Global J. of Engng. Educ., Vol.6, No.1
Published in Australia

Materials Science and Engineering Education in Taiwan: a Core Course and a Cornerstone*

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The importance of Materials science and engineering (MS&E) in engineering education has become obvious in recent years, although many people still hold misconceptions about MS&E. This paper looks at the impact of MS&E on industry through landmark discoveries, developments and the manufacturing of new materials. The Relative Citation Index (RCI) ranking of the five most advanced industrial nations shows the prominence of materials science. The paper also looks at the development of a basic course in materials science for all engineering students in Taiwan so as to supply more labour from education to industry. MS&E knowledge is a two-edged sword; it helps people unleash the Earth's resources and also guards the population against destroying the natural cycles of materials that surround them. Serious concerns have been raised in Taiwan regarding the declining environmental conditions over the last decade or two.

HISTORICAL PERSPECTIVE

Materials science is a discipline that uncovers the mystery of materials by means of scientific approaches; materials engineering involves the designing and processing of materials based upon function and property requirements. Materials science and engineering (MS&E) solve problems from both microscopic and macroscopic considerations with an open and unprejudiced perspective.

Since the time of the Stone Age, human civilisation has closely reflected the general progress of materials development. Humankind's early ancestors had access to only a limited number of materials. Yet their aspiration for exploration and the development of better materials distinguished them from animals and even from their human competitors. They discovered that the properties of a material could be altered or enhanced by alloying and heat treatments.

With advances in the microscopic observations of materials structure, the knowledge of materials was further expanded. The relationships between structures and properties were rapidly uncovered with the aid of high-resolution microscopes and theoretical treatments.

The history of human civilisation reveals a strong link between social prosperities and materials advancement. Breakthroughs in materials discovery or processing have often given rise to major developments in civilisation. The invention of paper, for instance, has been proven to be as early as 2 BC by Tsai Lun in ancient China [1]. That invention was followed by more than a century long period of prosperity and cultural advancement known as the golden age of Chinese history.

In the western world, the invention and processing of steel has gone through almost a century of development to give birth to the steam engine, railroads and finally the automobile industry in the early 20th Century. As such, steel has been considered as the most important cornerstone for modern technology and civilisation in both Europe and America [2].

Materials technology has been a prime factor contributing to national competitiveness during the two world wars and the subsequent Cold War era. In 1957, Sputnik, the first satellite, was launched successfully into orbit by the USSR, shocking the world. Most of all, it awakened US scientists and engineers. President J.F. Kennedy of the USA urged Congress to allocate substantial funding to expedite materials research across the nation at seven newly established

*A revised and expanded version of a keynote address presented at the 3rd *Asia-Pacific Forum on Engineering and Technology Education*, held in Changhua, Taiwan, from 8 to 11 July 2001. This paper was awarded the UICEE platinum award (second grade) by popular vote of Forum participants for the most significant contribution to the field of engineering education.

Centers for Materials Research (CMR) [3]. In 1969, the USA succeeded in sending astronauts to walk on the moon. A series of space explorations then ensued. It was clearly the triumph of materials breakthroughs that made the human dreams of space exploration come true.

THE IMPACT ON INDUSTRY

The old saying that *a grain of sand can change the world* in today's context is quite appropriate for what MS&E has done for the world. A grain of sand connotes a silicon chip of today's electronic technology. An old Chinese proverb states that *a strong will can order a stone to turn into gold*. Through the accumulated effort of numerous materials scientists and engineers, a grain of sand or a piece of stone has been transformed into the highly valuable silicon chip, which in turn has created the new world of today's silicon technology [4].

Although it is recognised that materials are the basic ingredients for most industrial products, they are often taken for granted, and even purposely neglected for their important contributions as if they were a matter of choice mainly for cost and accessibility reasons. However, it is obvious that without the materials development of say, steel and aluminum alloys, there would not have been the crowning achievements that grew out of the industrial age, including steamboats, railroads, aircrafts, high rise buildings, etc.

The discoveries of plastics and other polymers in the early 20th Century brought forth endless applications into modern civilisation. Finally, the invention or discovery of semiconductors in the middle of the 20th Century has created worldwide industrial developments in communications, computers and consumer electronics.

The above-mentioned steels, aluminums, plastics and semiconductors are just some of the better-known materials of one kind or another. There are many other lesser-known materials, at times behind-the-scenes, that have also played important roles in the course of industrial developments over a long period of time.

At this point, it is appropriate to stress that materials science or engineering is no longer an auxiliary or a side-seat player. In other words, materials scientists/ engineers now command the front-end position in technological development. Decision-making today is more in the hands of the materials scientists than it was many years ago.

The increasing numbers of new technologies today have become possible because of breakthroughs first in new materials. It was the discovery of a special composite material in the early 1980s that made the development of the stealth airplane possible. It was also the successful development of high temperature resistant porous ceramic tiles that have contributed to the safe return of the space shuttles to Earth.

New Materials

Today, many new materials can replace machines. It is the intrinsic properties or the combination of several peculiar properties of materials that not only can replace but also outclass some familiar machines. For example, a pressure- sensitive ceramic, or so-called piezoelectric material, can replace a reciprocal piston. An ultrasonic vibrator that uses piezoelectric materials can replace a mechanical cleaner and also a heat welder that bonds metals or plastics.

When combined with a microprocessor, a smart material becomes a smart structure or a smart system, and easily outperforms a traditional machine. Such materials and similar ones called ferroelectric and ferromagnetic materials are not very new, but their applications in microelectronics have grown rapidly in recent years.

THE PARADOXICAL TRAP

Materials science and engineering (MS&E) has bridged science, technology and industry together. However, while it has unleashed the Earth's resources for industrial prosperities, it has also inadvertently destroyed nature and created waste [5]. People live in two worlds: one is the natural world; the other is humankind's own creation of technologies and materials [6]. We have drawn ourselves into a paradoxical trap.

He Who Tied the Bell on the Cat's Neck is Responsible for Removing It

To summarise previous points:

- Materials science utilises a scientific angle to tackle the mysteries of materials
- Materials engineering covers the designing and processing of materials by focusing on functional and property requirements.
- MS&E solves problems from both microscopic and macroscopic considerations with an open and unbiased perspective.

Who then is responsible for the environmental crisis that is now encountered across many industrialised nations? Society tends to point its finger at the materials developers and manufacturers. In fact, it is the responsibility of the entire industry and society. However, the fable of the mouse and cat may help in identifying the nature of the paradox.

> *Once upon a time, a flock of mice gathered together in order to find out the best way to avoid a cat from attacking them without warning. One mouse suggested that a bell could be tied around the cat's neck so that whenever the cat started moving towards them, the bell would ring aloud to warn them. The proposal was unanimously endorsed, and the mouse who proposed the idea was assigned to carry out the plan. That mouse risked his life in order to tie a bell on the cat's neck. Many years later, they gathered again for another meeting. Some mice complained that life without the cat chasing after them was no fun. As such, they decided that the bell should be removed from the cat's neck. They told the mouse:* He who tied the bell on the cat's neck should be the one to untie it.

MS&E has been credited with many significant breakthroughs and achievements. But at the same time, society has also been quick to blame MS&E for many environmental wrongdoings. In this sense, MS&E is a two-edged sword in that can uncover the mysteries of the Earth's resources and turn materials into profitable industries. However, it is also capable of reducing the disruption of the natural cycles of materials so as to restore the Earth's environment.

It is possible to select or design the right materials that can meet the required functionalities without producing harmful or unrecoverable waste. It is still not too late for MS&E to redirect course structuring to help preserve the Earth. It must begin with engineering education.

MATERIALS SCIENCE AND ENGINEERING EDUCATION IN TAIWAN

Since 1980, the Taiwanese Government has chosen materials technology as one of the four national core technologies. The other three core technologies are comprised of: electronics, information and bioengineering. Such policy making was modelled after those of more advanced nations and further developed with the input of those citizens who were educated abroad and decided to return to Taiwan since the late 1970s. Such a brain influx into Taiwan reached a peak in the early 1990s.

Acknowledgement is also due to Prof. M. Cohen of the Massachusetts Institute of Technology (MIT) in Cambridge, Massachusetts, in the USA, who helped in drafting the *Development Plan for Materials Technological Education in Taiwan* for the Executive Yuan. Under such a plan, the Taiwanese Government started subsidising some selected public universities, such as the National Tsing Hua University in Hsinchu and Chengkung University in Tainan, with a considerable amount of money each year.

Departments of materials science and engineering in universities in Taiwan have grown from only one (National Tsing Hua University) in 1972 to 12 today. But the number of MS&E graduate schools has grown from only one in 1975 to 16 today. Such a phenomenal growth rate is quite unique; it is only matched by electrical engineering and computer science departments in schools of engineering.

According to the latest report by the Ministry of Education, there were about 800 graduates in 1999 with a BS in MS&E, while graduate students with an MS and PhD amounted to about 650 in the same year [5][7]. Such numbers are considered small compared to that of other engineering fields. For electrical engineering (EE) and mechanical engineering (ME), the number of graduates (BS) was about 3,200 and 2,600, respectively.

Industry Requirements

On the other hand, industry in Taiwan demands a far greater supply of college degrees. In the year 2000, there was a shortage of more than 5,000 college graduates with degrees in electrical/electronic engineering and materials science [7].

More careful analysis has shown that the actual demands of industry have been ill-defined and ill-reported [3]. In other words, industry in Taiwan needs more materials-trained human resources than was originally thought. This is especially so in the electronics industry, where there exist many jobs that could be better handled by materials scientists or engineers than by electrical or electronic engineers. Furthermore, in the area of electronics packaging, a materials scientist or engineer may actually serve their job better than would a chemical engineer or a mechanical engineer.

To better balance the human resources in Taiwan, there needs to be either an increase in the numbers of MS&E majors or else engineers of other disciplines have to broaden their abilities with materials knowledge and training. The former is a long-range approach, while the latter is an easier, effective and short-term strategy.

DEVELOPMENT/DESIGN OF A CORE CURRICULUM FOR MS&E

In many of the engineering schools, a course in engineering materials with two to three credits has been offered as a mandatory or a selective course for all or most of the engineering students at the freshman or sophomore level. Such a tradition has not been upgraded for a quite some time in Taiwan. In fact, downgrading is the tendency that has been observed at many schools; this has been mainly for such reasons as *too heavy requirements* or *too many selective courses* for engineering students. The key problem seems to be course content and the teaching quality.

Course Contents

The traditional engineering materials course taught to some non-materials engineering students still focuses on the old level of descriptive metallurgy. Today, materials science or MS&E is much more analytical and atomistic in approach and encompasses a much broader coverage of different materials. It is also more practical and more current in relation to industrial developments [5].

It is pertinent to offer students of non-materials majors as well as materials majors updated course contents to give them an accurate perspective and also to attract their interest into the exciting world of materials engineering.

Teaching Quality

Partly due to lack of teaching faculty with degrees or backgrounds in MS&E, and partly because of the changing nature of course contents described above, teaching quality has been quite rugged and varied across different schools and different departments. While it is granted that no unified teaching method should be enforced, instructors should at least be uniformly updated with the current perspective of the materials discipline.

It is proposed that a course of MS&E of at least three credits should be offered to all engineering major students as a basic and required course. Just as physics, chemistry and computers are taught to engineering students as basic and required courses all over the world, it is time to also enforce materials science, as well as biological science.

The prophecy that the 21st Century will bring forth a scientific revolution different from the past Industrial Revolution has been well documented [8]. Some would prefer to call it a Quantum Revolution that is built upon the progresses of materials science and biological science [9].

To bring the flavour of materials science and biological science into the engineering curriculum is more than just a matter of following a world trend simply because of their importance in the coming scientific revolution. As discussed earlier, the knowledge of modern materials science has today become an integral component of engineering, as it links and serves various engineering disciplines.

Such a significant change of view in the importance of materials science and engineering in the later years of the 20th Century can be supported with the Relative Citation Index (RCI) research conducted and published in *Nature* in 1998 and shown in Table 1 [10]. This ranking is defined as the ratio of the number of the most cited papers to the average number of cited papers. It can be observed in Table 1 that MS&E is the only field of discipline that appears among the first seven rankings of the five most advanced nations. Applied mathematics seems to be in second place behind MS&E, as it came short in the rankings in the United Kingdom and Japan.

The above proposal of teaching materials science course to all engineering students is just a minimal if not modest proposal. In fact, it has been seen in many of the various schools in Taiwan, and also in other countries, that some materials related courses have been offered from time to time at various levels to engineering students.

The most common courses seem to be: semiconductor materials and principles; semiconductor materials and processing or electronic packaging materials; and even VLSI processes and materials, etc. At some places, even a course like solid state physics or optical and electronic materials is offered without offering any basic Materials Science course. It should be insisted that a basic materials science course is prerequisite before a student intends to take any other materials related courses.

It should be emphasised, as stated before, that implementing the basic materials science course to all engineering students during their earlier years, say, freshman or sophomore year, is an easier and more effective approach in terms of producing more materials-oriented human resources. Such a view needs some clarification here. The enforcement of basic materials science courses to all engineering students should achieve at least two purposes, which are namely:

- To orient engineering students towards materials thinking or materials favouritism. Such an orientation should help a student to develop a

Table 1: The RCI ranking of technical papers for the five most advanced industrial nations [10].

Nation / Rank	United States of America		United Kingdom		France		Germany		Japan	
1	Appl. Math	1.62	Pharmaceutic	1.67	Material Sci.	1.47	Appl. Math	1.28	Elec. & Elec.	1.00
2	Physics	1.59	Agriculture	1.44	Chem. Eng.	1.42	Agriculture	1.25	Nursing	0.99
3	Chemistry	1.57	Pure Math	1.41	Appl. Math	1.25	Physics	1.20	Material Sci.	0.99
4	Material Sci.	1.52	Statistics	1.36	Civil Engng.	1.16	Elec. & Elec.	1.19	Gen. Engng	0.95
5	Elec. & Elec.	1.47	Mining Ext.	1.33	Geology	1.14	Mining Ext.	1.19	Chem. Engng.	0.92
6	Chem. Engng.	1.46	Material Sci.	1.31	Mech. Mfg.	1.12	Material Sci.	1.11	Agriculture	0.92
7	Mech. Mfg.	1.45	Food Sci.	1.25	Vet. Med.	1.11	Geology	1.06	Chemistry	0.91

Note: The RCI range for Taiwan is: 0.42-0.45

good materials perspective in his/her pursuit of engineering education. The industry in general is in favour of such materials oriented engineers.

- To invite non-materials students to transfer to the materials major. Taking a basic materials science course should encourage some engineering students to consider changing their major to materials during their undergraduate or graduate studies.

To achieve either of these two purposes, course contents should be carefully organised and prepared including the contents of the experimental course. Above all, the best teachers should be invited to teach such basic courses to impress the student.

Furthermore, the environmental problems being faced today can be concluded to be the human destruction of the natural cycles and harmonies of materials. The MS&E courses for engineering education should seek to achieve both environmental responsibility and industrial advances uncompromisingly.

THE ASIA PACIFIC HIGH TECH CENTRE

Quo vadis Taiwan? How should Taiwan survive in the competitive 21st Century? These questions have been challenged in recent years in the arenas of academia, industry and the Government in Taiwan.

Especially during the aftermath of the return of Hong Kong to China in 1997, a new strategic adjustment or national priority has become a hot issue in Taiwan. Many proposals or blueprints have been brought up, including the more familiar ones:

- Asia Pacific Centre for Trans-shipping.
- Asia Pacific Monetary Centre.
- Asia Pacific Centre for Manufacturing.

Prof. Michael E. Porter of Harvard University, in Boston, Massachusetts, in the USA, is a world-renowned consultant and author of *The Strategy of Competitiveness.* He was invited to Taiwan in 1997 for consultation. He bluntly pointed out that:

> *Taiwan, being a member of Asia Pacific nations, can raise the national competitiveness, as long as the government is determined to lay out a clear-cut goal and policy. However, the Asia Pacific Centre for Trans-shipping being planned so far may lead to too much dependency of Taiwan on Mainland China. Thus Taiwan should develop a more independent plan which is the Asia Pacific High Tech Centre; thereby the national competitiveness may be enhanced* [11].

His advice at that time might have sent a shockwave across the government and business arenas, but it was a stimulating message to academic and industrial groups.

In line with this new consensus of planning as the Asia Pacific High Tech Centre, engineering education in Taiwan should also rethink a new strategy. It is an opportune time to make materials science and engineering a core course in the engineering curriculum.

CONCLUSIONS

The historical role of materials science and engineering in engineering development was briefly reviewed in this paper in light of how materials science evolved from the ancient Stone Age to today's central stage of Quantum Revolution. It was interesting to note that historically a major breakthrough in materials discovery or processing would lead to the emergence of a new civilisation of prosperity. However, on the other hand, society has been critical about the environmental deterioration of recent decades and holds MS&E culpable for causing it.

Both the contents and the spirit of today's materials science and engineering are quite different from that of metallurgy or engineering materials of a long time ago. It provides powerful tools for both microscopic and macroscopic knowledge of materials and also provides both knowledge in the utilisation and preservation of the planet Earth's resources.

The labour supply of graduates with a materials major from colleges and universities in Taiwan is still small compared to that for other engineering fields. There is a great deal of room for educating more materials students for industry. However, it is equally important and urgent to popularise MS&E core courses to all engineering students to set their minds right with materials in regard to conservation and the clean care of the environment.

Taiwan has been fortunate to survive its industrialisation to become a developing country. The competitive edge of Taiwan in the 21st Century depends on high tech development. Both materials research and education may open up the opportunities for Taiwan to become the Asia Pacific High Tech Centre.

It is urged that changes must begin with engineering education. In particular, it is proposed to refresh and redirect the MS&E curriculum and make it a core requirement for all engineering students. It should add strength into the fabric of engineering education in Taiwan and also engineering conscientiousness for environmental care.

In the meantime, the more popular conscientiousness of the people in materials knowledge should help the island return to her old time name and image of *Ihla Formosa*: the Beautiful Island.

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BIOGRAPHY

Dr Fong-Ming Lee is a Professor and the Dean of the School of Engineering in the Faculty of Materials Science and Manufacturing at the Chinese Culture University in Taipei, Taiwan. He received his BS in mechanical engineering from National Taiwan University and his MS in metallurgical engineering from NC State University. In 1968, he received his PhD in materials science and engineering from Stanford University. He has worked in industry for 25 years; first for IBM and then for Litton Industries.

For more than 30 years, he has devoted himself to electronic connector and interconnection technology and has authored many papers and several patents in this field. In 1993, he founded the Taiwan Electronic Connector Association (TECA), which is now an organisation of more than 80 corporate members. He has also served as a Research Member of the Science and Technology Advisory Group under the Executive Yuan of the Government, and as a Consultant Member for the Industrial Technology Research Institute (ITRI).

In recent years, Prof. Lee has become engaged in research activities related to nano-structured materials, and conducted an International Symposium on Nano-Structured and Amorphous Materials in April 2000. Prof. Lee has been contributing papers to UICEE-run conferences since 1999, and is also an active member of the UICEE.