THE R.J. REYNOLDS TOBACCO COMPANY
AWARD FOR EXCELLENCE
IN TEACHING, RESEARCH, AND EXTENSION
DISTINGUISHED LECTURE SERIES

Lifelong Learning and Teaching in a Changing Profession

by

Dr. Carl C. Koch
Professor of Materials Science and Engineering
Associate Head of the Department of Materials Science and Engineering
North Carolina State University

College of Engineering
North Carolina State University
Raleigh, North Carolina

Based on the Lecture Presented November 19, 2003

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NINETEENTH RECIPIENT

DR. CARL C. KOCH

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Dr. Carl C. Koch, a highly influential researcher in materials science and engineering, has achieved notable accomplishments in materials science research, education, and extension. He is an internationally respected researcher; an outstanding teacher and departmental leader at North Carolina State University; a national figure as a former chair of the Minerals, Metals, and Materials Society (TMS) Accreditation Committee and as a former editor of one of the world's foremost materials research journals, *Materials Science and Engineering A*; and an extension leader in the Materials Research Society and National Science Foundation.

Designated one of the most-cited researchers in materials science by the Institute for Scientific Information, he is a charter member of the Highly Cited Researchers database. One of his most-cited works is a pioneering study published in 1983 in *Applied Physics Letters* that describes a novel method for processing amorphous materials in a variety of alloy systems. This mechanical alloying system is now widely used, and the paper has been cited internationally more than 700 times. In October 1995 Dr. Koch was cited in *Science Watch* for the third highest number of citations per paper in the world for high-impact articles in materials science for 1990 through 1994.

Dr. Koch, who joined the College of Engineering faculty in 1983, has been involved in a wide range of activities within the research community at NC State University, including numerous collaborations with researchers in a variety of engineering disciplines. His research interests include nonequilibrium processing, intermetallic compounds, and metastable materials. Collaborative work with other College of Engineering and College of Physical and Mathematical Sciences researchers on the processing, characterization, and superconducting properties of oxide superconductors has provided essential information for the development of these materials. Dr. Koch's studies of the structure and mechanical behavior of nanocrystalline materials are considered seminal in the field and have resulted in numerous international requests for invited conference presentations.

He has achieved the prestigious rank of fellow in several professional societies, including the Minerals, Metals, and Materials Society (TMS), the American Physical Society, ASM International, and the American Association for the Advancement of Science (AAAS) and is a member of the Materials Research Society (MRS) as well as Alpha Sigma Mu, Sigma Xi, and Tau Beta Pi technical honor societies. His professional awards include a Department of Energy Metallurgy and Ceramics Award, an I–R 100 Award, an NSF Research Award for Special Creativity, the Alcoa Distinguished Research Award, and the North Carolina State University Alumni Distinguished Research Award.

Highly active in professional associations, Dr. Koch has been national secretary of the Materials Research Society and a National Science Foundation expert on nanostructured materials. He has served on numerous committees for TMS and MRS. He has followed an interest in accreditation by becoming an evaluator for engineering programs in materials for the Engineering Accreditation Commission (EAC) of the Accreditation Board for Engineering and Technology (ABET) in 1994 and was appointed a member of the Engineering Accreditation Commission of ABET in 1999. In this capacity he led teams of evaluators on university visits to determine accreditation of their engineering programs. He was appointed an editor of *Materials Science and Engineering A* from 1997 to February 1, 2003, and he has served as an associate editor for *NanoStructured Materials* and is presently an editor of *Journal of Metastable and Nanocrystalline Materials*.

Dr. Koch received his bachelor's degree in metallurgical engineering in 1959, his master's degree in metallurgy in 1961, and his doctorate in metallurgy in 1964, all from Case Institute of Technology (now Case Western Reserve University). He was a National Science Foundation Fellow at Birmingham University, England, from 1964 through 1965. In 1965 he joined Oak Ridge National Laboratory, where he began as a staff scientist and advanced to group leader in the superconducting materials then the alloying behavior and design group. He also taught a graduate course in phase transformations at the Oak Ridge campus of the University of Tennessee during this time. Co-holder of three patents, Dr. Koch has edited or co-edited six books and authored or co-authored more than 210 scientific papers.

Contents

Abstract

This paper illustrates the need for lifelong learning and teaching, especially in technological fields. It uses the evolution of the discipline of materials science and engineering as a prime example of the development of a technology/science discipline in terms of research and in academic institutions. The history of the development of materials engineering as a profession, the history of engineering education, and education in materials science and engineering are briefly reviewed as part of this exposition. The career of the author is also used to demonstrate the continual learning necessary to maintain technical competence and to move into new research areas as warranted by changing societal priorities. The need for lifelong learning and teaching is expressed formally by the accreditation process we must satisfy, and the continuous improvement of our educational programs is driven by this and many other factors. Learning new concepts and techniques is often enjoyable for its own sake and can keep one mentally young.

1. Introduction

The need for continued learning throughout one's career is well known in many professional and technical fields, such as medicine and pharmacology. With the explosion of the information and computer revolution, it is becoming necessary in many other vocations. With the rapid pace of changes in the science background and technology of engineering fields, continued learning is clearly of high importance to prevent the obsolescence of one's knowledge and skills and to allow for continued advances in technology and therefore the economy. This need for lifelong learning is formalized in the requirements of the Accreditation Board for Engineering and Technology (ABET) for the accreditation of undergraduate engineering programs. In the list of outcomes deemed necessary for students graduating from accredited engineering programs is Criterion 3 (i) "a recognition of the need for, and an ability to engage in, lifelong learning." While all engineering disciplines have this need, the field of materials science and engineering presents a notable example of the evolution of a field of engineering/science. This is the author's vocation so he has personal experience with the changes in this field over the 45 years since he received his BS degree in metallurgical engineering.

The scope of this paper will include a brief discussion of what defines an academic discipline, the precursors of materials science and engineering as a field, the evolution of engineering education, and the evolution of materials science and engineering in academia, industry, and professional societies and journals. A very personal example of the need to learn new subjects and skills will be presented for the author's career from his graduation in 1959 to the present time. The paper will conclude with a discussion of the challenge for teaching undergraduates and graduate students in our evolving field of materials science and engineering.

2. What Defines an Academic Discipline?

Since the topic of this paper is the need for lifelong learning with the example of the evolution of the discipline of materials science and engineering, the definition of what comprises a discipline must be discussed. In a recent book, *The Coming of Materials Science*, [1] written by the distinguished materials scientist Robert Cahn, a chapter is devoted to "the emergence of disciplines." In this chapter, Cahn quotes the famous theoretical solid-state physicist, John Ziman, who defines the elements that comprise a scientific discipline. He says,

> Academic science could not function without some sort of internal social structure. This structure is provided by subject specialization. Academic science is divided into disciplines, each of which is a recognized domain of organized teaching and research. . . . An academic discipline is much more than a conglomerate of university departments, learned societies and scientific journals. It is an "invisible college" whose members share a particular research tradition. . . . A recognized discipline provides an academic scientist with a home base, a tribal identity, a social stage on which to perform as a researcher.

While this definition is specific to science disciplines it also partially applies to an "applied science" discipline like materials science and engineering. It is convenient to consider the following aspects of a discipline: (1) a university program or department, (2) the professional societies that serve the discipline, and (3) the journals that record the scientific and engineering progress of the field.

The concept of academic disciplines may be traced back to the medieval universities [2]. While in ancient Greece there were groups of learned societies that were concerned with a broad range of studies including mathematics, natural science, and philosophy, the concept of a university with distinct “disciplines” did not occur until the Middle Ages. In the early Middle Ages in Europe, education was provided mainly to the clergy and to some members of the ruling classes. Scholarship and education were focused to a large extent into translating, organizing, copying, and codifying sacred texts and materials from classical Greece and Rome. Education was conducted mostly in cathedral and monastery schools or in the private homes of the wealthy.

Charlemagne recognized the need for a literate bureaucracy to administer his empire so he decreed the formation of cathedral schools. The schools that had existed in the eastern part of the Roman Empire in Alexandria, Antioch, Athens, and Constantinople were storehouses of classical learning. The triumph of Islam in the Middle East and Northern Africa led to dissemination of classical and oriental learning to Europe from Spain, and teachers in cathedral schools from Spain. Along with theology and law, mathematics, astronomy, and the natural sciences became part of the curriculum in some cathedral schools. Pope Gregory VII issued a papal decree in 1079 mandating the creation of cathedral schools that would be responsible for educating the clergy.

The first recognized university was that of Bologna, founded in 1088. The liberal arts curriculum in medieval universities prepared students for careers in the church, law, business, and education. The curriculum, with its different disciplines, followed the Aristotelian models of ancient Greece and consisted of seven “disciplines”[3]. These seven disciplines were divided into two groupings: the *trivium*, which comprised the three verbal arts of grammar, rhetoric, and logic, and the *quadrivium*, which consisted of arithmetic, astronomy, geometry, and music. The quadrivium disciplines were considered the higher level subjects, and it is believed the term “trivial” is based on the trivium’s being the lower level disciplines. For a scientist/engineer, it is interesting to note that the quadrivium disciplines all had a major mathematical component. This includes music, which in terms of theory and composition is very mathematical in nature. These definitions of disciplines still form to some extent the categorization of disciplines in modern liberal arts education. The field of engineering was, as will be discussed in more detail below, not part of the education in medieval universities.

3. Materials and the Development of Civilizations

Before describing the evolution of engineering education and specifically education in the field of materials science and engineering, a brief discussion of the roll of materials in the development of civilizations will be given [4]. Early humans and, we now know, other primates used materials that were available to them in order to help them survive. Simple tools such as sticks and rocks could be used to help gather and hunt for food as well as provide shelter from the elements. In their struggle for survival, our ancestors came to realize that certain rocks they found could be useful for making weapons and tools. Flint and obsidian were particularly useful in these regards. While there is much speculation about the use of the stone tools found at the earliest human sites in East Africa, it is reasonable to assume they were used to butcher animals for food and clothing, to dig up roots and tubers, to crack open hard-shelled nuts, and to perform other tasks. Material developments produced more advanced tools such as axes, with the stone cutting tool fastened to a wooden handle with tree resin or bitumen. Finally, the bow and arrow were invented, which greatly facilitated hunting and warfare. Besides stone and wood, other materials such as bone and ivory were used by early man to make tools such as needles for sewing hides and hooks for fishing.

Archaeologists and historians have classified the epochs of ancient man into the “ages,” delineated by the most important materials that were dominant. Therefore we have the Old Stone Age — Paleolithic Period — of hunters and gatherers, followed by the New Stone Age — Neolithic Period — in which man began to settle down into fixed communities. The fashioning of effective tools presumably became a specialized task undertaken by those who were most proficient. The subsequent “ages” of ancient times were the Copper Age (about 4500 BC), the Bronze Age (about

3000 BC), and the Iron Age (about 1200 BC). The first metals used were those, such as copper and gold, that can be found uncombined with other elements, free in nature. Such metals are soft and ductile and were first used as ornaments. In the case of copper, it was found that hammering it, presumably with stone tools, increased its hardness and strength such that it could be made into useful tools. It had the desirable property of being tougher and less brittle than stone tools.

Before the revolutionary invention of smelting metals from their ores was discovered, another revolutionary materials development took place with the common material, clay. Clay minerals are fine-particle-sized hydrous aluminosilicates that develop plasticity when mixed with water. (Clay is well known to gardeners and farmers in the North Carolina Piedmont!) Clay is very malleable and easy to form into shapes such as pots and sickles. Of course, clay is very weak and would not hold its shape under any stress.

The first major materials science/engineering success of mankind was the discovery that by heating up clay it can be transformed into a hard, strong — but brittle — ceramic that can be used for storage of grain, water, wine, and so forth, and for tools such as sickles. Clay can easily be shaped because it has a layered atomic structure (Figure 1) such that it has thin plates, or lamellae, that are weakly bonded to their neighbors. A typical atomic structure of clay consists of an eight-sided (octahedral) arrangement of oxygen atoms enclosing an aluminum atom with a four-sided (tetrahedral) arrangement of oxygen atoms with a silicon atom at its center. Both the octahedral and tetrahedral units are tilted onto their triangular sides. Larger platelike clay crystals are built up by interweaving layers of octahedral units with layers of tetrahedral units and water and hydroxyl molecules. These stacks of crystals can easily slip past one another, like a deck of playing cards, which makes clay so easy to shape. When heated to a high enough temperature, the water and hydroxyl molecules are driven off. The clay then shrinks and a new atomic structure – a ceramic – is formed

This phase transformation from soft, malleable clay to hard, impervious ceramic was a major milestone in materials technology and was a revolution that helped shape agricultural civilizations from hunter-gatherer life. Like most early developments, how the discovery of ceramic

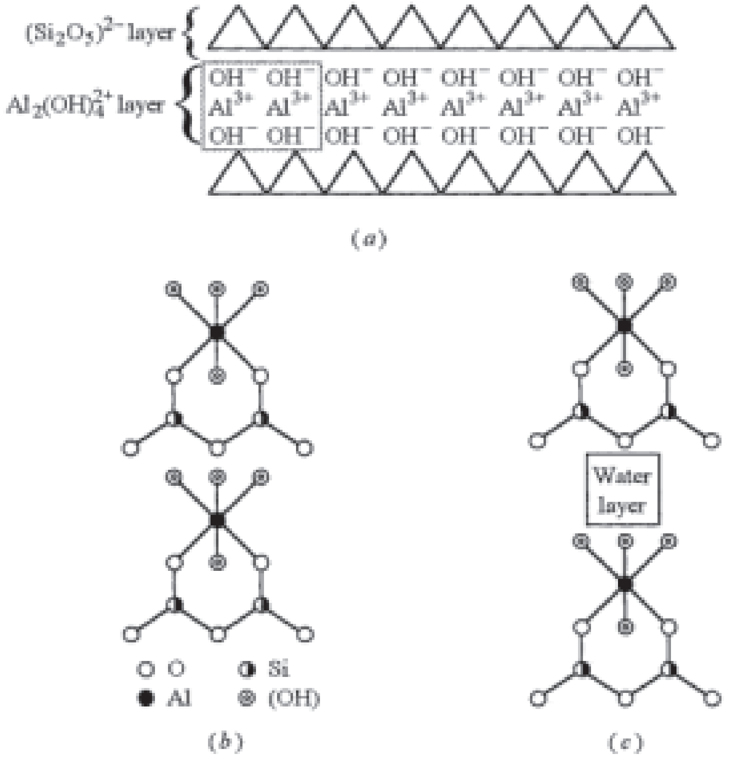

Fig. 1 (a) Structure of Kaolinite clay showing layered structure.
(b) Same structure as in a) but emphasizing bonding at $A1^{3+}$ ious
(c) Same as (b) but hydrated

M. W. Barsoum "Fundamentals of Ceramics" (1997) p. 78 McGraw Hill

formation by firing of clay occurred is not known. It can be speculated that someone accidentally put a clay object into a campfire and later found a hard ceramic among the ashes.

Another major materials technology development that presumably occurred by some serendipitous event was the smelting of copper metal from its ores. The discovery by early craftspeople that shiny, malleable copper could be obtained from certain brittle rocks (ores) required them to recognize the connection between the two very different substances, and then figure out how to extract the copper from its ores. Most important, copper ores are oxides, carbonates, or sulphides. To extract the copper from the compound in which it is trapped requires, typically, a reduction reaction such as $Cu_2O + CO \longrightarrow 2\,Cu + CO_2$. Burning charcoal could be the source of CO for such a reduction, but cooking fires were not hot enough to smelt copper. One possible explanation for the first smelting of copper is that a potter accidentally, or purposely, put the beautiful blue-green copper mineral malachite into his pottery kiln, which would have sufficient temperature and reducing atmosphere (CO) to smelt copper from this ore. To his surprise, after the kiln cooled, he found beads of shiny copper metal and associated them with the copper found free in stream beds.

Some copper ores used by the ancients contained arsenic, and the first copper alloys were copper-arsenic, which provided more strength than pure copper tools. However, arsenic-containing ores were limited, and there were technical and health problems associated with the volatile arsenic trioxide that could result from smelting these ores. Ancient man in Mesopotamia next found that, by adding tin to copper, a stronger alloy — bronze — could be obtained. The invention of the stronger, but still tough, bronze alloy allowed craftsmen to develop tools like saws and drills that were difficult to produce from copper or stone. Iron alloys were potentially stronger than bronze but much more difficult to extract from their ores. The melting temperature of iron is higher (1536˚C) than the highest temperatures available to ancient craftsmen (about 1200˚C) so, while it could be reduced from its ores with hot charcoal, solid iron mixed with unburnt charcoal and oxide, and silicate impurities (slag) was the result. This mixture could be heated and beat with a hammer to break out the brittle slag and charcoal. The resulting “wrought iron” was nearly pure iron and not as strong as bronze. Steel, which is an alloy of iron and carbon, could be made by heating the wrought iron in a carbon atmosphere for a long time to allow diffusion of carbon atoms into the iron. If the steel was then heated to a high temperature and quenched into water, and then subsequently heated at a lower temperature, the strong and tough “tempered martensite” structured steel could be formed, which is greatly superior to bronze in its mechanical properties

The development of such advanced metallic alloys must have been the result of trial and error and serendipity over many years. The craftsmen who developed these methods passed them on to their apprentices.

Besides the metals/alloys that have given their names to the Bronze Age and the Iron Age, other important materials, for example, glass by the Phoenicians and concrete by the Romans, were developed. Some knowledge of materials was lost during the Dark and early Middle Ages, such as the Roman composition for mortar. Otherwise, in Europe the material developments of the ancients were maintained but not significantly improved upon.

Innovations came from the East — India and China — through the Islamic Caliphate. Such items as gunpowder, paper, and the Damascus sword (Figure 2) are examples of materials transferred to Europe from and through Islamic countries. Materials development during all these periods was in the hands of craftsmen who typically learned their trade as apprentices. The important metallic materials were mined and extracted from their ores by practices developed over the centuries by trial and error. An important classic description of mining and metallurgical practices was given by Georg Bauer (1494–1555) — or the Latinized name by which he is usually known, Giorgius Agricola — in his book *De Re Metallica*. (This book was translated from the Latin by Herbert Hoover and his wife in 1912. Hoover was a successful mining engineer before he became President of the United States in 1929.)

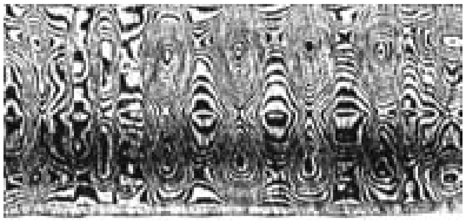

Fig. 2 Damascus sword (above) and closeup of distinctive Damascus pattern in a different sword blade (left).

Much of what we now recognize as materials science and engineering had as its precursors the empirical mining and metallurgical practices that developed into engineering disciplines in the 19th century [1]. The field of physical metallurgy also originated in the 19th century, with input from a variety of disciplines such as crystallography, thermodynamics, microstructural studies, and solid mechanics. The advent of the scientific method in the late Renaissance period and the reintroduction of the atomic theory of matter provided the basis for introducing science into the crafts of materials production, processing, and application. In the next section, the evolution of engineering as an academic discipline will be described, as a preface to discussions of the development of materials science and engineering as a discipline.

4. The Evolution of Engineering Education

Engineering in terms of the building of palaces, temples, harbor works, canals, fortifications, bridges, and aqueducts was carried out in ancient Egypt, Mesopotamia, Greece, and Rome [5]. However, with a few exceptions, little about the engineers who carried out such projects is known. Several architect-engineers in ancient Egypt are known, such as Imhotep (c. 2750 BC) and Ineni and Senumut (between 1500 and 1450 BC). These “engineers” were of noble birth, and their education was presumably by private instruction. While the Greeks carried out many notable feats of what we would call civil engineering, such practical applications of mathematics and natural science were frowned upon by the Greek intellectuals, and engineering education was not a part of the studies of the academies. Later, in the Hellenistic period, the most important engineering accomplishments of the Greek world were made. Archimedes (287–212 BC) is the most impressive example of an individual who combined knowledge of mathematics and science with great skill as an engineer. However, he too looked at his engineering works as inferior to pure mathematics and science. The Romans are credited with many impressive engineering accomplishments in both military and civil engineering (Figure 3). In the field of materials, as mentioned above, they invented concrete and improved glass-making and steel-making methods (albeit still at a level not capable of large output of this most useful structural material).

Fig. 3
Roman aqueduct

There are few records of the engineers who carried out these works or how they learned their profession. Presumably, as with other artisans, the education was based on an individual apprentice system. Ancient China also had successful “engineers” who were usually officials of the emperor’s bureaucracy. The breakup of the Roman Empire and the political fragmentation typical of the Middle Ages in Europe prevented such grand construction works as the roads and aqueducts of Rome. However, many significant structures were constructed, culminating in the soaring vaults and spires of the Gothic cathedral (Figure 4).

The guild system — which developed during the Middle Ages in Europe with advancement of an artisan from apprentice to journeyman to master in a given craft — was the educational system for architect-engineers that built the great cathedrals. A “master mason” was charged with both the design and the building of a cathedral. The engineer-architect received more recognition during the Renaissance. The most famous “engineer” of this period was Leonardo da Vinci. Although he was better known for his art, most of his work was in the field of engineering. As was the case in those times, his education was as an apprentice — to Verrochio, who was a metal founder as well as a painter and sculptor. Leonardo’s engineering skill was mostly self-taught. While engineering knowledge in the Middle Ages was passed on by the apprentice system, it was often not widely disseminated. This began to change as printing was developed (a technology from China) and many “engineers” were literate, unlike many of the master masons of the previous era. Books on engineering began to appear.

The first formal schools of engineering began in France [6]. In the 17th century, engineering studies for military engineering officers were carried out in the Corps of Engineers, which was formed within the French army in 1675. In 1716 a non-military organization, the *Corps des Ponts et Chausses* (Corps of Bridges and Roads), was added to France’s engineering establishment. Louis XV appointed Jean Rodolphe Perronet chief engineer of bridges and highways and gave him the authority to establish a school within the *Corps des Ponts et Chausses.* This school, established in 1747, is considered the first formal school of engineering in the world. In 1775 it was renamed the *Ecole Nationale des Ponts et Chausses.*

At the same time, the English continued to follow the apprentice system of the Middle Ages, with the many innovative engineers that led the Industrial Revolution acquiring their knowledge from the crafts and were millwrights, clockmakers, or stone masons. The Royal Military Academy was established in 1741 to instruct officers in artillery and other aspects of military engineering.

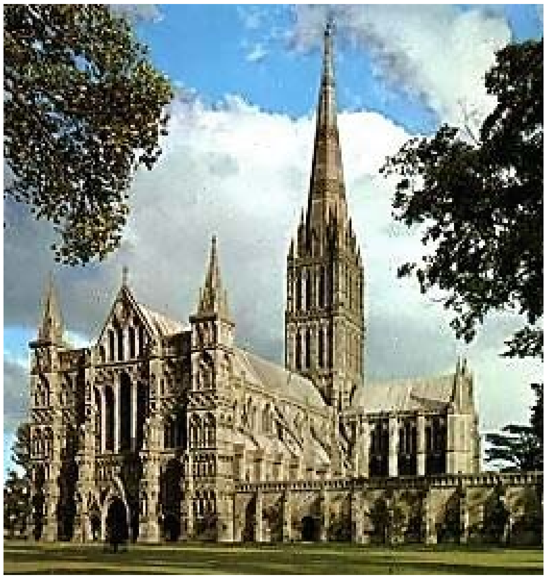

Fig. 4

Gothic cathedral
(Salisbury Cathedral)

The American English colonies followed the traditions of England in terms of formal training in engineering. However, during the American Revolution, it became apparent that there was a critical need for military engineers. George Washington, with his background and skill in surveying, construction, and military engineering, pushed for establishment of an engineering corps. In 1778 while the Continental Army was encamped at Valley Forge, Congress passed a resolution establishing an engineering department; however, no engineering school was provided in this resolution.

After the war, in 1783 it was decided to maintain a corps of engineers even in time of peace. The military school at West Point was begun in 1794 at the recommendation of Washington. The building housing this activity burned down in 1796; however, in 1802 Congress established the United States Military Academy at West Point (Figure 5). The engineers trained here were supposed to aid the country in the broad aspects of engineering, not just strictly military applications. Thus, West Point was the first engineering school in the United States.

Fig. 5
West Point

Other technical academies started in the early 19th century, and the American Literary, Scientific, and Military Academy at Norwich, Vermont, became the first civilian school of engineering in the US. Rensselaer School, established in 1824, first mentioned the term “civil engineer” in its catalog in 1828. The first degree of civil engineering was granted in 1835. Even though a number of schools were established that taught engineering, most engineering graduates in the first half of the 19th century came from West Point. Other engineering disciplines began to be taught along with military and civil engineering. The first course in metallurgical engineering was given at the University of Michigan in 1854, four years after an engineering curriculum was established within the School of Literature, Science, and Arts. Engineering education in the US was greatly accelerated by the Morrill Land Grant Act of 1862, the western expansion after the Civil War, and the building of the transcontinental railroad. Toward the end of the 19th century, the traditional engineering disciplines we recognize today, including civil, mechanical, electrical, and chemical engineering, were finding their places in university curricula. Metallurgical engineering typically was an offshoot of mining engineering.

5. The Evolution of Materials Science and Engineering

5.1 Industrial Laboratories

Industrial laboratories such as General Electric and DuPont had a history of using multidisciplinary research to solve materials problems [1]. This approach was accelerated after World War II. Notable examples are the work at Bell Laboratories and at General Electric (GE) Laboratory. At Bell Laboratories, physicists, chemists, chemical engineers, and metallurgists worked together on processing and structure-property relationships in development of the semiconducting materials silicon and germanium, which were required for the manufacture of transistors and diodes. The invention of zone-refining to produce silicon or germanium single crystals pure enough and free enough of defects (dislocations) was mainly due to William Pfann, who had been trained as a chemical engineer but had contacts with metallurgists. While GE had a long history of multidisciplinary research in the field of materials, this was given a major boost by the formation of new “metallurgy” research under the direction of J.H. Hollomon in 1946. Hollomon was an innovative administrator who hired an unusually competent group of researchers, whose names are well known now to materials scientists as the leaders in the field for their seminal contributions. These included David Turnbull and John Cahn, trained as physical chemists. Hollomon has been credited with taking the mostly empirical art of metallurgy into a field of study based on physics and chemistry. This also meant a broadening of materials studied, away from the strictly parochial concentration on metals. In this period, a number of corporations such as US Steel, Union Carbide, Westinghouse, and IBM, along with GE and Bell, established fundamental research laboratories wherein materials research was a major component, and in many cases began to reflect the integration of materials classes to solve technological problems.

The national laboratories also were established after World War II with funding from the Atomic Energy Commission. Materials problems were recognized as critical to reactor technology, and large materials groups were developed at Oak Ridge National Laboratory, Argonne National Laboratory, Brookhaven National Laboratory, and within the weapons laboratories at Los Alamos and Livermore. All materials classes were addressed in these laboratories, although polymeric materials were not emphasized. Major materials efforts were also established in government laboratories such as the Naval Research Laboratory. So the concept of materials science and engineering was developed *de facto* in industrial, national, and government laboratories.

5.2 Universities

The development of a university department of materials science and engineering began at Northwestern University under the leadership of Morris Fine. Fine was a metallurgist working at Bell Laboratories, and thus exposed to interdisciplinary research, when he was asked to start a graduate program in metallurgy at Northwestern in 1954. Part of his vision for a graduate department was that it be a materials department. With the help of Jack Frankel, who had developed a broad materials undergraduate course which he later turned into a book, Fine pushed for a graduate curriculum in materials science. Instruction along similar lines occurred in the undergraduate program as well. In January 1959 Northwestern approved the changing of the name of the Graduate Department of Metallurgy to the Graduate Department of Materials Science. The departmental title was soon changed to add “and Engineering” to better reflect the character of the program. In due course, the undergraduate metallurgy curriculum was changed to materials science and engineering. Other universities eventually followed Northwestern’s lead and the national trends in materials research. The number of departments with “materials” in their title rose from 11 in 1964, to 29 in 1970, to 51 in 1985. Of the approximately 100 programs in the US in 2003, approximately 75 percent called themselves “materials science and engineering” or “materials engineering.” It may be useful to trace the evolution of materials science and engineering as a department in two institutions. This will be done here for Massachusetts Institute of Technology (MIT) and NC State University.

MIT was incorporated in 1861, but its opening was delayed until 1865 because of the Civil War. A course in geology and mining was offered upon the opening of MIT in 1865. The course was renamed “geology and mining engineering” in 1871. In 1873 a separate course in metallurgy was offered. In 1884, metallurgy was combined with the geology and mining engineering course to form the Department of Mining and Metallurgy. The name changed again in 1889 to the Department of Mining Engineering and Metallurgy, and in 1892 geology was made a separate department. Geology joined the department again in 1920, and the name changed to the Department of Mining, Metallurgy, and Geology. Geology was again separated in 1926, and the department’s name became Mining and Metallurgy. In 1936 mining and metallurgy were split into two departments. Mining engineering was phased out and discontinued as of 1940. This evolution was common to many universities, and mining engineering is now relegated to a small number of universities in the US. Mineral engineering was assigned to the Department of Metallurgy and mineral resources to the Department of Geology. In 1967 following the national trend, the department name changed to the Department of Metallurgy and Materials Science. In 1974 the name was changed to the Department of Materials Science and Engineering, as it remains today.

At North Carolina State University (NC State), departments that were precursors to materials science and engineering formed in the 1920s. These were Ceramic Engineering (1924), Mining Engineering (1925), and Geology (1927). In 1935 the Department of Geological Engineering was formed from the geology and mining departments. Courses in metallurgy in the years before 1954 were taught in the Department of Mechanical Engineering by W.W. Austin. In 1954 the departments of Ceramic Engineering, Geological Engineering, and the Metallurgy Program in Mechanical Engineering were merged to form the Department of Mineral Industries with W.W. Austin as head. Separate degree programs were retained in ceramics, geology, and metallurgy. Geological Engineering left the Department of Mineral Industries in 1967 to become the Department of Geosciences in what is now the College of Physical and Mathematical Sciences. In 1969 the department name was changed to Materials Engineering, and the distinctions between ceramics and metallurgy degrees was removed. W.W. Austin continued as department head until his retirement in 1978. H.B. Smith (1979-80) and J.K. Magor (1980-81) served as interim heads until Hans Conrad was appointed head in 1981. Under Conrad, the Engineering Research Services Division personnel and facilities were merged into the Department of Materials Engineering. New faculty were recruited in the areas of polymers and microelectronic materials, such that the department now covered all materials classes of metals, ceramics, polymers, electronic materials, and composites. Hans Conrad returned to teaching and research in 1985, and John Hren became the department head. Hren created the Analytical Instrumentation Facility, which was managed through the department. In 1986, in keeping with national trends, the department name was changed to the Department of Materials Science and Engineering.

5.3 Professional Societies and Journals

The evolution of materials science and engineering from its precursors in metallurgical engineering, ceramic engineering, and polymer engineering is also reflected in the changes that have occurred in professional societies and professional journals. An example of such evolution can be given for TMS, the Minerals, Metals, and Materials Society. This professional society grew out of AIME, which originally (1871) stood for the American Institute of Mining Engineers. The word "Metallurgical" was added in 1919 and "Petroleum" in 1956 so that AIME became the American Institute of Mining, Metallurgical, and Petroleum Engineers, Inc. In 1957 the three constituent societies of AIME were formed as the Society of Mining Engineers (SME), The Metallurgical Society (TMS), and the Society of Petroleum Engineers (SPE). In 1985 TMS changed its name to The Minerals, Metals, and Materials Society, keeping the TMS acronym. This change represented a broadening of the scope of the society and the programming at the meetings it sponsored. TMS was traditionally the society for metallurgists in research and academia, while another society, the American Society for Metals (ASM) represented more the practitioners of the metallurgical industry. There was, however, some overlap in technical committee subject matter and some competition, but also collaboration, on organization of technical symposia. ASM got its start as the American Steel Treaters' Society in 1919. In 1933 the society changed its name to the American Society for Metals. In 1983 ASM officially expanded its scope to include not only metals but all engineered materials. In 1986 the name was changed to "ASM International." The current society identification of ASM International, "The Materials Information Society," was approved in 1990.

The Materials Research Society, MRS, was founded in 1973 as "an organization of materials researchers from academia, industry, and government that promotes communication for the advancement of interdisciplinary materials research to improve the quality of life." In its first logo in 1973, it specifically incorporated the disciplines of physics, chemistry and engineering and the materials classes of metals, ceramics, and polymers. It has served as a model to some extent for the broadening of scope of the former societies devoted to metals, as outlined above. Other societies that deal with materials research on specific materials classes have tended not to broaden their scope. These include the American Ceramic Society, the National Institute of Ceramic Engineers, and the Society of Plastics Engineers. The American Physical Society also has divisions devoted to materials, such as the Division of Polymer Physics, and the Division of Materials Physics. The American Chemical Society has a Division of Polymer Chemistry and a Division of Polymeric Materials: Science and Engineering.

Some technical journals devoted to dissemination of materials research have evolved from journals devoted to metallurgy to the broader scope of all materials classes. An example of this is *Acta Metallurgica*, which was a leading journal for experimental and theoretical research on metallic materials. It was started in 1953; the name and scope was changed in 1990 to *Acta Metallurgica et Materialia*, then in 1996 to simply *Acta Materialia*. Its sister letter journal *Scripta Materialia* went through identical changes. The journal associated with TMS started out as *Transactions of AIME (1958–1969)*, then changed to *Metallurgical Transactions (1970–1974)*, to *Metallurgical Transactions A: Physical Metallurgy and Materials Science (1975–1993)*, and finally to *Metallurgical and Materials Transactions A: Physical Metallurgy and Materials Science (1994–present)*. The journal *Materials Science and Engineering* was established in 1966 and included all materials classes in its content. The journal split into two parts in 1988, part A – structural materials, and part B, electronic materials. The journal sponsored by MRS, the *Journal of Materials Research*, also covered all materials classes from its inception in 1986. Much materials-related research is published in a wide variety of other physics, chemistry, and mechanics journals. Other journals are still devoted to specific classes of materials, such as the *Journal of the American Ceramic Society* (ceramics) and *Macromolecules* (polymers).

6. Personal History of the Author as an Example of the Need for Lifelong Learning

This section is an account of my career from the time I received my BS degree in metallurgical engineering in 1959 to the present. It will reflect the changes in the field of metallurgy to that of materials science, and my own shift from research and management at Oak Ridge National Laboratory to teaching and research as a professor at North Carolina State University.

I received my BS in metallurgical engineering from Case Institute of Technology (now part of Case Western Reserve University) in June 1959. My undergraduate training included the usual engineering core subjects as well as specialization in metallurgical engineering, which included courses in extractive metallurgy (steel and non-ferrous metals) as well as physical and mechanical metallurgy. I chose to remain at Case (Figure 6) for my graduate degrees for several reasons. In those days, "steel was king." Most of the research carried out at Case was on structural materials, and steel was the main material of interest. My thesis advisor was Dr. Alexander Troiano, who was also the department head. His main research thrust when I worked for him was on the phenomenon of hydrogen

Fig. 6
Modern-day Case Western Reserve University

embrittlement of high-strength steel. The mechanism proposed to explain this phenomenon and the related delayed failure effect was based on stress-induced diffusion of hydrogen to regions of high stress concentration where cracking was initiated. He attempted to use the model he and his students developed for this with other similar phenomena that might be grouped together under the name "strain aging."

It was in this general area that I carried out my graduate research — my master's thesis dealing with the influence of retained austenite on hydrogen embrittlement in a 9 percent nickel steel, and my doctoral thesis on strain aging embrittlement and delayed failure in alpha brass. Thus, my graduate work was in metallurgy and on the mechanical behavior of metals. While I was in graduate school at Case, changes in the curriculum and research program were already underway. The first faculty member in the area of ceramics was hired in the department, and I took a graduate course in ceramics. A new building for a newly established Center for Materials was erected adjacent to the new metallurgy building that we moved into in 1961. Dr. Donald Gibbons was hired as the director of this center. Dr. Gibbons had been at Bell Laboratories and, while trained as a metallurgist, was essentially doing solid-state physics. I took a course on the band structure of metals from him. For the first time at Case, a number of researchers in the field of polymers were hired for the Center for Materials. These were Eric Baer, Phillip Geil, and Jack Koenig. Eric Baer became a member of my doctoral thesis committee. Dr. Baer went on to establish the Department of Macromolecular Science, which is now one of the leading centers for polymer research in the US.

I was fortunate to have obtained a National Science Foundation Postdoctoral Fellowship. After spending five years working on the mechanical properties of metallic alloys, I wanted to move into another research area. I was interested in the solid-state physics courses I had taken in graduate school and thought that making more use of this background would be desirable. I wrote to several universities in England and decided to use my NSF Postdoctoral Fellowship at the University of Birmingham.

I went to Birmingham in September 1964 to work for Dr. G.V. Raynor on the topic of the alloying behavior of intra-rare-earth alloys. Dr. Raynor was the department head and a former student of Dr. Hume-Rothery, the "father of alloying behavior." The interest here was to determine the electronic changes that occur in Ce depending on its environment. That is, Ce is a rare-earth metal with one 4f electron that may be promoted to the conduction band, changing the valence from 3 to 4, approximately. The experimental approach was to alloy Ce with other rare-earth elements such as Gd and precisely measure the lattice parameters as a function of alloy concentration. This allowed for the estimation of the atomic volume of Ce, which reflected its electronic structure. Magnetic susceptibility measurements were also made to help confirm the alloying behavior. Therefore, my post-doctoral experience required me to learn new experimental techniques, new concepts, and also learn something about the British university system. During my postdoctoral year, I was fortunate to visit Oxford University and meet with Dr. Hume-Rothery in 1965, three years before his death.

After returning to the US following my postdoctoral experience in Birmingham, I accepted a position as a staff scientist at Oak Ridge National Laboratory in a group studying superconducting materials. This was the beginning of another major learning experience. My only knowledge of superconductivity was from a few lectures in solid-state physics courses in graduate school. I had to learn many new concepts about the field of superconducting materials as well as the low-temperature physics experimental methods to measure the various superconducting properties. Our charter was to study the structure-property relationships in superconducting materials that determined the magnitude of the critical current density, J_c.

This parameter, J_c, is important to maximize to allow for construction of high-field superconducting magnets. In high-field, type II superconductors, a magnetic field enters the superconductor in the form of quantized “fluxoids,” in which the magnetic field is a maximum at the center of the fluxoid, and a vortex of circulating supercurrent surrounds each fluxoid (Figure 7). The mutual repulsion of the fluxoids results in the formation of a regular lattice of them, with the lattice parameter a function of the magnetic field strength. If current is passed through a superconducting wire in the presence of a magnetic field, the fluxoid lattice will move under the Lorentz force created, and the movement of the normal cores of the fluxoids results in resistance, heat, and eventual destruction of superconductivity. For a large current density to be sustained, the fluxoid lattice must be "pinned" so that a gradient in magnetic field can be obtained. The strength of the fluxoid pinning determines the magnitude of the critical current density – that is, the current density at which superconductivity is destroyed. Pinning the fluxoid lattice can be accomplished by the interaction of inhomogeneities in the superconductor, such as precipitate particles, dislocation arrays, and grain boundaries. The microscopic pinning forces between such pinning centers and the fluxoid lattice can be calculated. The bulk pinning force on the superconductor can be calculated by measuring the critical current density at a given field. The relationship between the bulk pinning force and the individual microscopic pinning forces is not a simple summation. The complex statistical problem has never been adequately solved.

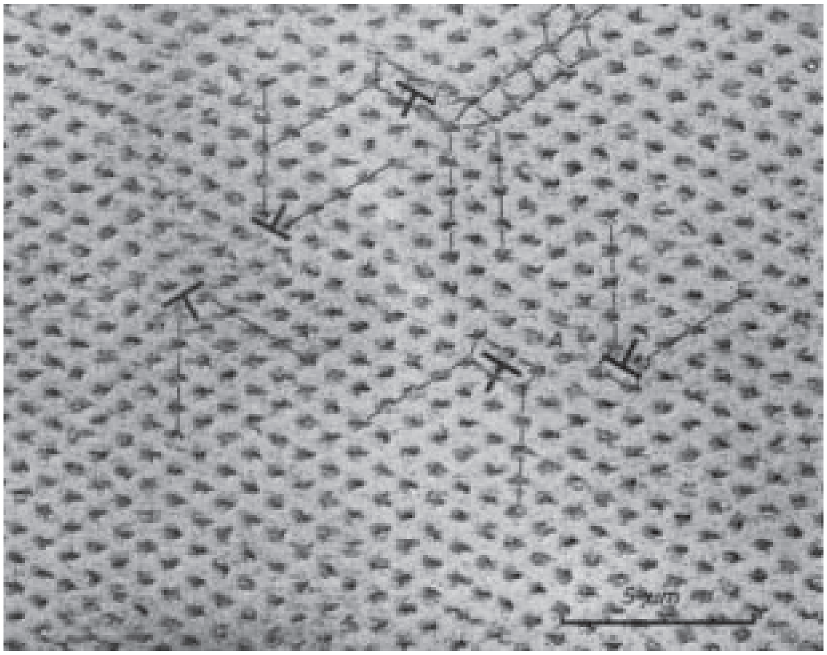

Fig. 7 Fluxoid lattice decorated by ferromagnetic particles.

M. Essmann p. 36 in "International Discussion Meeting on Flux Pinning in Superconductors" Sonnenberg, Germany 1974

It was on this fluxoid pinning problem that my group at Oak Ridge focused for over 10 years. A comprehensive set of experimental tools were developed for measuring superconducting properties using direct resistive measurements, ac measurements of the fluxoid density gradient, and dc magnetization measurements. The very difficult precise measurement of ac losses in superconductors was also carried out. Another aspect of our work on superconducting materials was a study of the influence of mechanical stress on superconducting properties in the multifilamentary Nb_3Sn materials to be used for high-field magnets in the fusion energy program. We were given a Department of Energy Metals and Ceramics award for our work in this area. Another sideline of my work on superconducting materials was a study of technetium (Tc) metal and its alloys. Tc is an element that does not occur naturally but is a fission product. At atomic number 43, it is a transition metal with an hcp structure. Our interest in Tc was that it has the second highest superconducting transition temperature, exceeded only by niobium (Nb), for an element. It is radioactive, being a beta emitter as well as emitting weak gamma rays. It is not a serious radiation hazard, but all experimental work had to be carried out in glove-box facilities, which complicated our experimental studies. I became an “expert” on Tc and wrote the section on it for the *ASM Metals Handbook*.

In 1976 I was asked to be the technical assistant to the ORNL associate director for the physical sciences, Alex Zucker. I took this position since I thought I might wish to rise in the management ranks from my position as group leader, and this had been a “fast track” to such positions. This was another major learning experience, in that I needed to learn about the broad scope of materials science and engineering, physics, chemistry, chemical technology, and other areas that came under Zucker’s authority. I interacted with higher management as a member of the director’s division. I spent two years in this position and learned that working strictly in management was not what I enjoyed doing.

I returned to the Division of Metals and Ceramics and the leadership of my former group. At that time, the field of superconductivity research was declining in interest, and our group collectively decided to move into another research area. After some study, we concluded that the area of metastable/amorphous materials produced by nonequilibrium processing methods such as rapid solidification was an appropriate field for us. We obtained the approval of our management and the Department of Energy sponsors. This, then, was another new learning experience for me.

I attended a NATO summer school on liquid and amorphous materials in 1979 and a Department of Energy workshop on amorphous materials in 1980 as part of my learning experience. In 1981, I was asked to take responsibility for a larger group during a reorganization of the division. I became the leader of a group I named the "alloying behavior and design" group, which comprised programs in metastable materials, still under my technical leadership, as well as programs in alloy design, under C.T. Liu, and fundamental mechanical behavior at elevated temperatures, under M.H. Yoo. This gave me more managerial responsibility, which meant I was asked to take some short courses in the Union Carbide Management System, as well as courses in management at the University of Tennessee. However, I was still able to devote the majority of my time to research.

At the end of 1982, I met Hans Conrad at a TMS meeting. In our conversation during breakfast, he asked if I had ever considered moving into academia. He had recently become department head at NC State and was adding faculty to the department. I replied that I had always had an interest in eventually teaching although, as the years had gone by at ORNL, I thought this was not likely. I sent him my resume and, in December, came to NC State to present a seminar, which was also a job interview. At the end of the day, I was offered the position of professor with tenure. On returning to Oak Ridge, I was faced with the most difficult decision of my career. After much thought and discussion with others, I decided to remain at ORNL. I conveyed my decision to Conrad but told him what a difficult decision this had been. He gave me another week to think about it. At the end of this week, I again said no. However, with the support of my wife, and with the "gut feeling" that this was something I really wanted to do, I called Conrad back three days later and said I had changed my mind. This was a decision I have never regretted. In July 1983, I joined the faculty at North Carolina State University.

Following the advice of several colleagues, I began to write research proposals immediately on my arrival at NC State. Proposals in the areas of intermetallic compounds, amorphous materials, metastable crystalline materials, and the mechanism of mechanical attrition were written to the

Department of Energy, the National Science Foundation (NSF), the National Aeronautics and Space Administration (NASA), and the office of Naval Research (ONR). To my pleasant surprise, all four proposals were funded. This got me off to a good start doing research. My success rate since that time has never been as good, but I have managed to have continuous research support from NSF up to the present time.

My initial teaching experience was, however, an unpleasant surprise. I had been told that I give excellent technical talks, and I had taught a graduate course at the Oak Ridge campus of the University of Tennessee for which the students gave me high praise. I assumed that I would be able to teach effectively with little problem. I was rudely awakened when I taught my first undergraduate courses and found how difficult it is to be an effective teacher at the undergraduate level. Learning to teach well has been a continuous process to the present time. I took a short course and several workshops on teaching effectiveness by Dr. Rich Felder. I also attended workshops on critical thinking and on inquiry-based teaching. Perfecting teaching skills is indeed a lifelong process.

My research on the amorphization of materials by ball-milling of powders — mechanical attrition — led me into the study of nanostructured materials. The alloys that became amorphous after the severe deformation of ball-milling presumably did so because the defects introduced by plastic deformation raise the free energy of the crystalline solid to that of the amorphous alloy. The only defects with enough energy to accomplish this are grain boundaries, or disordering energy in ordered compounds. It was observed that all the materials became nanostructured, that is, developed grain-sized structures less than 100 nm, as ball-milling progressed. Some materials then transformed to the amorphous structure; others did not. However, virtually all materials became nanocrystalline after a sufficient ball-milling time (Figure 8). It was concluded that this was an effective method to produce nanocrystalline materials.

Since about 1988 my research has been focused on nanostructured materials, their preparation, and mainly on their mechanical behavior. I was selected to be part of an eight-person panel by the International Technology Research Institute, World Technology (WTEC) Division, which was sponsored mainly by NSF. During 1996-98 this panel made visits to Japan and Europe and held a workshop in the US. The purpose of this

Fig. 8 Dark field transmission electron micrograph of nanostructured zinc.

panel was to assess research and development status and trends in nanoparticles, nanostructured materials, and nanodevices worldwide in comparison with those in the US. The results of the panel's findings were presented at a meeting in Washington, DC, and published in a book by Kluwer Academic Publishers. This study was a precursor to the nanoscience and technology initiatives sponsored by NSF and other funding agencies.

7. The Teaching Challenge in an Ever-Changing Profession

As the above sections point out, materials science and engineering is a profession that has evolved over the years and remains a dynamic field. It will be a significant challenge for academia to keep pace with changes in industry and society, which will demand new materials. How we may need to change our courses, our curricula, and even our discipline are questions that must be addressed so that the appropriately trained professionals will be available to meet the coming challenges. As an engineering field, materials science and engineering has some unique characteristics. It is both “science” and “engineering.” That is, many of our students leave with BS degrees and practice materials engineering in various capacities in industry. However, an almost equal number desire a career in research, and as is the case with other sciences such as physics, chemistry, and biology, an undergraduate degree is not sufficient. So our undergraduate curriculum must reflect these different needs and must be structured accordingly. At the undergraduate level, we have the input of the Accreditation Board of Engineering and Technology (ABET) to focus our efforts for continuous improvement.

In 2002, the BS-level materials programs at 59 institutions in the US were accredited by ABET. The criteria and procedures for ABET accreditation were changed during the period 1999–2001 to be less prescriptive and to allow more flexibility in curricula. The ABET accreditation process has affected undergraduate materials education and continues to do so. Within ABET, responsibility for evaluation of engineering programs rests with the Engineering Accreditation Commission (I was a member from 1998 to 2003), which includes representatives from 21 professional engineering societies. TMS, the Minerals, Metals, and Materials Society, is the lead society for materials and metallurgical engineering programs, and the National Institute of Ceramics Engineers (NICE) is the lead society for ceramic engineering programs. The Materials Research Society (MRS) is also affiliated with ABET and cooperates with TMS and NICE in materials accreditation activities. In the late 1990s ABET rewrote criteria for accreditation of undergraduate engineering programs, with active participation of representatives from engineering deans, industrial leaders, and engineering professional societies. The resulting Engineering Criteria 2000 (EC2000) was an outcomes-based accreditation scheme that is now the basis for all ABET accreditation of engineering programs.

Under EC2000, each engineering program must develop Educational Outcomes — the statements that describe the expected accomplishments of graduates during the first few years after graduation. These Educational Outcomes are developed in consultation with the program’s constituents, who may include advisory committees of prominent academic and industrial materials scientists and engineers, the employers of its students, and the students and faculty themselves. The program's faculty must collect evidence of whether these Educational Outcomes are being met and must use this information to modify the program. It is this part of the ABET EC2000 that gives direct input into the evolutionary changes that the field may require as technology advances and societal needs change. The role of the advisory committee, with its direct knowledge of current industrial needs in the materials field, is critical to providing the knowledge on which to base any changes in the curriculum.

While graduate programs do not have a formal mechanism for evaluating the effectiveness of the program, since graduate study is research driven, the research climate in the US, in terms of what areas receive funding from the major federal agencies or from corporations, has a significant influence on its direction. When I was in graduate school in metallurgy, the emphasis was on structural materials, especially related to defense in those days of the Cold War. More recently, research emphasis has shifted to electronic materials as part of the information revolution. At the present time, there is growing interest in bioengineering and biomaterials. It remains to be seen how this will influence our program and discipline. Many departments are starting research programs in biomaterials, which in turn will influence both graduate and undergraduate education in materials.

Materials science and technology is an “enabling” technology. Better materials can make some technologies feasible or make others more efficient. The new nanomaterials may provide revolutionary advanced materials for such possible applications as terabit memory and microprocessing, biomedical sensors, and magnetic refrigerants. Better materials for high temperature service could increase the efficiency of jet engines. Advanced materials are recognized as a scientific and technological priority both nationally and internationally. Keeping academic programs in materials at the cutting edge of research will remain an ongoing challenge.

8. Conclusion

This paper has illustrated the need for lifelong learning and teaching by using examples of the evolution of the materials science and engineering discipline, and through an account of the author's career in this field. It is clear that learning new concepts and skills is necessary as societal needs, science, and technology change. However, it is also an enjoyable experience to continually delve into new areas, and this keeps one mentally young. Learning all the aspects of a broad technical discipline is a never-ending process.

To quote from Robert Louis Stevenson's *A Child's Garden of Verse*,

"The world is so full of a number of things, I'm sure we should all be as happy as kings."

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1. *The Role of Solid-State Research in Electrical Engineering* by John Reid Hauser, Professor of Electrical Engineering, North Carolina State University, April 27, 1982.

2. *Does Engineering Education Have Anything To Do With Either One?* by Richard Mark Felder, Professor of Chemical Engineering, North Carolina State University, October 12, 1982.

3. *Materials and Devices for Optical Fiber Communications* by Michael Anthony Littlejohn, Professor of Communications and Signal Processing, North Carolina State University, November 10, 1983.

4. *Two Theories of Communication* by John Benjamin O'Neal, Jr., Distinguished Professor of Communications and Signal Processing, North Carolina State University, October 31, 1984.

5. *On Zero and Risk* by Harold B. Hopfenberg, Camille Dreyfus Professor and Head of the Department of Chemical Engineering, North Carolina State University, October 29, 1985.

6. *An Overview and a Point of View on Heat Transfer* by M. Necati Ozisik, Professor of Mechanical and Aerospace Engineering, North Carolina State University, October 29, 1986.

7. *On Quality, Automation, Cultural Relativism, and Things Like That* by Salah E. Elmaghraby, University Professor, Operations Research and Industrial Engineering, North Carolina State University, November 12, 1987.

8. *Humans to Mars* by Fred Roark DeJarnette, Professor of Mechanical and Aerospace Engineering and Director of Mars Mission Research Center and Hypersonic Aerodynamics Program, North Carolina State University, November 9, 1988.

9. *The Time Has Come* by Carl Frank Zorowski, Professor of Mechanical and Aerospace Engineering and Director of Integrated Manufacturing Systems Engineering Institute, North Carolina State University, November 15, 1989 (printed lecture unavailable).

10. *Science is . . . Sensual* by Ruben G. Carbonell, Hoechst Celanese Professor of Chemical Engineering, North Carolina State University, November 7, 1990 (printed lecture unavailable).

11. *Education, Research, and Entropy* by Ronald O. Scattergood, Professor of Materials Science and Engineering, North Carolina State University, November 13, 1991 (printed lecture unavailable).

12. *Research Is Teaching* by Salah M. Bedair, Professor of Electrical and Computer Engineering, North Carolina State University, November 4, 1992.

13. *The Role of Monte Carlo Methods in Engineering Education* by H. A. Hassan, Professor of Mechanical and Aerospace Engineering, North Carolina State University, November 3, 1993.

14. *Radioisotope and Radiation Measurement Applications* by Robin Pierce Gardner, Graduate Alumni Distinguished Professor of Nuclear and Chemical Engineering and Director of the Center for Engineering Applications of Radioisotopes, North Carolina State University, October 28, 1998.

15. *Silicon Carbide, Diamond, and Gallium Nitride: Sources for New Electronic Materials, New Gemstones, and New Corporations* by Robert F. Davis, Kobe Steel Ltd. Distinguished University Professor of Materials Science and Engineering, North Carolina State University, October 27, 1999.

16. *Trends in Power Discrete Devices* by B. Jayant Baliga, Distinguished University Professor of Electrical and Computer Engineering, Director of the Power Semiconductor Research Center, North Carolina State University, November 1, 2000.

17. *On Habitual Domains, Fuzzy Sets, Variational Inequalities, and Optimization* by Shu-Cherng Fang, Walter Clark Professor of Industrial Engineering, Director of Graduate Programs in Industrial Engineering, North Carolina State University, November 14, 2001.

18. *Going to Extremes: Observations from the Biology/Engineering Interface* by Robert M. Kelly, Alcoa Professor of Chemical Engineering and Director of the North Carolina State University Biotechnology Program, January 30, 2003.

19. *Lifelong Learning and Teaching in a Changing Profession* by Carl C. Koch, Professor of Materials Science and Engineering, North Carolina State University, November 19, 2003.

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- Scholarly activities, including research, design, writing, and speaking that are recognized locally, nationally, and internationally.
- Extension and public service activities, including assistance and advice to industry, business, government, and other educational institutions, and contributions to professional societies.

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