zettlemoyer at Lehigh University; Walter Stockmayer at M.I.T.; R. Fuoss at Yale University; A. V. Tobolsky in Princeton; F. d'Alelio and E. Guthin at Notre Dame; Richard Stein at the University of Massachusetts; Charles Price at the University of Pennsylvania; John Ferry at the University of Wisconsin; George Butler at the University of Florida; etc.

In summary, through 1959 there existed only one large concentration of polymer chemists in academia (at the Polytechnic Institute of Brooklyn) with several smaller academic centers featuring concentrations in textiles, celluloses and wood, rubber, and coatings. Series of short courses, seminars, journals, monograms, and textbooks had been established and were to grow through the 1960s to the present.

The 1960s saw an increase in the number of formally designated polymer or macromolecular institutions. An unusual, and I believe possibly unhealthily, the trend of including polymer chemists and polymer chemistry in engineering colleges and departments of

chemical engineering rather than integrating them within departments of chemistry was apparent. For example, the comprehensive programs at Case-Western Reserve, University of New York at Buffalo, Washington State University, University of Massachusetts, and North Carolina State University all began in the 1960s and all were headquartered within engineering colleges. The danger is that if the academic institutions sense they can hide, segregate, or ignore polymer chemistry with selected token institutions, then it will be far more difficult to integrate polymer science into the curriculum of our academically trained chemists–most of whom will eventually end up in polymer-related research.

This trend of greater acceptance of polymer chemistry outside of departments of chemistry continues today.

Some of the older polymer institutions grew, such as the rubber- and polymer-based institute at the University of Akron, which was formed in the 1940s, and where Maurice Morton took the directorship in 1954. Others remained essentially the same and still others slipped. "Brooklyn Poly," the center of academic polymer chemistry in the United States in the 1940s and 1950s, remained as such but became less dominant because a number of their excellent staff left to found other institutes. For instance, Charles Overberger, who rose to Dean of Science and Director of the Polymer Research Institute at "Brooklyn Poly," left in 1967 to take the chairmanship of the Department of Chemistry at the University of Michigan where he helped found their macromolecular-based institute.

The lack of a proper response of academia to the training, both of graduate and undergraduate students, in the principles of polymer chemistry was clearly evident with this situation often publically and privately debated. For instance, Maurice Morton organized a panel discussion held on September 15, 1967, during the 154th National ACS meeting in Chicago, on "Polymer Chemistry in the Undergraduate Curriculum" (summaries are published in Ref. 2) which concluded that there was an "astonishing lack of emphasis" of polymer chemistry in the undergraduate curriculum of academically trained chemists. Charles Overberger, in his presidential address presented September 11, 1967, also at the Chicago ACS meeting, outlined the importance of polymer chemistry to today's society and chemists, and challenged the universities to consider polymer chemistry in its proper perspective. This challenge was again made by other ACS presidents such as Robert Cairns [2] and William Bailey, but this challenge was yet to be properly recognized even a decade later though, as will be subsequently noted, recognition is now beginning.

A number of professional societies were involved directly and indirectly with encouraging, assisting, and monitoring polymer education including the ACS, APS, SPE, SPI, and PRI. The Journal of Chemical Education continued to be helpful, often publishing polymer-related articles and symposia, such as the one published in Ref. 3. Included in this compilation is an article by Wayne Sorenson, Continental Oil. Co., outlining a number of polymer exercises still applicable to today's classes.

The dominant textbook of the 1960s, and one which even today is possibly the most utilized introductory polymer chemistry textbook, was Fred Billmeyer's Textbook of Polymer Chemistry (the 1961 and subsequent editions were named Textbook of Polymer Science). Billmeyer's text contains portions on most aspects of polymer chemistry from synthesis to characterization to fabrication. It begins with basic concepts assisting the student to bridge the gap between their "classical chemical knowledge" to basic concepts of polymer chemistry. Other significant texts include Introduction to Polymer Science, Raymond Seymour, 1971 (McGraw-Hill) which was superseded by Polymer Chemistry, Ray Seymour and Charles Carraher, 1981 (Dekker); Polymer Chemistry, Bruno Vollmert, 1973 (Springer); Introduction to Macromolecules, Leo Mandelkern, 1972 (English Universities Press); Introduction to Polymer Chemistry, John Stille, 1962 (Wiley); Organic Polymers, Turner Alfrey and Edward Gurnee, 1967 (Prentice-Hall); Organic Chemistry of Synthetic High Polymers, Robert Lenz, 1967 (Wiley); Polymer Chemistry, Malcolm Stevens, 1975 (Addison-Wesley); Principles of Polymer Systems, F. Rodriguez, 1970 (McGraw-Hill); Polymers: Chemistry and Physics of Modern Materials, J. M. Cowle 1974 (In text); Principles of Polymerization, G. Odian, 1970 (McGraw-Hill); and Organic Chemistry of Macromolecules, A. Ravve, 1967 (Arnold).

Most textbooks for organic chemistry and physical chemistry gave only the slightest of mention of polymer chemistry, with topics such as perfumes, steroids, and dyes receiving more attention. It is interesting to note that there appears to be no change in lack of emphasis of inclusion of polymer topics in the organic, general, and physical undergraduate and graduate level textbooks since the 1950s through the mid-1970s.

A number of additional short courses and special symposia dealing with specific and general polymer chemistry joined the few that grew from the 1940s and 1950s. These mainly originated from academic institutes such as the one associated with paint-related topics based at what is now the University of Missouri–Rolla. Severl companies such as Hercules, Monsanto, and DuPont sponsored or permitted informal courses in polymer-related topics to be presented during company time and/or using company facilities. The "teachers" or discussion leaders could be either one of the participants or an invited academic or industrial "expert." These "in-house" courses have increased in popularity and today are part of many companies schedule of activity.

The beginning of the 1970s saw a continuation of the academic apathy which marked the 1960s–a pattern which was not to be broken until about 1974.

A 1972 National Science Foundation workshop, co-organized by Professor F. R. Eirich and M. Williams, concluded "that the importance of the polymer industry, not withstanding its being one of the major segments of the United States economy, has not been fully appreciated by the public, government and academia. As a result,

government incentives to promote and extend scientific and technological progress have been lacking, balanced provision for personnel training has been inadequate, a coordinated national policy has not been formulated, ecological considerations have not been sufficiently evaluated, the extremely important economic potential of the polymer industry has not been generally recognized, expecially in connection with the international leadership position in polymer science engineering and technology, and it was the collective opinion that we are rapidly losing our advantage in many vital areas ..." [5].

The ACS Committee on Professional Training noted that "industry continues to use a major fraction of its chemists in various aspects of polymers, synthetic fibers, elastomers, and related structural materials, an area given cursory treatment in all but a few of our graduate departments of chemistry" [6].

Dr. Paul Lindemeyer, previously with the National Science Foundation, indicated concern about a number of factors which can lead to loss of United States world and economic leadership in polymer science–"... the decline of industrial support for basic polymer science, the lack of recognition of polymer science in our universities and the nearly complete absence of coordinated public support ..." [7].

Maurice Morton chaired a symposium jointly sponsored by the Divisions of Chemical Education and Polymer Chemistry (ACS) held at the 164th National Meeting in New York City, August 29, 1972, dealing with "Learning Chemistry from the Macromolecules" [8] which was meant to illustrate how the inclusion of polymer topics can actually enhance student interest in classical academic classes.

The SPE Education Committee began surveying college level course offerings of polymer-related courses in 1951 followed by surveys in 1953, 1956, 1960, 1964, and 1967 [4]. These surveys are not to be considered complete, but selected universities were surveyed, the last three surveys being conducted utilizing arts and sciences, engineering, and graduate school bulletins. Such schools as the University of Southern Mississippi (offering courses since the 1940s), North Dakota State University (offering courses since the 1940s), University of Missouri–Kansas City (which offered a doctorate with a major in polymer chemistry by 1966), and the University of South Dakota (which offered courses since the 1950s) were omitted. The final three surveys were limited to include only 106 schools. The surveys are valid regarding trends within the selected 106 schools. From 1960 to 1967 the percentage of institutions (of the 106 studied) offering at least one course in polymer science increased from 79 to 93%. Twenty-three of the schools offered more than 20 credits in polymers in 1967 with only about 10 offering degrees in polymer science or related areas. Total credits in 1967 were reported to be 1528 with 387 (25%) offered in departments of chemical engineering and 434 (28%) offered in departments of chemistry. Only 16 schools reportedly offered polymer laboratory courses.

Salamone, Deanin, Young, and Pearce reported another survey in 1973 on polymer education in academia in the United States [9]. Of

those schools responding, 104 reported offering at least one course in polymer chemistry. I know of about a half-dozen other schools that also regularly offered courses in polymers which were not included in the survey. As of 1971, there were probably about 125 schools in the United States, or about 10% (as of 1969 there were about 1014 departments of chemistry at the college and university level in the United states), offering courses in polymer chemistry. Of the reported 104 schools which offered courses in polymer science, 46, or about 44%, did not offer any polymer courses within their departments of chemistry. The largest course offerings were at the University of Akron, 93 credit hours (23 in chemistry); Case Western Reserve University, 59 (zero); University of Connecticut, 33 (24); Lowell Technological Institute, 120 (34); University of Massachusetts, 58 (6); Newark College of Engineering, 33 (zero); North Dakota State University, 39 (zero); Polytechnic Institute of Brooklyn, 32 (12); Rensslaer Polytechnic Institute, 31 (19); Richmond College, CUNY, 30 (27); University of Southern Mississippi, 91 (5); University of Tennessee, 30 (6); Washington University, 30 (zero); and the University of Wisconsin, 39 (7). Thirty-two schools offered programs and degrees in polymer science and engineering with typical degrees being in Polymer Science, Macromolecular Science, Materials Science, Plastics Technology, and Polymer Chemistry or within a department within the units offering the emphasis or within a Department of Materials Science. The majority of these programs were interdisciplinary in nature and jointly sponsored.

It is difficult to compare the SPE surveys of the 1950s and 1960s [4] with the Salamone, Deanin, Young, Pearce survey of 1971-1972 [9] since the surveying was done in a different way. The SPE later surveys were developed from 106 selected schools utilizing their bulletins whereas the ACS survey was generated using questionnaires covering a wider potential audience but in reality ending with about the same number of schools–106 compared to 104. There is a large overlap with school covered (about 72%), thus some general comparisons can be made. While the number of total hours increased from 1528 in 1967 to 1841 in 1972, the number of hours offered by chemistry departments remained about the same (434 in 1967 and 459 in 1972) but the number of credit hours offered in departments of chemical engineering increased (387 in 1967 and 553 in 1972). The number of schools offering degree programs increased (from 10 in 1967 to 32 in 1972). There was an increased emphasis in polymer laboratory courses (from 16 schools in 1967 to 36 in 1972), but the actual schools offering at least some polymer laboratory experiences is probably much greater since many of the "lecture" courses included laboratory portions.

There has been an early and continuing interest of industry to foster and encourage the inclusion of polymer related topics into academics since the 1940s. For instance, since the early 1950s The Society of the Plastics Industry has made available a brochure entitled A Program for Plastics Education in Science and Engineering. Even

with such interest, no real widespread impact resulted, possibly due to a number of factors including those already noted. Additionally, the unfamiliarity of most advocates of polymer chemistry as to how to influence the academic machinery through such organizations as the ACS Division of Chemical Education and the associated committees dealing with education matters and the American Science Teachers Association contributed to this lack of progress. As will be noted later, the real move toward greater inclusion of polymer chemistry in academia had to await key appointments.

In summary, the period from the 1940s through 1973 saw a steady, healthy increase in postgraduate education spearheaded by academics, industry, and government and a slower, steady increase in the number of schools offering graduate education in polymer chemistry, but the latter was clearly undernourished in comparison with the relative importance of polymer chemistry in industry. By the 1950s, polymer chemistry had largely made the transition from a largely empirically based branch of endeavor to a strong, well-developed scientifically based major branch of science.

RECOGNITION: 1974 TO PRESENT

William Bailey's presidential address again challenged academic centers to come to grips with the lack of proper recognition of polymer science. This time the call did not die but acted as a signal for the Polymer Division's Education and Public Relations Committees to coalesce under a common cause of increased emphasis of polymer chemistry in academia. Further important key committee positions were being filled by advocates of increased emphasis of polymer science in the training of academic chemists. This was being done through the offices of Bill Bailey and others.

The initial meeting where the formulation of an overall plan occurred took place at the Atlantic City ACS meeting in 1974 at the direction of Joe Salamone and Eli Pearce who called myself and others under the auspices of the Division of Polymer Chemistry's Committees on Education and Public Relations. We kiddingly referred to this meeting as the "Vienna Meeting"—named for the restaurant where we first met. We agreed that not only was graduate education in polymer chemistry lacking the emphasis it deserved and that previous attempts aimed at increasing the emphasis of polymers in graduate education had received only minimal success, but that there was almost no emphasis on undergraduate education related to polymer chemistry. Rather than repeating the same programs that had received minimal success aimed at graduate education, we were convinced that the solution to the problem of polymer education throughout the educational levels would better be solved if we focused our efforts on undergraduate education which would result in a much easier upward flow of interest in polymer chemistry if we were successful at the undergraduate

level. Further we realized that we needed a large-scale, well-orchestrated approach with the cooperation of all of the subpolymer disciplines and their many members. That week I contacted Lieng-Huang (Sam) Lee, Clara Craver, and George Brewer concerning our proposed emphasis. Their support was quite positive, asking me to serve as Education Liaison and to compose an Education Committee for the Division of Organic Coatings and Plastics Chemistry.

Of note was (and continues to be) the efforts of the joint Education Committees of the Divisions of Polymer Chemistry (chaired by Eli Pearce; presently chaired by Guy Donaruma) and Organic Coatings and Plastics Chemistry (chaired by Charles Carraher). Most of the accomplishments noted following could not have been accomplished without the joint cooperation of these two committees which acted as one "super" committee.

The period between the Atlantic City meeting and the Philadelphia meeting was very active, and directions for achieving our goal were cemented. The major steps were 1) preliminary investigation aimed at obtaining NSF support for summer short courses in polymer chemistry for college teachers of undergraduate general, organic, analytical and physical chemistry; 2) generation of a laboratory manual for use in undergraduate courses of general, organic, and physical chemistry–using polymer exercises to illustrate chemical principles usually illustrated utilizing nonpolymers; 3) contacting Stanley Kirschner and the ACS Committee on Education concerning support for the greater emphasis of polymer chemistry in undergraduate curriculum; 4) contacting Theo Ashford and the Examinations Committee offering the services of polymer chemists to serve on examination committees (Les Sperling has served admirably as our liaison in this behalf); 5) working with John Howard and the Committee on Professional Training (ACS) to include a course in introductory polymer chemistry as a recommended advanced course for the ACS Approved Major; and 6) working with "popular" chemistry journals toward greater inclusion of polymer-related topics. It is interesting to note the overlap between the steps we independently generated and those offered by one of the inventors of butyl rubber, William J. Sparks, in 1967 (Ref. 2, p. 505).

A preliminary proposal related to the summer short courses was drafted by Eli Pearce and myself. This was submitted to the NSF Education Office of Experimental Projects and Programs in November of 1974. Papers were also prepared and presented to members of the ACS Committee on Professional Training and the Committee on Education. During this time, Bill Bailey and others were active in our support. In December 1974 we received from NSF a request for a formal proposal.

The Council Committee on Chemical Education went on record at the Philadelphia meeting favoring greater emphasis of polymer chemistry in the undergraduate training of chemists. Through the efforts of many, the Committee on Professional Training voted to include a course in polymer chemistry in the ACS approved major in the 1978 publication. This topic will be considered later in greater detail.

At the Philadelphia meeting, Ray Seymour and myself met with the ACS Examinations Committee. We were asked to generate answers to a number of questions in preparation for a decision by them to support or not support an ACS standardized test in polymer chemistry. To gather information needed for this and other projects, Rudy Deanin surveyed over 110 departments offering courses in polymer chemistry, assessing the potential need and use of a standardized test in polymer chemistry and evalutating topics which should be included within an introductory polymer course. Shalaby Shalaby and Eli Pearce were asked to edit an issue of Chemistry devoted to polymer chemistry.

During this time the first ACS interaction Series–"Polymer Science and Technology–An Interdisciplinary Approach" - under the direction of Eli Pearce, Shalaby Shalaby, and Garth Wilkes was under preparation.

I met with the ACS Examinations Committee at the Chicago ACS meeting and presented the results of Deanin's survey. I was asked to formulate and chair a testing committee for the purpose of generating a standardized test.

The results of the Deanin-Carraher survey are of interest because they were used to help "drive" the proportion of questions within given polymer areas. They also show a fairly good commonality of desired course content for an introductory course in polymer chemistry, something that was hoped for but something that was not known. Ten of 24 topics obtained a rating of 80% +, including measurements of molecular weight and size, polymer structure and physical properties, stepwise polymerizations, radical-chain polymerization, molecular forces and chemical bonding in polymers, copolymerization, morphology and order in crystalline polymers, polymer solutions, rheology and mechanical properties of polymers, and ionic and coordination chain polymerizations (in decreasing order of preference).

The Ninth Biennial Education Conference of the ACS met on October 16-18, 1975, and strongly endorsed the need for increased emphasis of polymer education.

At the ACS meeting in New York City, two pretests were constructed for use. This was done with the considerable help of Charles Gebelein, Les Sperling, and Angelo Volpe utilizing Deanin's survey of topics as a guide. The ACS, through the active support of the Divisions of Polymer Chemistry and Organic Coatings and Plastics Chemistry, helped in the generation of this examination. Over 60 contributors from schools and industry directly helped in such areas as pretesting and submission of questions. Thus the generation of the first ACS Stardardized Examination in polymer chemistry was accomplished with help from a wide base. The examination has sold about 1000 copies during the first year since its publication in 1978. Considerable interest has been shown by chemical societies from other nations in the examination, and the ACS Committee on Examinations is currently considering permitting its use outside of the United States. This

examination should assist in generating additional commonality in introductory courses. I believe that some diversity is important to relect the breadth of polymer science–textiles, natural materials, rubbers, plastics, materials engineering and processing, etc. Thus, while there is an aim toward standardization of content and topics, it is generall accepted that the amount of this "standardization" should only be in the 70 to 80% range.

The NSF proposed Short Course in Polymer Chemistry died a death of old age since, by the time it emerged from CEPACC in 1977, the climate at NSF had changed so that teacher retraining programs were no longer in fashion even though a strong case was made that this was of such a strong need and of sufficient worth to the United States that an exception should be made. The Divisions of Polymer Chemistry and Organic Coatings and Plastics Chemistry still believe in this program and are currently looking toward industry to help finance several mini-short course projects. If successful, these could begin in the summer of 1982. In the fall of 1979, the Columbus Section of the ACS offered a short course series, similar to that outlined in our proposal, illustrating that such programs can be conducted locally, using local "talent."

Probably the most significant single event in polymer education occurred in 1978. The latest edition of Undergraduate Professional Education in Chemistry: Criteria and Evaluation Procedures by the ACS Committee on Professional Training states: "In view of the current importance of inorganic chemistry, biochemistry, and polymer chemistry, advanced courses in these areas are especially recommended and students should be strongly encouraged to take one or more of them. Furthermore, the basic aspects of these three important areas should be included at some place in the core material." After almost 30 years as a king of the sciences, polymer chemistry has been recognized as essential core material in the training of all ACS accredited undergraduate majors.

The full impact of these new provisions is yet to be fully recognized. What is being advocated is that polymer chemistry is being recommended as advanced work, but possibly of greater importance, that "basic aspects" of polymer chemistry be included in the core material. The education committees of a number of divisions and societies associated with polymer science are working toward adopting recommendations involved with these two major related points.

The establishing of a somewhat standard introductory course in polymer chemistry with respect to content and depth has begun. Frank Harris has been working for some time on the generation of a model course content for a polymer course which considers physical topics first, followed by topics associated with organic aspects. Charles Gebelein and others are active at drafting a general outline for more "traditional" (orderwise) introductory courses where topics in organic aspects are intermixed with topics on physical properties, solution behavior, etc. Generation of the first standardized examination in polymer chemistry will also assist in "standardizing" course content

and level. Further, national surveys such as the Deanin-Carraher and Gebelein surveys will assist in developing course content.

The content, level, and duration of the introductory course is actively being evolved, and evolution will continue, hopefully with the active assistance of those teaching introductory courses. There is a strong feeling among those in many of the education committees that the introductory course should contain a laboratory portion which may include both synthesis and characterization of a polymer. This laboratory portion should emphasize topics covered in the lecture portion, giving students first-hand experience in the "joy and trauma" of polymer science (such as polymers typically taking several days before becoming dissolved).

Much less has been done concerning what, where, and to what extent should "basic" polymer concepts be presented in the core offerings which normally includes one year of basic general chemistry (including descriptive inorganic chemistry and qualitative chemistry), one year of organic chemistry, one year of physical chemistry, and one semester of instrumental analysis.

We must address the "where, extent, and what" of polymer concepts before "purists" are able to extract polymer chemistry from its newly deserved place in core material. We have advocated inclusion of basic polymer concepts into existing courses including analytical, inorganic, organic, and physical chemistry but not the exclusion of other basic material. Polymer chemistry deserves a proportion of the student's time as do other more traditional topics, and what should be done is that the proportion of time spent on given general topics should be in a general (!) manner described by the ACS. We, as polymer chemists, must be a part of this discussion and final action.

The question as to "where" basic polymer concepts and examples should be included has a brief solution in that polymer topics, concepts, and examples naturally fall from topics classically covered in all of the core (traditional) offerings, and it is the experience of most teachers that inclusion of polymer-related material appears to "turn on" students. Again, inclusion of polymer-related material can usually be done with little loss of conceptual content, but with enhancement of coverage being the general rule.

Following are other current and recent-past ventures related to polymer education. A series of experiments appeared in the 1978 Journal of Chemical Education which were aimed at introducing polymer-related experiments into traditional courses [10]. More of this type of presentation must be forthcoming.

NSF funded polymer science modular experiments are now available from Eli Pearce. There are 15 of these modules for use with an introductory polymer science course or for use with a separate beginning polymer laboratory course.

There is an increased awareness of the place of history in science, particularly polymer science, where many of those who contributed the basic building blocks are still alive. Ray Seymour is doing a series on the Pioneers of Polymer Science for Polymer News.

Fred Eirich has been asked by the Journal of Chemical Education to write a history of the development of the "macromolecular concept." (As a side comment, those associated with the Journal of Chemical Education, such as Tom Lippincott, have been "friendly" toward polymer chemistry and have assisted in the attempt to bring polymer chemistry into the mainstream of material presented to both the teaching staff and chemistry students alike.)

Recently, the Education Committees of the Polymer and Organic Coatings and Plastics Chemistry Divisions initiated a tape cassette program asking a number of pioneers of polymer science to recite their thoughts, philosophies, recollections, etc. not to form an oral history, but rather so in years to come teachers can play portions of the tapes to their students and say, "This is what Carl Marvel says about ... in his own words." This program is ongoing. V. Harry DuBois has also compiled a series of cassettes by plastics pioneers and these are displayed in the Smithsonian Institute in Washington.

Polymer News, edited by Gery Kirshenbaum, has a long-standing series featuring academic polymer centers. Those associated with the particular institution are asked to present their programs, aspirations, intents, etc. These are typically well done. Polymer News also features a column on Polymer Education which offers a wide variety of information including booklets, tapes, and films related to polymer science; special education (academic and inservice) experiments; polymer science education outside of the United States; recent activity in education committees; featured polymer chemists in academics; reports on education related conferences; etc.

The Manufacturing Chemists Association (now the Chemists Manufacturing Association) presented four polymer chemists with national MCA Chemistry Teacher Awards, the latest awardee being Malcolm Renfrew in 1977. The others are Walter Stockmayer (1960), Eugene Rochow (1970), and Raymond Seymour (1976).

Once a year the Polymer Division includes within their publications, Polymer Preprints, addresses, topics and abstracts, and duration and level of polymer-related talks which members of the Polymer Division are willing to give. This is coordinated by Eli Perry. SPE also has a list of speakers dealing with plastics. The Public Relations Committee of the Polymer Division also periodically publishes, again in the Polymer Preprints, a listing of available films related to polymer chemistry suitable for use from K-college and for classroom or general audience.

Under the leadership of Eli Pearce and Shalaby Shalaby, and the sponsorship of the Divisions of Polymer Chemistry and Organic Coatings and Plastics Chemistry, an entire issue of Chemistry was devoted to polymer chemistry (Vo. 51, No. 5, June 1978). Several thousand extra copies were purchased for a wide variety of uses by academic and industrial organizations for distribution to youth and the general public.

Two national ACS-related symposia with polymer education were conducted in 1979. Both were co-chaired by Eli Pearce and Charles Carraher. The first occured during the Hawaii ACS meeting and was

initiated at the invitation of Robert Brasted on behalf of the Division of Chemical Education and jointly sponsored by the Divisions of Organic Coatings and Plastics Chemistry and Polymer Chemistry. Topics were centered about helps and introductory course contents. The second symposium occurred at the Washington, D.C., meeting co-sponsored by the same three divisions. This was a full symposium with about 20 talks given, varying from how to introduce polymer topics into undergraduate courses of inorganic, organic, and physical chemistry to those noting the importance of polymers to society and to the proper education of chemists and to special projects related to polymer education.

In summary, the 1970s began with the same academic passiveness toward polymer education that marked the 1950s and 1960s, but in 1974 major developments aimed at the greater inclusion of polymer chemistry into the curriculum of chemists began and for the first time emphasized the undergraduate training of chemists. The most significant single event was the ACS pronouncement that aspects of polymer chemistry were to be core material in the training of ACS accredited chemistry majors.

CONTINUING EDUCATION

While much of the previous material centered about formal aspects of polymer education focusing on academic institutions, there are an increasing number of opportunities which can be loosely grouped under the title of continuing education. This includes the following which have already been discussed: 1) proposed national NSF funded summer short course program for the purpose of introducing academic professors to fundamentals of polymer chemistry, and 2) correspondence course in "Polymer Science and Technology" sponsored by the ACS and Division of Polymer Chemistry.

Following is a brief description of only some of the many continuing education opportunities now available in polymer science. The majority are highly technical "state-of-the-art" presentations of necessity servicing a limited number of scientists.

Continuing education formats are quite varied and can include almost any of the devices that are being developed in other education areas as delivery vehicles including a wide variety of short courses including those given at a central institution or within the confines of the particular industrial concern, correspondence courses, TV tapes (both live and pre-recorded), audio and video tapes supplemented by printed or live group discussion leader material, films or film strips and slide presentations, computer-assisted instruction, programmed textbooks, seminars, and combinations of the above. Their delivery modes can be associated with technical conferences and meetings, sales conventions, expositions, etc.

There are numerous other continuing education opportunities including the already mentioned short courses. Aspects of continuing education are more fully developed in Ref. 11.

The continuing education opportunities are essential and must be continued. The extent of such ventures is somewhat unusual relative to other areas of chemistry and is remindful of what is also occurring within the area of computers where academics is unable to supply the necessary "state-of-the-art" educational opportunities. These continuing education opportunities are typically not suitable for use with the training of academic polymer chemists for the single reason of their high cost which is typically borne by the employer. An exception is closed circuit or educational TV programs which can be easily monitored by the academic community.

The Society of Plastics Engineers (SPE) has an Education Committee that has been quite active in a number of ventures including frequent surveys of course offerings by American Universities. The SPE also offers an annual technical conference (ANTEC) featuring technical symposia and sessions on the engineering aspects of polymers, divisional technical conferences (DIVTEC), and regional technical conferences (RETEC) along with a number of special meetings emphasizing recent advances. At intervals the SPE publishes a polymer science book list.

The Plastics Institute of America (PIA) is a nonprofit corporation with headquarters at the Stevens Institute of Technology. It was founded in 1961 and was formed as a result of the recognition by the SPE and SPI that there was a need for the plastics industry to participate in enhancing the availability of scientists motivated and trained to work in the plastics industry. Courses offered by PIA are designed to give participants a familiarity and competence within specific area such as polymer additives, extrusion processes, injection molding practices, coloring, packaging, and flame retardants in fibers. New courses are generated to meet needs, and course content varies to include new practices. There are now over 30 courses presented at Stevens Institute of Technology and about 15 other cooperating centers of learning.

The PIA and the ACS offer a number of audio courses including topics concerning injection molding, mechanical properties of plastics, and rheology of polymer melts. Both the ACS and PIR offer audio courses in "Introduction to Polymer Chemistry" by Ray Seymour and Angelo Volpe, respectively. Mini-audio courses are currently being developed by PIA which would consist of only one or two cassettes plus a manual to cover timely topics.

Areas that appear to be minimized are those of polymer science applied to such health-related areas as artificial limbs, blood, heart-portions, and particularly natural polymers. The latter point will be commented on later.

An additional consideration concerns reevaluation of the aim of most of the postgraduate ventures which now consist of presentations of highly technical "state-of-the-art" aspects of polymer science and technology. Might it not be better to offer more courses in the basics of polymer principles, textile principles, etc., allowing the participant to place his experiences and training within a growing framework,

and allowing more free flow of the participant from one specific project to another with some appreciation of the overall principles involved in his general area of research?

In summation, polymer-related continuing education opportunities are necessary and dynamic and will continue to increase. The societies, etc., putting on these programs may consider presenting related programs for academic chemists free or at reduced fees.

CURRENT PROJECTS AND FUTURE TRENDS

About 83% of the professional chemists are employed in industry and government. According to the latest survey made by the joint ACS Education Committees of the Divisions of Polymer Chemistry and Organic Coatings and Plastics Chemistry made by Gebelein in 1979, over one-third of all current technical personnel in chemical companies are involved in polymer chemistry. This survey was directed at presidents, vice-presidents, and research or technical directors. The technical persons included many nonchemists and did not necessarily include monomer synthesis, etc. Thus it is not out of line with other surveys which typically report that about 40 to 60% of all professional chemists are engaged in polymer chemistry and about another 10 to 30% are indirectly related to polymer chemistry. An average value of those indirectly and directly engaged in polymer chemistry is probably about 50%.

What is going to be the future demand for polymer chemists? The exact numbers are unknown but we can carry out a simple calculation based on generally acceptable assumptions to gain insight as to the general magnitude of need.

There are about 200,000 professional chemists (ACS membership is about 120,000) in the United States with about one-half directly and indirectly involved with polymers. The polymer-based industries are expanding at an approximate rate of 10% yearly, meaning that about 10,000 additional chemists will be added yearly to the ranks of polymer chemistry. There are about 150 colleges and universities teaching one or more polymer courses, so each of these colleges should average about 70 students graduating with a varied formal exposure to polymer chemistry to meet the demand. Not even the largest polymer-based programs graduate near 70 students per year with any in-depth exposure to polymer chemistry. The actual percentage of students graduating with even one course in polymer chemstry is at the most 15% (150 schools offering polymer courses/1000 total schools) assuming that all students that graduate from the school offering polymer courses take these polymer courses. (The latter assumption is not valid. For instance, only about one-half of our chemistry majors take our polymer courses, and our indications are that this is high since many of the schools that do offer polymer courses do not do so within the Department of Chemistry, etc.)

Understanding of the basic principles underlying polymer science assists in the description of behaviors and properties of smaller molecules since polymers often accentuate subtle differences in the behavior of smaller molecules leading to a clearer, more accurate description of the physical and chemical nature of smaller molecules. Thus many of these principles are basic to all of chemistry and should be included in the curriculum for chemists and chemical engineers.

Current projects include 1) generation of a twice yearly newsletter covering aspects of polymer education which would go to the Departments of Chemistry of four- and two-year colleges and universities and to polymer chemists in academics; 2) survey of polymer courses and trends within academics, 3) generation of a number of model course outlines; 4) intense discussion related to the inclusion of polymer chemistry topics, concepts, and examples into the undergraduate courses; 5) greater emphasis on in-service training of both academic and nonacademic situated chemists in the basics of polymer science; 6) strengthening bonds between industry (the user) and academics (the generator) in the training of chemists in aspects of industrial chemistry; and 7) presentation of an abbreviated short course series aimed at introducing basic polymer concepts to current teachers of undergraduate general, organic, inorganic, physical, and analytical chemistry.

There is what I believe to be an unhealthy trend toward isolation of polymer chemistry from chemistry with the formation of a few excellent centers of academic polymer chemistry. While the formation of such centers is in itself positive, the trend for polymer chemists to be located in macromolecular institutes, chemical engineering departments, etc. but away from chemistry departments can result in future stagnation in the training of the bulk of chemists. Thus most chemists, many who eventually will become practicing polymer chemists, will have omitted from their academic training the integration of basic concepts related to and aptly demonstrated by polymers.

Related to the institutes, these institutes need not be large to be effective. For instance, the Department of Polymers and Coatings at North Dakota State University includes Zeno Wicks as chairman and Peter Pappas and Loren Hill on a shared basis with the Department of Chemistry. One of the most rapidly growing institutions is that at the University of Southern Mississippi under George Bufkin where the addition of five new positions is planned over the next 3 years. This institution, which has been designated as the center of the state systems formal venture into polymer science, will also offer a correspondence course in coatings science. It appears that many of the institutions are trying to create their own images to be distinguished from other institutions. This is probably healthy if not overdone, contributing to the vastness and variety that is polymer science.

There continues gradual growth in the number of institutions offering introductory and advanced training in polymer chemistry. This trend should become accentuated as the ACS Guidelines for the preparation of undergraduates becomes more appreciated.

The increased awareness of polymer chemistry has been assisted by the large proportion of ACS presidents who were polymer chemists. Polymer chemists must continue to take active roles in the decisions which influence the direction of such societies as the ACS if polymer chemistry is to recognize its role as a King of Science.

There are still a number of problem areas, some of which are being addressed in current projects. Others which are not yet addressed are the lack of substantial grant and contract support of academic polymer-related research. It can be argued that since only 3 to 5% of the academic chemistry community is active in polymer chemistry, the grant level should only be 3 to 5%. If this argument is to be permitted to stand, then the status quo will be maintained and the move toward necessarily greater inclusion of polymer chemistry into academics will be directly opposed [12].

A second problem lies in the continued lack of general acceptance of polymer chemistry as a science worthy of inclusion in proper, classical academic settings. This must change and is gradually changing. We must be friendly but persistent. We must spread the message of polymer chemistry as a valid science to be included naturally into the academic training of chemists; we must encourage textbook writers to incorporate polymer examples, topics, concepts, etc. into their books.

A third area which has been almost totally ignored is the recognition that those principles which apply to synthetic polymers are also valid for biopolymers. We need to work within both our own ranks and with groups such as the ACS Division of Biological Chemistry toward rectifying this void.

In summary, polymer education can be divided into three periods–Historical and Empirical, Developing, and Recognition–with the latter period still in effect. We must continued to be active at promoting the greater inclusion of polymer topics, illustrations, and concepts into the formal and informal education of our chemists and chemical engineers, not just because we ourselves are polymer chemists, but because it is critical to the growth of our industries, our nation, as well as many related branches of science, health, and technology.

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